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Establishing successful university–industry collaborations: barriers and enablers deconstructed

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Abstract

University–Industry Collaboration networks are increasingly significant to national economies. Previous studies have identified barriers and enablers of University–Industry Collaborations, however our understanding of the evolution of such collaborations is still limited thereby restricting our ability to nurture their development. This study explores the establishment of a successful University–Industry Collaboration and considers a range of perceived barriers and enablers through four emergent evolutionary phases: *embryonic, initiation, engagement* and *established*. The study adopted a qualitative research approach using a single site case study, focusing on the pharmaceutical industry, with 10 multinational firms and 8 academic institutions involved in a pharmaceutical collaboration. The results demonstrate that specific University–Industry Collaboration barriers and enablers emerge at different points in time, for example, strong lack of trust; strong fear of knowledge leakage, reluctance to share in the embryonic phase evolve to achieving integrity based trust and an intellectual property agreement in the engagement phase. These barriers were overcome using a range of phase appropriate mechanisms, for example, prior experience of the partners was critical in the embryonic phase, while cohesiveness and knowledge complementarity were vital in the engagement phase. The study emphasizes the significance of public funding and its distribution among members in order to support industry evolution and competitiveness. The University–Industry Collaboration continues to attract new participants and additional network-specific investments and has become a global centre of excellence for pharmaceutical research and development.

Keywords University–industry networks · Collaboration barriers · Collaboration enablers · Government funding

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1 Introduction

Collaborations between university and industry, often supported by state intervention, are regarded as critical to improving regional and national systems of innovation (Philpott et al., 2011) and driving economic development (Rajalo & Vadi, 2017). Indeed, the performance of an industry is impacted by how well its network of collaborators is managed. Firms are increasingly turning to external sources to acquire the technological knowledge they need to introduce product and process innovations (Möller and Svahn, 2006; Sherwood & Covin, 2008). Networks are one mechanism through which organisations share knowledge and generate innovations effectively and efficiently (e.g., Gulati, 1999; Powell et al., 1996). "*University–Industry innovation collaboration processes are based on interactions between university and industry scientists who are working to translate academic science with commercial potential towards market applications.*"(Oliver et al., 2019; 758).

Universities are increasingly engaging in collaboration with external networks involving other universities as well as industry participants (Chai & Shih, 2016). These collaborations are a source of financial gain for universities and firms in addition to providing stimulus for economic growth (Fischer et al., 2019; Siegel et al., 2003; Tseng et al., 2020). For instance, University–Industry Collaborations (UICs) promotion of innovative product development leads to sales growth in the market (Mindruta, 2013). However, despite the obvious benefits for both industry and university, success is not guaranteed, and many University–Industry Collaborations (UICs) experience tensions that impede successful collaboration, leading to less effective technological diffusion (e.g., Cyert & Goodman, 1997; Siegel et al., 2003). Cultural differences between universities and industry also result in differing approaches to research. Universities are interested in research that creates and disseminates new knowledge and may require longer development horizons, while industry generally requires more focused research that seeks to exploit knowledge as quickly as possible (Cyert & Goodman, 1997). Given their differing orientations and the degree of knowledge dispersion produced through collaborations, industry is often in conflict with university researchers over research topics and the timing and disclosure of results, overcoming these and other challenges is critical (Bruneel et al., 2010; De Wit-de Vries et al., 2019).

Although scholars have discussed the differences in motives, incentives, and organizational cultures between industry and universities (e.g., Cyert & Goodman, 1997; Siegel et al., 2003), our understanding of the underlying mechanisms of U–I interaction is still limited (Rajalo & Vadi, 2017; Steinmo & Rasmussen, 2016; Villani et al., 2017). Pre- and post- UIC formation studies have identified problems and solutions, for example, a lack of common understanding can be addressed by frequent social interactions and intermediaries (i.e. technology translators), which also help to reduce opportunistic fears and develop calculative trust. Individual and organisational trust are critical in UICs. Initially individual trust is based on scientist's characteristics, such as professional reputation and shared background, while organisational trust is based on organisational reputation and the contract specification process (Oliver et al., 2019). However, there is little empirical research available from a UIC evolutionary perspective (Al-Tabbaa & Ankrah, 2016; Huggins, 2010; Payne et al., 2011; Zaheer et al., 2010) and static network pictures provided by current studies (Huggins, 2010; Payne et al., 2011; Zaheer et al., 2010) do not capture the distinctive phases of relationship development (Grayson and Ambler, 1999). Moreover, studies rarely take into account the perspective of both academic and industry partners (Al-Tabbaa & Ankrah, 2016; Fischer et al., 2019; Perkmann et al., 2013); or the long-term evolution of collaboration mechanisms and benefits.

Furthermore, UIC literature does not analyze the network benefits achieved by network members over time. Scholars have referred to the resources furnished by such networks as network resources and contrasted their benefits with those ascribed to internal resources (e.g., Gulati, 1999; Lavie, 2006). While strategic management research has witnessed a surge of research on the innovation potential of in inter-organizational business networks, research on strategic UIC networks has provided little attention to the resources resulting from membership or participation to networks. Specifically there is a dearth of studies on the barriers and enablers to collaboration that emerge over time in UICs (Bruneel et al., 2010; Plewa et al., 2013).

This paper contributes to literature on the barriers and enablers to collaboration across projects (for example, Barnes et al., 2002; Lee, 2011) in establishing successful UICs. Most existing UIC studies rely on cross-sectional data and focus on either project (e.g. Barnes et al., 2002) or dyadic level with a shortage of empirical studies on the evolution of UICs (Huggins, 2010; Payne et al., 2011; Zaheer et al., 2010), the collaboration mechanisms, and the benefits achieved by UIC members over time (Bruneel et al., 2010; Plewa et al., 2013). The study explores the context of the collaboration and elucidates the barriers and enablers of collaboration as experienced by academic and industry partners during the evolution of a UIC. The research results illustrate the range of mechanisms that policy makers and TTOs can use to overcome UIC barriers and improve innovation and technology outcomes (Perkmann & Schildt, 2015). In adopting a qualitative research approach to generate depth of insight, this paper informs policy formulation supporting UIC development, identifying how localized investments might be best targeted. While findings from this study are exploratory they could be generalized to university collaborations with knowledge-intensive industries or knowledge-intensive collaborations such as collaborations with medical equipment, automotive, or the aerospace, industrial business actors. The paper is structured as follows: first, literature on UICs is reviewed, second, the research methodology adopted is outlined, third, findings are presented and discussed and finally, conclusions are drawn.

2 University–industry collaborations

University–Industry Collaborations (UICs) are characterised by three critical features that shape their nature and performance; first, they are populated by people from different professions (academics and industry practitioners); second, the collaboration is between individuals and not organisations; third, the collaborators are members of differing organisations (Amabile et al., 2001). Harnessing motivations to facilitate collaboration to enriching overall expertise and access unique resources such as technology, knowledge, and capabilities involves careful navigation of barriers and optimal use of enablers. The resulting UIC "*allows firms and universities to tap into complementary skills of each other and thus potentially help with saving cost and enhancing research outcomes.*" (Hemmert et al., 2014; 605).

Successful UICs involve lower research and development costs, generate higher levels of innovative output (George et al., 2002) and have a greater capacity to commercialise academic and intellectual property (Etzkowitz, 2003). However, not all UICs achieve their goals because "*public research institutes and private industry are characterised by highly divergent missions, organisational structures and management systems*" (Abramo et al., 2009; 503). In this context Perkmann and Walsh (2009) identified four types of University–Industry projects, (knowledge generation, idea testing, technology development and problem solving); ranging from basic research projects, to applied problem solving projects (McKelvey et al., 2015). However, despite the range of different kinds and scale of projects, the primary purpose of UICs is to generate new knowledge (Petruzzelli, 2011) or to re-combine/re-discover existing knowledge (Butcher & Jeffrey, 2005), particularly in science and technology where universities act as explorative organisations (Petruzzelli, 2011) and industry partners act as commercial catalysts.

