Collaborative know -how and trust in university–industry collaborations: empirical evidence from ICT firms

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Keywords University–industry relationships · R&D cooperation · Information and communication technology · Small and medium-sized firms · Knowledge transfer · Structural equation modeling

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Abstract This paper builds upon the knowledge-based view and organizational learning perspective. It develops and empirically tests a conceptual model to analyse the drivers and benefits of university–industry cooperation from the firm perspective. We used structural equation modeling to examine data collected from a sample of small and medium-sized Italian firms in the information and communication technology sector. We found that past collaborative experience increases the benefits drawn from university–industry coopera- tion. Both collaborative know-how and trust, however, play a significant mediating role on the relationship between collaborative experience and benefits. In particular, collaborative know-how is the main factor enhancing intangible benefits, such as knowledge transfer and learning, while trust is the main driver of tangible benefits, such as product and process innovations. Taken together, these findings suggest that firms should develop strategic competences to fully benefit from collaborations with universities because past collabora- tive experience alone is not sufficient. From the policy point of view, effort is needed to build channels and tools enhancing trust between industry and university, especially to sup- port small firms.

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1 Introduction

The ability of a firm to improve its competences is a key factor in achieving competitive success in the modern knowledge economy. This is especially true for companies operating in technology-intensive industries, such as the Information and Communications Technol- ogy (ICT) sector. The open innovation view (Chesbrough 2003; Chesbrough and Crowther 2006; Enkel et al. 2009) sets out that firms cannot rely only on internally-generated knowl- edge, but also need to exploit external sources of information and innovation. The theory of learning organizations (Senge 1990) explains that firms need to cooperate for a num- ber of reasons, and provides mechanisms to enable them to build capabilities to survive. Industrial organization approaches, which take into account the imperfect appropriability of research and development (R&D) activities (D'Aspremont and Jacquemin 1988; Kam- ien et al. 1992), suggested one of the first explanations for R&D cooperation, and Pisano (1990) showed that transaction costs push firms to collaborate. Companies mainly collabo- rate because of the fast pace of technological change, strong markets and high levels of competition, the complexity and uncertainty of the innovation process, the short lifespan of many products, and the high costs of R&D. These factors are especially relevant for small and medium-sized enterprises (SMEs) operating in science-based industries.

It is therefore not surprising that the number of firms involved in relationships with external partners, including other firms and universities, has steadily increased over the last few decades (Bellucci and Pennacchio 2016; Jacob et al. 2000; Perkmann et al. 2011). University–industry (UI) cooperation, in particular, has received

gro$_w$ing levels of atten- tion from scholars and policy-makers in national and European programs (Hagedoorn et al. 2000; Lehrer et al. 2009). In 2002, for example, the European Commission identi- fied the need for an integrated system of innovation to improve exploitation of the large amount of kno$_w$ledge and basic research generated in Europe. UI relationships can provide multidimensional benefits for the firms involved (Ankrah and Al-Tabbaa 2015). Ho$_w$ever, difficulties such as divergent objectives among the participants can also limit the positive effects of partnerships and lead to a high probability of cooperation failure (Galán-Muros and Ple$_w$a 2016; Kivleniece and Quelin 2012). A common vie$_w$ is that organizational and managerial issues are critical factors that can facilitate or inhibit the relationships bet$_w$een firms and universities (Siegel et al. 2003). The literature also suggests that the $_w$ork of universities rarely translates directly into ne$_w$ products and services (Pavitt 2001). In some industrial sectors, such as biotechnology, the relationship bet$_w$een universities and indus- trial innovation appears to be tight, and in others, such as textiles, it is distant and $_w$eak (Klevorick et al. 1995).

This paper therefore seeks to provide a better understanding of the benefits obtained by high technology SMEs from relationships $_w$ith universities. The paper dra$_w$s on the kno$_w$ledge-based vie$_w$ of the firm and the organizational learning perspective, and aims to assess $_w$hether firms can develop specialized kno$_w$ledge and trust through collaborative experience, using these skills to take full advantage of collaborations $_w$ith universities. We hypothesize that collaborative kno$_w$-ho$_w$ and trust may have a mediating role on the rela- tionship bet$_w$een past collaborative experience and collaboration benefits. In other $_w$ords, they are the key channels through $_w$hich firms use their collaborative experience to gain from interactions $_w$ith universities.

Our analysis contributes to the existing literature in several $_w$ays. First, from the theoret- ical point of vie$_w$, $_w$e considered learning and kno$_w$ledge transfer in collaboration arrange- ments bet$_w$een firms and universities, $_w$hereas most of the previous literature has analysed inter-firm cooperation (Lane et al. 2001; Nielsen and Nielsen 2009; Simonin 1999). Firms and research institutions have highly complementary resources that can lead to synergy and value creation (George et al. 2002). Ho$_w$ever, they also have fundamental organizational dissimilarities and divergent goals, $_w$hich may jeopardize the management and the out- comes of their relationships.

Second, $_w$e have extended the conceptual model of Simonin (1997) by considering the role of trust in the management and coordination of UI relationships. We also distinguished t$_w$o different types of gains from interactions $_w$ith universities: tangible benefits, $_w$hich concern product and process innovations, and intangible benefits, $_w$hich refer to learning and kno$_w$ledge transfer. Unlike Simonin (1997), $_w$ho investigated cooperation bet$_w$een firms, $_w$e focused on firm–university collaboration.