To date, UICs have been explored using many different lens, for example, the types and impact of government policies (e.g.,Leydesdorff & Sun, 2009; Mowery & Sampat, 2004; Park & Leydesdorff, 2010); the motivations of academics to engage with industrial partners (e.g., D'Este & Perkmann, 2011; Perkmann et al., 2013); the role of grants and contracts in explaining academics' engagement with industry (Bozeman & Gaughan, 2007); the obstacles to the growth of academic spin-offs (Galati et al., 2017); the role of boundary organizations in facilitating open access (Perkmann & Schildt, 2015); the channels through which academic researchers interact with industry (D'Este & Patel, 2007); the propensity of firms to draw upon public research (e.g., Cohen et al., 2002; Laursen & Salter, 2004); the role of different types of intermediaries in University–Industry technology transfer (Villani et al., 2017); the role of social networks in U–I technology transfer (Schaeffer et al., 2020); and the nature and value of output produced through UIC in different geographical contexts (e.g., Chai & Shih, 2016; Fischer et al., 2019; Leydesdorff & Meyer, 2006; Liyanage & Mitchell, 1994).

While these studies have undoubtedly generated a great deal of insight, UICs are not always successful, frictions often emerge and impede collaboration (e.g. Al-Tabbaa & Ankrah, 2016; Barnes et al., 2002) and sub-optimal outcomes are realised. Existing studies on barriers and enablers restrict their analysis to a single theory (e.g. Al-Tabbaa & Ankrah, 2016) or involve cross-sectional dyadic or project-level quantitative approaches at a particular point in time (e.g. Barnes et al., 2002; Bruneel et al., 2010). Based on a systematic literature review of scientists' engagement in collaborations with industry actors Perkamn et al. (2013) developed three enablers/barriers categories; Individual (e.g., demographics, attitude, motivation), Organizational (IT support, Leadership department climate, University/Department quality), and Institutional (scientific discipline, regulation public policy).

In a study of Warwick University's Manufacturing Group, Barnes et al. (2002) identified the key themes across six different projects, namely project management skills (i.e., objective setting, progress monitoring, effective communication and deploying only trained, high quality project managers to run the collaboration); trust, commitment, and continuity; the capacity to flexibly adapt to changes in strategy or project direction (because collaborations tend to be influenced by external factors such as corporate instability); and that an appropriate balance between academic objectives and industrial priorities (with particular care being taken in defining the role of student). They also stress that these factors do not cause project success or failure in all situations rather their effect is dependent on the context. New factors identified in this study included: the role of the lead researcher and the role of postgraduate students. Barnes et al. (2002) also stress that these factors are context specific and are not related to project success.

Bruneel et al. (2010) identify two main barriers, 'orientation-related barriers', namely those related to differences in the orientations of industry and universities; and 'transaction-related barriers', namely those referring to barriers related to conflicts over intellectual property (IP), and dealing with university administration. They found that prior collaboration experience may mitigate some orientation-related barriers such as attitudinal differences between the partners in targets and research methods, but it does not lower the perceived barriers related to IP conflicts and university administrative procedures (Bruneel et al., 2010); adopting multiple channels for interaction does reduce orientation-related barriers but it increases transaction-related barriers, while trust reduces both types of barriers studied. They emphasize the importance of trust by stating that a firm's level of trust towards academic partners shapes the firm's perception of the barriers to working with universities (Bruneel et al., 2010). This is echoed in a study by Muscio and Vallanti (2014) who in their investigation of academics perceptions of the barriers to technology transfer found that misalignment of objectives between academic researchers and potential industrial partner, IP conflicts, lack of recognition and reward for academics engaging in UIC activities, all acted as barriers. Literature also illustrates that cultural differences (Bjerregaard, 2010), transaction costs (Sampson, 2004), geographical distance (D'Este et al., 2012), risk of free riding, opportunism, misappropriation of technological and strategic knowledge (Al-Tabbaa & Ankrah, 2016; Bstieler et al., 2015) are all barriers to UIC.

It is interesting to note that some of the same challenges identified as barriers are also identified as enablers, for example, finding an appropriate balance between academic objectives and industrial priorities (Barnes et al., 2002) and trust (Barnes et al., 2002; Santoro & Bierly, 2006; Sherwood & Covin, 2008). In an investigation of how trust enhances and/or impedes UIC innovation projects outcomes Oliver et al. (2019) used 30 semi-structured interviews with participants in four funded projects in Israeland found that individual and organizational trust explains success in UIC. Hemmert et al. (2014) used a survey of 618 UICs in different countries (US, Japan, South Korea) and industries (biotechnology, microelectronics, software) to examine the role of culture in trust formation in different countries and identified reputation and the leadership of academic champions as drivers of trust in countries like South Korea. Trust was also identified as a key enabler in a survey of 105 University–Industry (UI) collaborations in the US biotechnology industry examining the roles of universities' IP policies and of shared governance for trust formation between academic and industrial partners by Bstieler et al. (2015). They found that flexible and transparent university IP policies, shared governance, and champion behaviour enable the formation of trust, which is central for achieving success in UIC. This is supported by research by Santoro and Bierly (2006) who found that intellectual property policies are enablers in effective explicit knowledge transfer for university research centres. Knowledge transfer also featured in studies by Sherwood and Covin (2008) and Santoro and Bierly (2006) who found that tacit knowledge transfer in UICs is affected by trust, partner and technology familiarity, alliance experience, formal collaboration teams, technology experts' communications, social connectedness, technological capability and relatedness.

Furthermore, in analysing the effect of the reforms of the Japanese government to formalize and promote UIC based on the case study of the Tokyo Institute of Technology, Lee (2011) found that contractual arrangements, organizational commitments, specialized coordination, and formal evaluation procedures enables alliance partners to initiate more explorative research, to organize interdisciplinary projects with faculties in different research fields, and to establish larger scale R&D projects. Barnes et al. (2002) used six collaborative research projects at Warwick University's Research Center to analyse the factors that affect the perceived collaboration success of UIC and found that project management skills; commitment; continuity; the capacity to flexibly adapt to changes in strategy or project direction also acted as enablers. This is complemented by a large scale study of UK academic researchers analysing researchers' interaction—engagement channels with industry by D'Este and Patel (2007) who found that a variety of channels are used to interact

Table 1 Examples of some barriers and enablers of UIC

Barriers	Institutional barriers (Bruneel et al., 2010), Cultural differences (Bjerregard, 2010), Transaction costs (Sampson, 2004), project management skills; trust; commitment; continuity; the capacity to flexibly adapt to changes in strategy or project direction; and an appropriate balance between academic objectives and industrial priorities (Barnes et al., 2002); geographical distance (D'Este et al., 2012); Risk of free riding, opportunism, misappropriation of technological and strategic knowledge (Al-Tabbaa & Ankrah, 2016; Bstieler et al., 2015)
Enablers	Contractual arrangements, organizational commitments, specialized coordination, and formal evaluation procedures (Lee, 2011); Competence (Bäck and Kohtamäki, 2015); Social capital (Al-Tabbaa & Ankrah, 2016); UIC formal management mechanisms (moderated by innovative climate); Intermediaries (Villani et al., 2017); UIC regulation implementation (Huang & Chen, 2017)

with industrial collaborators, such as consultancy and contract research, joint research, or training.

Plewa et al. (2013) used quantitative methods to investigate success factors in UI linkages in Australia noting the importance of communication across all stages of relationship development. A finding which is reflected in a study by Al-Tabbaa and Ankrah, (2016) who explored the role and evolution of social capital in mitigating barriers in the preformation and post-formation of UICs in the Faraday Partnership, a UK government-backed scheme for enhancing innovation, they found that social capital strength improves trust. Communication is also used as a tool to help build motivation and absorptive capacity two factors found by Rajalo and Vadi (2017) in their qualitative study, using 12 case studies, to build individual levels of both, and to determine the likelihood of the success or failure of UIC. Literature also illustrates that competence (Bäck and Kohtamäki, 2015); social capital (Al-Tabbaa & Ankrah, 2016); UIC formal management mechanisms (moderated by innovative climate); intermediaries (Villani et al., 2017); UIC regulation implementation (Huang & Chen, 2017); and funding (Tseng et al., 2020) (See Tables 1 and 7). In a Taiwanese study measuring the influence of UIC funding on universities' technology innovation performance Tseng et al. (2020) found that the management mechanism, innovation climate, and reward system all positively affect UIC funding and universities' technology innovation performance.

Most studies in this area rely on cross-sectional data and focus at project (e.g. Barnes et al., 2002) or dyadic level and none focus on the network level assessing the perspective of both academic and industrial partners at the same time (Ankrah et al., 2013). Few studies have provided explanations of ways to reduce the barriers in these collaborations (Bruneel et al., 2010). Moreover, the evolutionary perspective to the study of networks has received credit but little empirical research (Huggins, 2010; Payne et al., 2011; Zaheer et al., 2010), especially in the analysis of the collaboration mechanisms and benefits achieved in UIC networks (Bruneel et al., 2010; Plewa et al., 2013). Zaheer et al. (2010), note that the evolutionary perspective in the study of a network provides the needed theoretical insights on network origins, dynamics, and change. However, despite these challenges the need to build competitive advantage and sustainability propels both parties to explore UIC (Enkel & Heil, 2014). This review of literature illustrates that few studies have investigated how the barriers and enablers to UIC evolve over time. Only a study on the evolution of a network can help to understand how the relationship between these actors change over time and how these actors overcome collaboration barriers and achieve long-term objectives. This study explores the evolution from informal interactions to long-term, sustained collaboration between industrial and universities partners at the network level, contributing to the evolutionary perspective on UIC networks. Understanding this progress will aid the formulation of effective policy measures to support UIC. Research on UIC evolution can provide useful insights on the type of mechanisms that policymakers and TTOs can use to overcome UIC barriers and improve collaboration outcomes (Perkmann & Schildt, 2015).

3 Research methodology

3.1 Research context

Ireland is one of the favored global locations for pharmaceutical firms establishing headquarters and manufacturing centers. It is home to more than 120 pharmaceutical companies (including 9 of the top 10 global players), providing direct and indirect employment to approximately 50,000 people, producing 5 of the top 12 medicines in the world, accounting for nearly 50% of goods exported (IPHA, 2021). In line with government policies in other countries (Park & Leydesdorff, 2010; Perkmann et al., 2013) the Irish government continues to create a culture of support for innovation in order to consolidate the pharmaceutical industry in Ireland. As part of these efforts, the UIC project leader secured €7.7 million euros from the Irish government to create the Solid State Pharmaceutical Cluster (SSPC). The SSPC is mandated to conduct research through knowledge networks that would ensure that Ireland remained competitive in the global pharmaceutical industry. It defines itself as *"a world-leading hub of Irish research expertise developing innovative technologies to address key challenges facing the pharmaceutical and biopharmaceutical industry. Our in-depth scientific and engineering research expertise aids companies who need tailored solutions to their bespoke challenges."* (https://sspc.ie/, December 2021). Originally established with 5 universities and 9 multinational pharmaceutical companies based in Ireland, the SSPC has expanded to 17 pharmaceutical companies, 36 academic investigators, 24 industrial partners, 115 PhD positions, 87 Post-Doctoral Research positions, a community of 400, and 9 research performing institutes.

This study focuses on a UIC in which the actors involved in it are normally competitors; however, in this context they 'coopete' gaining mutual benefits from their participation in the network. Nalebuff and Brandenburger (1997) coined the term "coopetition" to describe the simultaneous use of cooperative and competitive strategies. Firms that adopt this concept do not conceive all players as competitors, rather some of apparent competitors are viewed as complementors who can add value to the firm's own products and services.

The SSPC has developed and utilizes significant competences in process innovation and research collaborations; such has been their success that within 5 years of formation they secured an additional €40 million in funding; an exceptional sum in terms of Irish government funding. The cluster has established itself as a centre of excellence for effective, safe drug manufacture, with fewer associated costs. It focuses on medicine, manufacturing, molecules, materials, modelling, and bio-capabilities using advanced technologies to observe and study crystallization (i.e., Crystallization, Isolation and Drying Test-Bed). The SSPC has recently entered its second iteration and has expanded into manufacturing and modelling with additional funding bringing its total budget to €61 M.

4 Research approach

The research adopted a qualitative interpretivist methodology using a single site case study with the 18 founding members, involving 7 academics and 11 industry participants (representing 5 universities and 9 multinational firms) (Yin, 2013). Case study methodology has become more prevalent in UIC studies in recent years, helping to explain and understand the multidimensional process as it evolves (Villani et al., 2017; McKelvey et al., 2015). In order to ensure that the researchers understood and appreciated the processes involved, in addition to undertaking depth interviews with the 18 founding members externally published documents and internal reports and memoranda were reviewed. The industry participants are all competitors and there was no history of collaboration in this sector prior to this initiative. Interviews lasting between 50 and 105 min were conducted (see Table 8 for a list of anonymised participants).

The interviews used a protocol that included an initial question asking informants to describe the evolution of the network over time, with subsequent questions asking respondents to discuss the problems they faced, how the problems were solved, and the benefits derived from their participation in the network. All interviews were recorded and transcribed verbatim. In addition, interview data were triangulated using different data sources, such as interviews with R&D managers and academics directly involved in the activities of the network, documentation, archival resources, newspaper articles, presentations, and online resources.

Data were analyzed using open coding (Strauss & Corbin, 1998), specifically searching for information about the range of barriers to and enablers of UIC collaborations at the different evolutionary points in time. Data analysis commenced with a systematic search for similarities and differences in data categories and concepts, progressing through open coding (derived from data), abstract coding and a final set of conceptual and theoretical codes (Catterall, 1996; Goulding, 1998). Codes were evaluated and re-evaluated for their interrelationships (Shaw, 1999), data displays were created in a series of matrices and charts, first on an interview by interview basis before engaging in case analysis (Carson et al., 2001; Miles & Huberman, 1994), helping to organise data and facilitate analysis and the emergence of concepts. This led to the identification of four distinct evolutionary phases, the Embryonic phase (prior to Year 1), the Initiation phase (Year 1–3), the Engagement phase (Year 4–7) and the Established phase (Year 8 to date). The phases were identified based on the language used by respondents and in documentation describing the four times periods; the frequency of, and significance attributed to network activities; occurrences in communication including emails, presentations, newsletters and online resources.

The findings were compared with the extant literature noting variance; this process enhanced internal validity and generalisability in theory building (Lindgreen, 2000). In order to check the validity and reliability of the index and sub-categories obtained, academics who had not been involved with the interviews were asked to test the inter-rated agreement. In developing categories and sub-categories in a sample of the data, the academics found no new categories; validity and reliability were also guaranteed by asking academics with expertise in UIC to comment on the results of this study.

5 Findings—phases of UIC development and associated barriers/enablers

Analysis of interview data allowed us to identify four distinct phases in the SSPC evolution, first, the *Embryonic phase* (prior to Year 1) where a key actor (in this instance an academic) identified the opportunity to work jointly with other academics and industry partners on a common scientific area of interest. Second, the *Initiation phase* (Year 1–3) where network members got to know each other, built trust, demonstrated their respective skills and capabilities (academics), and discussed their needs (industry). Third, the *Engagement phase* (Year 4–7) where different actors began to engage in knowledge-sharing activities. Fourth, the *Established* phase (Year 8 to date) where the network achieved its first important results, attracted additional funding, and increased in size.

5.1 Embryonic phase (prior to year 1)

The pharmaceutical industry is highly fragmented and dominated by a hierarchy with demarcation between the generic companies and applied or 'ethical' firms; these firms were disconnected from, and competitive with, each other. The project manager noted that *"The pharmaceutical industry is very insular, very intellectual property concerned I would say. Very much closed in terms of how they share information. That has come about specifically with the emergence of generic competition. I worked in a couple of pharmaceutical companies over the years and what was said always was that generic was the low end of things. There is snobbery in the industry towards generic companies. There was a view that these guys are just preying on IP… they call themselves the ethical industry versus the generic industry"*. (Peter, University 1). Therefore, even though everyone knew of each other's existence, there was little collaboration among the different players due to low levels of trust and high levels of risk in sharing knowledge.

Academics' lack of willingness to share knowledge is often dependent on the personality of academics, their need to lead research projects, establish specific areas of expertise and publish in top tier academic journals. Thus, working with knowledge competitors in the same area of expertise may offset or reduce important advantages, such as the visibility of a research paper in a top journal, or being the first to publish research on a very specific topic or new phenomenon. However, in the SSPC network *"there are no big egos which can sometimes be a problem when you are dealing with academics….. Sometimes the academics are almost reluctant to share their research with the other partners."* (David, Company 6), *"It worked here I supposed because we were bringing different expertise together"* (Angela, University 1). Thus, the embryonic phase was dominated by barriers based on skepticism and enablers based on experience (see Table 2).

The embryonic phase started with the possibility of forming a network to secure research funding. Its title indicates the activities undertaken by the founding actors to build a collaborative research network. Initially it was the possibility of winning funding that motivated early discussion and collaborative bid writing. The phase was characterised by participant recognition of a common production opportunity in addressing issues related to the lack of reproducibility of solid-state forms. Based on the interviews it became evident that the leadership (and reputation) of the key actor, and communications between the technology transfer officer (TTO) liaisons were fundamental to developing the idea of the cluster. Competence-based trust was an important enabler of the collaboration; it was

Table 2 UIC embryonic phase

	Industry–university	Industry–industry	University–university
Barriers	Strong perception of poor value	Strong fear of knowledge leakage (core capability) resulting from collaboration initiatives	Strong reluctance to share
	Strong lack of trust		Strong reluctance to work with competitors in the same 'knowledge area'
Enablers	Prior collaboration experience	Prior experience in making network connections	Awareness of research centers
	Prior experience in making network connections		Prior experience in making network connections
	Possibility of winning government funding		Possibility of winning government funding

determined by industrial partners' perceptions of credibility and expertise of the key actor, who had been very successful in the past and had credibility in formulating mutually beneficial IP, patent and licensing policies (Santoro & Betts, 2002).

The key actor recognized that both industry and academia had an interest in addressing issues related to the lack of reproducibility of solid-state forms. *"Well it was all driven by [Robert] (University 1); he originally thought that it might be possible to do something in this general area. He then contacted people to see what they would think." (Mark, University 3).* The network members shared the same vision of the future state of the network as a future in the centre of research excellence or research hub on crystallization. Hence, a significant enabler at this phase was the previous experience that industrial partners had of working with the key actor, their trust in his capabilities and reputation, their shared vision: "*I see that this cluster could lead to or morph into a new national pharma competency centre. A one-stop shop for all of the active ingredients and the hub of technology*." (James, Company 1).

Findings show that although pharma companies were aware of each other before the development of the network; they rarely collaborated on a shared project or engaged in joint problem solving activities. They were aware "*that industry has to operate with a very clear understanding of its own position and with individuals within the company but equally with Ireland Inc as an overall umbrella."* (Samuel, Firm 8). However, fear of knowledge spill overs and the risk associated with opportunistic behaviour during collaboration limited their knowledge sharing activities. The pharmaceutical sector is a knowledge-intensive industry whose core competence is mainly based on tacit knowledge where product development takes a considerable amount of time with high financial investment, resulting potentially in high financial risks of knowledge leakage when collaborating with other firms in the same sector. *"Pharma IP… takes a long time to develop a drug… They tend not to want to share anything with regard to core competency"* (Angela, University 1).

Data from the interviews show that the degree of cohesiveness between academics and business people in the working in the pharmaceutical industry in Ireland is high, *"the cooperation that exists between the companies is what has distinguished us here in Ireland"* (Mark, University 3). *"Here we are pretty close together. It's easy to get together to work together, the logistics are easier, we know each other….Knowing each other helps with logistics… it also helps with confidence and trust in each other. Once you build those things up, you can accelerate your progress in terms of helping each other understand your needs, and work openly and discussing openly….where the challenges are and where you need to go to fix those."* (Joseph, Company 7).

5.2 Initiation phase (Year 1–3)

The trigger for the Initiation phase was the receipt of project funding. The Initiation phase is characterised by recognition of the advantages of sharing resources and knowledge through collaboration with competitors, which is offset by the risk of sharing core capabilities, which could result in knowledge leakage in the absence of a formal intellectual property rights agreement (see Table 3).

During this phase government funding of 7.7 million euros was used to establish the infrastructure of the network and to buy state of the art technologies and equipment, to recruit a project manager (Peter, University 1), post-doctoral researchers and PhD students across the five academic groups. The equal distribution of funding amongst the partners supported collaborative efforts, this form of network specific investment "*was one of the*

Table 3 UIC initiation phase

	Industry–university	Industry–industry	University–university
Barriers	Perception of poor value	Lack of IP Rights agreement	Reluctance to share resources, knowledge, projects etc
	Moderate lack of trust	Strong fear of knowledge leakage (core capability) resulting from collaboration initiatives	Reluctance to work with other academics in the same 'knowledge area'
	Lack of IP Rights agreement		
Enablers	Shared vision	Shared vision	Shared vision
	Prior experience in making network connections	Prior experience in making network connections	Prior experience in making network connections
	Network—specific investments (Equally distributed Government Funding)	Network—specific investments (Equally distributed Government Funding)	Network—specific investments (Equally distributed Government Funding)
	Reputation-based trust		Reputation-based trust

chief objectives in the beginning for the group to collaborate. It needed the financial ability to be able to purchase equipment to start progressing the research and getting the researchers in that was fundamentally a huge requirement to get SFI approval and support in going forward"" (Matthew, Company 3).

Government funding fostered academics' willingness to work together, share knowledge, and cooperate. Interviewees noted that equality was maintained between parties by the key actor who divided the financial resources evenly between all of the academic parties. "*In this partnership everyone is equal. That is unusual even in research clusters, there normally tends to be one partner that is bigger. In the SSPC each of the partners is seen very much as equal and that goes down to the level of funding that is received…So everyone got similar level of capital equipment and similar level of personnel. So that was certainly an important characteristic.*" (Andrew, University 2). This equal division of funding was crucial in nurturing a sense of equality, partnership and ownership within the participant network, increasing their commitment to making this UIC a success.

A significant enabler at this phase of collaboration development was that the previous experience that industrial partners had with each other; *"before the project began… a lot of us worked together in the IBEC R&D*[1] *group and we would be very familiar with each other and very comfortable in our discussions with each other. So it was a natural transition rather than one that needed to be generated. That is probably an advantage that we have with the existence of the R&DI group. Who would involve themselves in any project like that going forward. There is already a synergy or collaboration there already."* (Samuel, Firm 8). In addition they had significant experience of working with the key actor, they trusted him and his reputation, and his vision for the SSPC. Significantly, other network members shared the same vision. In particularly, they shared the same first order goal (to keep the pharmaceutical multinationals in Ireland) and second-order goal (to improve the skills, competencies, and capabilities of Irish researchers in order to increase the value generated from R&D activities). *"We want the pharmaceutical industry in Ireland to be better than the pharmaceutical industries in other places…[Robert] wanted to found the cluster because he was aware that the pharmacy industry could lose out and we might not get more investment from the companies because Ireland would not be seen as a high tech place anymore."* (Mark, University 3). This shared vision promoted mutual understanding and facilitated the exchange of knowledge and ideas between key participants who shared an extensive range of knowledge, which was focused on a common problem, crystallization. While this was a useful starting point, it was widely recognized that the recruitment of a project manager who had previously worked in both industry and academia was critical to its ultimate success. "*I came on board shortly afterwards, we realised that we still had a lot of hurdles to come. In terms of building a level of trust that companies could begin to trust each other and academia. That is one of the biggest things that I would have seen coming in from industry, industry is suspicious of academia."* (Peter, University 1).

As expected, intellectual property (IP) emerged as an issue during this phase (see Table 2). From the academics perspective they needed to establish/solidify a reputation in the scientific community by publishing new knowledge. Initially IP was perceived to be a barrier to knowledge sharing activities between members, so in order to avoid any potential conflicts between companies around IP issues the network members decided to work on a generic compound with no IP concerns, while they were waiting establish an IP agreement.

[1] IBEC is the Irish Business and Employers Confederation. It has industry specific collaborations for R&D. see https://www.ibec.ie/influencing-for-business/enterprise-and-innovation/about-enterprise-and-innovation.

"I suppose the obstacles are around intellectual property and confidentiality …industry has to have ownership, or no constraints, on anything that comes out of the collaboration" (David, Company 6). From an industry perspective IP needed to be secured (given that IP rights are critical in knowledge-intensive industries such as pharmaceuticals)—securing IP rights for a particular drug can determine significant long-term revenues. The development of the IP agreement was led by industry and their respective legal teams and started with agreement on the manufacture of a generic compound based on knowledge exploitation with little or no IP risk. "*So each company protects their own compound and they have their IP protection on that compound for a certain period of time. So we chose to work on compounds that were hard crystallised, made sense, but were not linked to any one company."* (Angela, University 1). This helped to build trust between the negotiating parties and formed the basis of a step by step negotiation of an IP agreement which would facilitate knowledge exploration.

5.3 Engagement phase (Year 4–7)

The finalization of the IP agreement was the impetus for the Engagement phase: "*I think …intellectual property…is still a potential problem. But a lot of work went into coming up with the IP agreement*." (David, Company 6). However, this issue was approached in a collaborative manner: "*they got the industry companies to help them write the IP. So that was unusual and good.*" (James, Company 1). Members engaged heavily in order to overcome the IP challenge, and this phase was dominated by actors in the network developing and approving the IP rights document and getting involved in knowledge sharing activities (see Table 4).

Genuine proactive engagement enabled knowledge sharing activities addressing the common crystallisation problems (with no IP concerns) experienced by all actors. The complementarity of knowledge contributed to enhance their motivation to share knowledge "*in the case of our cluster…everyone is willing to share and work with one and other and I think personally part of the reason was that any of the PIs, I think bar one, none of us had received [government] funding previously*." (David, Company 6).

One of the conditions that fostered an effective collaboration among academic actors was the complementarity of knowledge needed to address crystallization problems through different perspectives. Accordingly, the academic side of the network was made up of disciplinary departments from different universities each approaching crystallization from a different angle, providing specific expertise and a distinct, yet complementary, background knowledge related to the domain of pharmaceutical solids. Network partners were sharing knowledge that complemented their area of expertise, and this contributed to enhancing their motivation to shared knowledge in order to have a holistic understanding of the process of crystallization. *"Everyone was complementary to everyone else."* (Mark, University 3).

The role of project manager (Peter, University 1) in achieving these objectives emerged as crucial. The harmonization of objectives, perspectives and modes of operation of diverse organizations (as is the norm in UIC); *"I think if I was to point to any one single item that could be learned from this cluster it was the fact that we have people in the academic space who have worked in industry and understand industry's needs and they can talk the industry's language to their academic partners. They are really able to bridge that gap between industry and university."* (Matthew, Company 3).

Table 4 UIC engagement phase

	Industry–university	Industry–industry	University–university
Barriers	Moderate perception of poor value	Moderate fear of knowledge leakage	Moderate fear of knowledge leakage
Enablers	Cohesiveness	Cohesiveness	Cohesiveness
	Geographical proximity	Geographical proximity	Geographical proximity
	IP agreement	IP agreement	Project manager and TTO
	Project manager and TTO	Project manager and TTO	Complementarity of knowledge
	Integrity-based trust		Reciprocity
	Knowledge transfer routines		Extrinsic rewards
	Platform projects		

This phase also demonstrates how government investment can be used as a platform to attract firm-specific funding (i.e. platform projects) to specific network members as the network evolves. These forms of funding increased the interaction and engagement with firm-specific tasks and goals. In addition, *"One of the unique advantages here in Ireland is ... the scale of the country and the proximity that we have to each other, University 5, 4, 1 and 3 were all within a couple of hours of each other...we all know each other. We either all went to college together or we meet through industry forums or through conferences. So you know there is a lot of contact, you know that's our advantage*" (Mark, University 3). As the UIC has grown, the possibility of further government funding resulted in plans for more creative, innovative and productive collaboration that would previously not have been possible.

The academic actors recognised that there was a significant lack of fundamental understanding of the science and engineering challenges of the manufacturing process; they set up quarterly technical meetings (e.g. presentations on crystallisation/polymorph case studies, areas of future research, etc.) and training sessions (e.g. solid state fundamentals, from crystallisation to pre-formulation, etc.) where different academic partners presented their work in progress to others. Industry accelerated this learning by inviting PhD students and researchers into their laboratories for a period of three months to learn the manufacturing process and engage in company-specific research projects.

Collectively, these routines may be viewed as a capability in managing knowledge flows in inter-firm networks (Lorenzoni and Lipparini, 1999). The project manager noted the significance of managing knowledge flow capability; *"So we said let's give them high-level training, not post-doc training but let's get primary investigators in front of the industry people. Let's do it in a place that is convenient for them and we set that up in three locations...and we got a couple of 100 man-day's training over the first year. Companies came and really bought into it."* (Peter, University 1). Through participation and engagement in high-level workshops integrity-based trust emerged extending the scope and remit of the collaboration.

These knowledge-sharing routines were designed not only reach a mutual understanding in a specific scientific area, but also to gain an appreciation of each other's needs and capabilities. This was fundamental in fostering additional knowledge sharing routines on ad-hoc platform projects involving dyadic relations between academics and businesses. It was *"designed in such a way to show the capabilities of the academic groups and to show the industry what we were doing and what we were capable of doing. Then if industry were happy at that stage they might come up with company specific projects."* (Jean, University 4).

The project manager noted that during this phase the successes far outweighed their initial expectations: *"Our original plan was that we would have companies coming to us after year three and saying we will work with you on solo projects. Now we have companies coming to us, five years later and saying will you work with us on something in continuous crystallisation. So we now have three platforms identified where we would have 4–5 companies working within each platform with 2–3 universities to develop centres of excellence in three specific areas."* (Peter, University 1). Thus the engagement phase was dominated by 'fear of knowledge leakage' based barriers and cohesiveness based enablers as illustrated in Table 3.

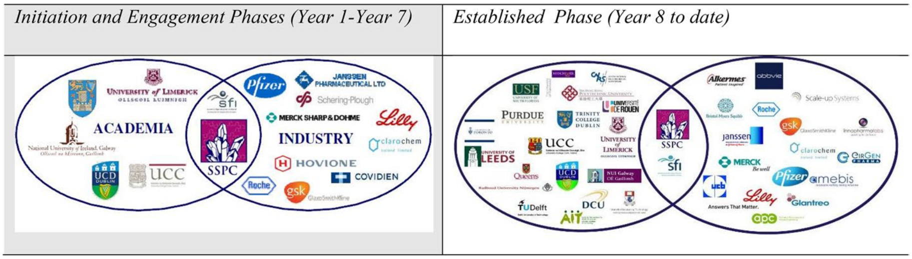

Fig. 1 Members of the solid state pharmaceutical cluster at the different phases of its evolution (initiation vs. established)

Table 5 UIC established phase

University	Business
Achievements	
Attraction of new academic partners	Attraction of new Industry partners
Additional network-specific investments	Additional problem solving knowledge
Hiring of 90 researchers (among PhDs and post-docs)	Learning how to move from batch manufacturing to continuous processing
	Additional network-specific investments

5.4 Established phase (Year 8 to date)

The Established phase represents the link between the end of the first seven years and the start of a new chapter for the life of the network. During this phase some of the benefits from the participation to the SSPC network start to emerge and, as a result, the network received an additional €40 million euros in funding, €30 million from the Irish government and €10 million from industry partners. The SSPC network today includes 17 pharmaceutical companies, 36 academic investigators, 24 industrial partners, 115 PhD positions, 87 Post-Doctoral Research positions, a community of 400 and 9 research performing institutes with a total budget of €61 M (Fig. 1).

In the established phase (See Table 5) with additional government support, the network aims to become a global hub for pharmaceutical process innovation and manufacturing, linking university and the pharmaceutical industry to address and resolve important research questions. The findings indicate that network-specific investments, government policy and funding, promoted a positive attitude among academics towards sharing knowledge and collaborating with each other and with industry. They illustrate how the allocation of funding can be used to foster collaboration among university disciplines competing in the same knowledge area.

In this industry, the processing of materials is traditionally based on batch manufacturing, whereby each unit dosage form is identified by a unique batch. However, batch manufacturing lacks flexibility. In other industries (i.e. the petrochemical/chemical), polymer continuous manufacturing is adopted. The pharma sector is moving from batch to continuous processing in order to minimize the size of new manufacturing plants and to use available capacity efficiently. Thanks to the activities performed by the cluster, industrial and academic actors have" *learned about the potential of crystallization in manufacturing*" (*Christopher, Firm 10)* and they are attempting to figure out how this can help them to move from batch manufacturing to continuous manufacturing in order to remain competitive. Thus, in the continued engagement phase the network has becomes a global hub for pharmaceutical process and manufacturing innovation, linking academia and the pharmaceutical industry to address and resolve important research questions. The vision of the network is *"to be the leading research centre of excellence shaping the future of the global pharmaceutical industry"* (www.SSPC.ie, 2021).

The SSPC developed a repository, the "crystallization best practice website", where the knowledge produced within the network is made available to all network participants in the form of articles, presentations, and documents; *"They agreed to put together a best practice document which would gather information that was already in people's heads… It's much easier to share it once you've captured it … They brainstormed on all the information they had and put it together on an electronic portal called the BPX website. Anybody in the company can access that and that has been really good" (Angela, University 1).* These knowledge-sharing routines advanced business understanding of solid crystallization and its potential for improving the manufacturing process. In particular, some actors learned how to revolutionize their manufacturing process. *"The problem before we had the cluster here in [Firm 6], we thought we knew about crystallization. You do not appreciate the potential that there is in crystallization and what it can contribute to the business by improving the process… I'm very pleased to see the success and I think each year there has been success" (David, Firm 6).*

5.5 UIC barriers and enablers

In exploring the evolution of a UIC in the pharmaceutical industry this study illustrates a range of phase appropriate collaboration mechanisms utilised by members to consolidate and progress collaborative relationships. The study highlights the intellectual, financial, organisational, performance and relational benefits achieved by UIC members over time, giving insight into a range of mechanisms that policy makers and TTOs can use to overcome UIC barriers, using targeted investments to improve innovation and technology outcomes.

The study illustrates that throughout the UIC evolution there are consistent and transient barriers and enablers. The findings illustrate the consistency of certain barriers such as fear of knowledge leakage and perception of UIC as poor value (reducing in strength from strong to moderate over time). It also finds that certain barriers transition to being enablers, for example, trust evolves from being a barrier in general, to being an enabler, first as reputation based trust, and then as integrity based trust.

It is significant to note that the findings do not identify any consistent enablers. This indicates that enablers appear to be phase specific, that is, once the enabler has been embedded additional enablers become apparent. For example, in the two early UIC phases, Embryonic and Initiation, prior experience in making network connections are significant for all participants, signalling the relational benefits to members of the evolution of the

UIC, however in later phases, Engagement and Established cohesiveness emerges as an enabler.

It is also interesting to explore UIC barriers and enablers in the context of inter-relationships, for example, industry to university, industry to industry, and university to university relationships. Initial industry to university barriers centre on initial perceptions of poor value and lack of trust culminating in the absence of an IP Rights agreement. These were overcome by enablers in the Embryonic phase such as prior collaboration experience and prior experience in making network connections which helped to establish the shared vision, additional relational and funding network experience which built reputational trust in the Initiation phase. As they continued to work together on projects additional enablers such as cohesiveness supported by geographical proximity, an IP agreement, knowledge transfer routines and platform projects were routinized by the project manager and TTO which helped to build integrity-based trust (see Table 6).

Initially in the Embryonic and Initiation phases, industry to industry barriers came from a strong fear of knowledge leakage in core capabilities resulting from collaboration initiatives which were not protected by an IP Rights agreement. In the Initiation phase progress was enabled by participants' prior experience in making network connections, a shared vision and government funding. In the Engagement phase the project manager and TTO's were able to build cohesiveness based on shared projects, consolidate an IP agreement, and maximise the benefits accruing from the geographical proximity of partners.

University to university relationships faced similar barriers to those faced by industry to industry relationships. They were dominated by a strong reluctance to share resources, knowledge, projects, and to work with competitors in the same 'knowledge area' which was dominated by a fear of knowledge leakage. These fears were mediated by enablers such as their awareness of research centres and prior experience in making network connections. Over time this translated into a shared vision for the project and access to government funding and reputation-based trust. This built cohesiveness which was helped by geographical proximity, complementarity of knowledge and reciprocity, extrinsic rewards and the careful stewardship of the project manager and TTOs.

6 Discussion

This paper contributes to UIC literature by exploring the barriers and enablers throughout the evolution of the UIC, identifying four phases of network evolution (embryonic, initiation, engagement, and established). This study is among the first that focuses on academic and industrial actors involved in network collaborations, identifying barriers such as scepticism and fear; and enablers such as opportunity recognition, trust, cohesiveness; all of which were underpinned by equal distribution of government funding to all parties. Tseng et al. (2020) had previously noted the significance of funding in influencing the construction of well-developed UIC environments within universities, however it had not explored the equal distribution of funding between all partners and the impetus this brings to industry evolution and competitiveness.

We contribute to literature on network dynamics showing how emergent forms of networks become intentionally or rationally structured over time as a result of institutional networks (Koza & Lewin, 1998). The structure of an emergent network is sparse, unregulated,

Table 6 UIC barriers and enablers

	Industry–University	Industry–Industry	University–University
UIC barriers			
Barriers UIC embryonic phase 1	Strong perception of poor value	Strong fear of knowledge leakage (core capability) resulting from collaboration initiatives	Strong reluctance to share
	Strong lack of trust		Strong reluctance to work with competitors in the same 'knowledge area'
Barriers UIC initiation phase 2	Perception of poor value	Lack of IP Rights agreement	Reluctance to share resources, knowledge, projects etc
	Moderate lack of trust	Strong fear of knowledge leakage (core capability) resulting from collaboration initiatives	Reluctance to work with other academics in the same 'knowledge area'
	Lack of IP Rights agreement		
Barriers UIC engagement phase 3	Moderate perception of poor value	Moderate fear of knowledge leakage	Moderate fear of knowledge leakage
UIC enablers			
Enablers UIC embryonic phase 1	Prior collaboration experience	Prior experience in making network connections	Awareness of research centers
	Prior experience in making network connections		Prior experience in making network connections
	Possibility of winning government funding		Possibility of winning government funding
Enablers UIC initiation phase 2	Shared vision	Shared vision	Shared vision
	Prior experience in making network connections	Prior experience in making network connections	Prior experience in making network connections
	Network—specific investments (Equally distributed Government Funding)	Network—specific investments (Equally distributed Government Funding)	Network—specific investments (Equally distributed Government Funding)
	Reputation-based trust		Reputation-based trust
Enablers UIC engagement phase 3	Cohesiveness	Cohesiveness	Cohesiveness
	Geographical Proximity	Geographical Proximity	Geographical Proximity
	IP agreement	IP agreement	Project manager and TTO
	Project manager and TTO	Project manager and TTO	Complementarity of knowledge
	Integrity-based trust		Reciprocity
	Knowledge transfer routines		Extrinsic rewards
	Platform projects		

with a lack of trust and high perceived risk, so at this phase only knowledge exploitation activities are possible. However, if this structure mutates into a more regulated, cohesive structure, and trust develops, knowledge exploration can take place. Thus, we contribute to the debate around the interplay between knowledge exploitation and exploration (e.g. Gupta et al., 2006) in the context of UIC networks. Our findings illustrate that exploitation is the starting point in UIC networks however we find support for the argument that exploitation and exploration can coexist (Gupta et al., 2006; Raisch et al., 2009) and that exploitation precedes exploration in the context of UIC but that it is dependent on the contextual factors highlighted above.

Government policy and funding (that is, network-specific investments) promoted a positive attitude among academics towards sharing knowledge and collaborating with each other and with industry (Park & Leydesdorff, 2010; Perkmann et al., 2013). This supports suggestions that government funding enhances academic engagement with industrial partners (Bozeman & Gaughan, 2007). Notably, our findings demonstrate that equal allocation of funding can be used to foster collaboration among university disciplines competing in the same knowledge area. The study also demonstrates how government investment can be used as a platform to attract firm-specific funding (i.e. platform projects) to specific network members as the network evolves. These forms of funding increased interaction and engagement through firm-specific tasks and goals.

The significance of government funding cannot be underestimated in that it encouraged, supported and propelled collaboration which would not have taken place otherwise. Initially it was the possibility of winning funding that motivated early discussion and bid writing. During the next phase the equal distribution of funding amongst the partners supported collaborative efforts through facilitating networking and training. Increasing familiarity created new opportunities and indeed an impetus to address IP challenges. As the UIC grew, the possibility of further government funding resulted in plans for more creative, innovative and productive collaboration that would previously not have been possible. At each phase the possibility of additional government funding acted as a stimulus for the next phase, however as the UIC moved into the Established phase private equity started to follow government funding, reducing the dependency of the UIC on public funds and enabling funding of commercially oriented privately funded research projects.

We find that within the UIC studied, the presence of shared vision and goals promotes mutual understanding, and facilitates the exchange of knowledge and ideas (Borup et al., 2006). Perceived barriers including academics' unwillingness to share resources, knowledge and funding and to collaborate with knowledge "competitors" can be overcome by establishing parity and reciprocity among academic partners. Academics felt more involved in the activities of the network because they received the same resources as other members and partners clearly provided complementary knowledge.

Much of the success achieved by this UIC is attributed to the positive impact of the project manager. The project manager was vital in harmonizing different objectives, needs, perspectives, and modes of operation of academic and industrial organisations. This corroborates the suggestion that projects are more likely to be derailed in the absence of an effective project manager (Barnes et al., 2002). The findings also demonstrate the importance of the adoption of rules in addressing everyday management problems (Alexander et al., 2020).

The absence of an IP rights agreement was perceived as a critical impediment to knowledge sharing at the early stage of academic industry collaboration (Al-Tabbaa & Ankrah, 2016), to overcome this barrier the SSPC UIC adopted a collaborative IP agreement construction process involving all parties. The process was supported by knowledge transfer routines (Dyer & Nobeoka, 2000; Zollo et al., 2002) as evidenced by regular meetings, training and the online platform developed. This helped the evolution of trust which was critical in the progression of this UIC (Al-Tabbaa & Ankrah, 2016; Sherwood & Covin, 2008) reducing fears of opportunism and knowledge leakage. However, different types of trust became important at different stages of network evolution. At the initiation phase, competence-based trust was important to attract potential industrial partners and to get them on board of the network project. This type of trust was initially directed towards the key actor because of his previous achievements, but was later extended to other academic participants through their engagement in industry workshops. At the engagement phase, integrity-based trust was more important given that academics and companies were sharing more tacit knowledge.

The importance of knowledge sharing routines and trust has been highlighted in buyer–supplier relationships (Dyer & Nobeoka, 2000) and in strategic alliance literature (Zollo et al., 2002). We also found that exploitation and exploration knowledge-sharing routines enhance learning between partners. On one hand, academics learned (a) to appreciate the challenges faced by industry, (b) how their knowledge and competences apply to an industrial context and (c) to engage in explicit knowledge sharing (i.e. knowledge exploitation). On the other hand, industrial partners learned about the potential of crystallization and how to move collaboration forward with the aim of revolutionizing manufacturing processes in the pharmaceutical industry (from batch manufacturing to continuous manufacturing, i.e. knowledge exploration).

Furthermore, trust has been consistently highlighted as a success factor in academia-industry collaborations (e.g., Barnes et al., 2002; De Wit-de Vries et al., 2019; Oliver et al., 2019). In this study, we highlight how trust evolves at different stages of UIC network evolution. There is an initial trust towards a single individual, a key actor. The study corroborates findings regarding the importance of reputation and leadership of academic *champions* in the formation of trust also in a country with established and mature UIC networks (Hemmert et al., 2014). An academic champion acted as the key player in identifying the complementarity of academia and industry's skills, knowledge and resources, and in formulating forward-looking and ambitious plans and goals that motivated many organizations to get on board (Santoro & Betts, 2002).

The findings demonstrate the importance of geographical proximity in facilitating knowledge transfer and collaboration (Petruzzelli and Murgia, 2020). Previous studies explored geographical distance as a barrier in UIC (D'Este, et al., 2012); highlighting the role of intermediaries in managing proximity dimensions (Villani et al., 2017); and noted the danger of knowledge spillovers from universities to geographically proximate firms (Mukherji and Silberman, 2021). Geographical proximity was instrumental in reducing cognitive proximity between partners independently of the activity of intermediary organizations. This supports the result of previous studies highlighting the role of proximity in British companies' decision to collaborate with top-tier universities (Laursen et al., 2011).

This study highlights the dynamics of different proximity dimensions. Laursen et al. (2011) and Steinmo and Rasmussen (2016) reveal that science-based companies focus on cognitive and organizational proximity in establishing collaborative relationships; our study shows that geographical proximity is instrumental in reducing cognitive dissonance between partners, independently of the activity of intermediary organizations. That is, geographical proximity facilitated the implementation knowledge transfer routines and learning. Industry and academic actors' interactions facilitated mutual understanding. This has policy implications for Governments in terms of facilitating co-location of firms in technology parks close to institutions of higher education.

Finally, the study emphasizes the range of benefits that both university and industry partners achieved over time. Previous studies focused on the number of patents and publications generated (e.g. Fischer et al., 2019; Lin, 2017; Petruzzelli, 2011), however in this study we found that yes, academic partners did increase their publications, but they also received additional government investments, hired new post-docs and PhDs (90), and they increased their reputation through the attraction of new academic partners. Industry members improved their knowledge of solid crystallization and could identify new solutions (i.e. they learnt how to move from batch manufacturing to continuous processing), developed best practice (codified and stored in a wiki), and increased their reputation by attracting new industry partners. Furthermore, industry and academic partners contributed to developing a world-leading research centre with expertise in developing innovative technologies to address the challenges faced by pharmaceutical and biopharmaceutical companies. Therefore, this study advances the literature about the range of positive outcomes deriving from UIC and suggestss a number of important alternative evaluative metrics.

7 Conclusion

In considering the evolution of a UIC this study contributes to the UIC literature by identifying and classifying the phases of UIC evolution; exploring the perceived barriers to, and enablers of, collaboration; and identifying a range of mechanisms and conditions that were instrumental in overcoming those barriers at each phase. We suggest that there are stage appropriate mechanisms in industry–university, industry–industry and University–University relationships which helped to establish the UIC and its evolutionary trajectory. Specifically,

- The availability of significant government funding was vital to attracting the attention of the key actor and to motivate involvement by other participants. Establishing reciprocity and parity of funding within the collaboration was critical.
- Government funding in the form of network-specific investments was shared equally amongst the partners to establish a culture of collaboration; as the network evolved funding was expanded to include firm-specific funding for specific network members.
- The process of defining IP rights needed to be collaborative, inclusive, continuous and conclusive.

- Knowledge sharing routines enhanced learning between partners, with academics learning about the challenges to their knowledge and competence in an industrial context; while industrial partners learned about revolutionizing manufacturing processes in the pharmaceutical industry.
- The identification of an efficient and effective project manager who understood the challenges facing both industry and university was crucial.

This evolution was underpinned by shared goals and vision and reciprocity which promoted mutual understanding, and facilitated an exchange of knowledge and ideas which helped academics to learn to share resources and collaborate with ‘competitors’. A closed network composed of partners with a higher technological diversity supported knowledge exploration, thereby increasing partners’ ability to benefit from technologically diverse partners. The associated resource optimisation, activities and practices were carefully managed by the project manager who was crucial in harmonising the different objectives, needs, perspectives, and modes of operation of academic and industrial organisations operating across the network.

This exploratory study has several limitations; first, the study was conducted within a relatively small European country, extending it to other geographical regions with larger industry sectors and larger industries would strengthen the requisite theory building. It would also be of interest to compare the results with those from unsuccessful UICs initially in similar or proximate industries and geographies, and then in unrelated industries and geographies. Second, UIC partners in one industry, the pharmaceutical industry, were included in this research project, and while this provided an appropriate research site it would be beneficial to extend the current study format to include other network collaborations in other industries, a larger sample would facilitate the extension of the study to include sectoral analysis. This merits further examination in different organizational, national and industrial contexts. Future research could also include quantitative analysis to explore barriers and enablers across industries, countries and phases. This would further develop the research findings from indicative to confirmatory. Finally, the triple helix of government, university and industry should form the basis of further research.

Appendix

Appendix 1

See Table 7.

Table 7 Examples of some UIC barriers and enablers

Author	Methodology	Scope and context	Findings
Barnes et al. (2002)	Qualitative analysis of six collaborative research projects at Warwick University's Research Center	Analysis of factors that affect the perceived collaboration success of UIC	Project management skills; trust; commitment; continuity; the capacity to flexibly adapt to changes in strategy or project direction; and an appropriate balance between academic objectives and industrial priorities are enablers of collaboration
Santoro and Bierly (2006)	Survey of 173 firms located in US	Analysis of predictors of tacit knowledge transfer	Social connectedness, trust, technological capability, and technological relatedness are more effective predictors of tacit knowledge transfer, while university research centres' technology transfer–intellectual property policies are more effective for the transfer of explicit knowledge
Sherwood and Covin (2008)	Survey with 104 industry managers	Exploration of the effects of various knowledge transfer mechanisms in UICs	Tacit knowledge acquisition is affected by trust, partner and technology familiarity, alliance experience, formal collaboration teams, and technology experts' communications
D'Este and Patel (2007)	Large scale survey of UK academic researchers	Analysis of researchers' interaction- engagement channels with industry	Researchers use a variety of channels to interact with industrial collaborators, such as consultancy and contract research, joint research, or training
Bruneel et al. (2010)	Large survey of British firms	Exploration of mechanisms that reduce collaboration in university–industry links	Collaboration experience and breadth of interaction diminish orientation-related barriers while inter-organizational trust diminishes orientation-related and transaction-related barriers

Table 7 (continued)

Author	Methodology	Scope and context	Findings
Lee (2011)	Case study of the Tokyo Institute of Technology	Analysis of the effect of the reforms of the Japanese government to formalize and promote UIC	Contractual arrangements, organizational commitments, specialized coordination, and formal evaluation procedures enable alliance partners to initiate more explorative research, organize interdisciplinary projects with faculties in different research fields, and establish larger scale R&D projects
D'Este et al., (2012)	Collaborative research grants awarded by the UK Engineering and Physical Sciences Research Council	Investigation of the contribution of proximity to UIC formation	Geographical proximity increases the likelihood of UIC, particularly when the parties have joint experience in partnerships
Plewa et al. (2013)	Sampled researchers Australian involved in the ARC Linkage Grant Scheme (217 respondents)	Analysis of UIC success factors over three evolutionary stages	Communication is a predictor of success at the different stages of UIC evolution. The initiation stage also helps to merge goals, keep partners aligned and increase trust
Perkamn et al. (2013)	Systematic Literature Review	Literature review of scientists' engagement in collaborations with industry actors	Categorization of engagement enablers/barriers into *Individual* (e.g., demographics, attitude, motivation), *Organizational* (IT support, Leadership department climate, University/Department quality), and *Institutional* (scientific discipline, regulation public policy)
Muscio and Vallanti (2014)	Interviews with university departments in Italy	Investigation of the barriers to technology transfer activity as perceived by academics	Perceived barriers from academic actors include misalignment of objectives between academic researchers and potential industrial partner; IP conflicts; lack of recognition and reward for academics engaging in UIC activities
Hemmert et al. (2014)	Survey of 618 UICs in different countries (US, Japan, South Korea) and industries (biotechnology, microelectronics, software)	Examination of the role of culture in trust formation in different countries	Reputation and the leadership of academic *champions* are drivers of trust in countries like South Korea

Table 7 (continued)

Author	Methodology	Scope and context	Findings
Bstieler et al. (2015)	Survey of 105 UI collaborations in the US biotechnology industry	Examination of the roles of universities' intellectual property (IP) policies and of shared governance for trust formation between academic and industrial partners	Flexible and transparent universities' IP policies and shared governance, and champion behaviour enable the formation of trust, which is central for achieving success in UIC
Al-Tabbaa and Ankrah (2016)	Faraday Partnership, a UK government-backed scheme for enhancing innovation	Exploration of the role and evolution of social capital in mitigating barriers in the preformation and post-formation of UICs	The strength of a tie improves trust
Steinmo, and Rasmussen (2016)	Longitudinal study of 15 successful UICs	Analysis of proximity dimensions affecting the selection of partners in engineering *versus* science-based companies	Engineering-based firms focus more on geographical proximity and previous collaborations, while science-based companies focus on cognitive and organizational proximity
Giunta et al. (2016)	They use co-publishing as a proxy of UIC	Investigation of the conditions favouring joint publishing between industrial and academic collaborators	Geographical proximity and prior partnership foster joint-publications
Rajalo and Vadi (2017)	Multiple case-study research (12 cases)		Individual levels of motivation and absorptive capacity determine the likelihood of the success or failure of UIC
Gulbrandsen and Thune (2017)	Survey of 4400 academics in Norway in humanities and social science	Analysis of staff with non-academic *versus* academic background in relation to interaction with external stakeholders and research performance	Staff with non-academic background are more likely to interact with external stakeholders
Villani et al. (2017)	Case study based on 9 intermediary organizations in Italy	Investigation of the role of various intermediaries (Technology Transfer Office) in reducing cognitive, geographical, organizational, and social distance in UIC	Different types of intermediaries reduce the different dimensions of distance between university and academia via various activities

Table 7 (continued)

Author	Methodology	Scope and context	Findings
De Wit-de Vries et al. (2019)	Literature review	Identification of enablers of knowledge transfer in UIC	Identifies barriers to knowledge transfer related to differences in goals due to different cultures, which cause ambiguity, problems with knowledge absorption and issues with knowledge implementation. Knowledge transfer enablers are communication, trust, prior experience, intermediaries, which can smooth the barriers to knowledge transfer
Oliver et al. (2019)	30 semi-structured interviews with participants in four funded projects in Israel	Investigation of how trust enhances and/or impedes UIC innovation projects outcomes	Findings show that individual and organizational trust explains success in UIC
Tseng et al. (2020)	in Taiwan	Measurement of the influence of UIC funding on universities' technology innovation performance	Management mechanism, innovation climate, and reward system positively affect UIC funding and universities' technology innovation performance

Appendix 2

See Table 8.

Table 8 List of SSPC interviewees

Name, organisation	Role	Organisation profile
Robert, University 1	Project Lead	825 research postgraduates, 410 academics
Peter, University 1	Project Manager	825 research postgraduates, 410 academics
Angela, University 1	Technology Transfer Officer	825 research postgraduates, 410 academics
Andrew, University 2	Academic	1900 research postgraduates, 950 academics
Mark, University 3	Academic	785 research postgraduates, 649 academics
Jean, University 4	Academic	1864 research postgraduates, 741 academics
William, University 5	Academic	900 research postgraduates, 727 academics
James, Firm 1	Director	86,600 employees globally, 1500 employees in Ireland
Daniel, Firm 2	R&D Director	122,000 employees worldwide, 2100 in Ireland
Matthew, Firm 3	Principal Scientist	61,500 globally, 350 in Ireland
Michael, Firm 4	Team Leader Process Engineering	40,000 globally, 470 in Ireland
Emily, Firm 5	Director	103,000 globally, 1400 in Ireland
David, Firm 6	R&D Director	74,000 globally, 238 in Ireland
Joseph, Firm 7	Vice-President	50,000 globally, 1800 in Ireland
Samuel, Firm 8	Director	430 globally, 40 in Ireland
Luke, Firm 9	Process development team leader	41,000 worldwide, 2000 in Ireland
Christopher, Firm 10	Director	47,500 worldwide, 2850 in Ireland
Jack, Firm 11	Manager process implementation	31 in Ireland

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