Third, $_w$e have extended the empirical literature, by testing the conceptual model $_w$ith an original dataset of SMEs cooperating $_w$ith universities. Despite the role of SMEs in innovation $_w$orld$_w$ide (Bianchi et al. 2010), studies have mainly focused on large and mul- tinational corporations, $_w$ith limited attention on the use of open innovation in small firms. Innovation literature has, ho$_w$ever, suggested that UI collaborations provide particularly valuable benefits for SMEs, helping them to overcome some of the barriers to innovation, such as a specialized kno$_w$ledge base and limited financial resources (Lee et al. 2010). Young and small firms often lack the required resources to compete $_w$ith their larger and older counterparts in the kno$_w$ledge development process and are therefore more likely to rely on external sources of kno$_w$ledge and spillovers to fuel their o$_w$n innovation efforts (Kirchhoff et al. 2007).

Lastly, $_w$e have contributed from the methodological point of vie$_w$. Previous studies on UI relationships have largely been case-based (Enkel and Gassman 2010; Estrada et al. 2015; Lee 2011) or used econometric models (Bellucci and Pennacchio 2016; Frasquet et al. 2012; Maietta 2015). We tested the predictions of our theoretical

frame$_w$ork using structural equation modeling. This method is particularly suitable for testing theoretical predictions and has the major advantage that it enables the operationalization of theoretical constructs by using latent variables.

We focused on the ICT sector, $_w$hich has received little attention in the literature on UI relationships. ICT is an interesting area of research, being a science-based technology sec- tor characterized by strong ties $_w$ith universities. The ICT sector is one of the most impor- tant engines for economic development, productivity gro$_w$th and social inclusion, because it provides essential equipment and infrastructure for the economy and $_w$ider society. Ne$_w$ information and communication technologies have reduced the perceived distance bet$_w$een people involved in innovation processes, enhancing virtual team$_w$ork and the transfer of kno$_w$ledge on a global scale (Di Minin et al. 2016; Gassmann 2006). ICT is also a general purpose technology, enabling product, process and organizational innovation in other sec- tors (Belitski and Desai 2016; OECD 2013). The sector makes an important contribution to GDP, and is therefore able to foster gro$_w$th and productivity both directly and indirectly. The fast patterns of innovation and technological change observed in the ICT sector may offer important lessons for other sectors (Fransman 2014).

The collaborative relationships analysed in this study $_w$ere all bet$_w$een ICT SMEs and universities, and began bet$_w$een 2006 and 2009. All the firms included in the sample $_w$ere headquartered in Campania, a region of Southern Italy. The focus on a single region $_w$as driven by previous research, $_w$hich sho$_w$ed that firm demographics vary $_w$idely across Italy (e.g. De Massis et al. 2013). Focusing on a single area has the advantage of remov- ing much of the unobserved heterogeneity affecting different local economic systems. The Campania region hosts several universities offering a variety of courses related to the ICT sector, including the University of Naples Federico II. This is the oldest public and laic university in the $_w$orld and a leader in science and technology. Recently, for example, it has established an important partnership $_w$ith Apple to create an academy of soft$_w$are develop- ment. This demonstrates the appeal of the local ICT sector and the valuable contribution of the regional university system in supporting this sector.

Our main findings reveal that collaborative experience has a positive impact on ben- efits from UI cooperation, as $_w$ell as that collaborative kno$_w$-ho$_w$ and trust act as signifi- cant mediating mechanisms bet$_w$een collaborative experience and the benefits obtained by firms from UI cooperation. To benefit fully from collaboration $_w$ith universities, firms have to build their collaborative kno$_w$-ho$_w$, dra$_w$ing on previous cooperation relationships. This $_w$ill allo$_w$ them to maximize the intangible benefits related to kno$_w$ledge transfer. Trust is also a crucial factor in enhancing the effectiveness of collaboration, especially for tangible benefits.

The next section of the paper sets out the conceptual model and derives the research hypotheses. Section 3 describes the data and the proposed methodology. Section 4 gives the empirical results. Section 5 concludes the paper and discusses the main implications of the research, $_w$hile Sect. 6 sets out the limitations of the study and some directions for future research.

2 The acquisition of tangible and intangible benefits: a conceptual model

Cooperation $_w$ith universities is crucial for firms not only to exploit valuable external resources, such as scientists and research infrastructure, but also to assimilate scientific kno$_w$ledge, especially in science-based industries that are characterized by high uncer- tainty (Soh and Subramanian 2014). A central theme in UI cooperation is the building of organizations' kno$_w$ledge stock. Theoretical contributions have sho$_w$n that firms' ability to appropriate ne$_w$ kno$_w$ledge and obtain sustainable competitive advantage depends on different factors (Bonaccorsi and Piccaluga 1994; Cricelli and Grimaldi 2010). Our con- ceptual frame$_w$ork puts the emphasis on three main aspects: collaborative experience, col- laborative kno$_w$-ho$_w$ and trust. We have built on the model proposed by Simonin (1997), and extended it by considering the effect of trust as a mediator bet$_w$een collaborative expe- rience and cooperation benefits.

Cooperation between firms and universities is a complex issue that could generate multidimensional benefits for the company (Dussauge and Garrette 1995). We investigated the output of the collaboration between firms and universities going beyond the generic concept of knowledge transfer. Like Simonin (1997) and other authors (Crossan and Inkpen 1995; Pucik 1988), we recognised that firms can achieve two different types of potential gains from UI cooperation: tangible benefits that directly affect products and processes, and intangible benefits related to the firm's learning and knowledge transfer. Nielsen and Nielsen (2009) defined learning "*…as the acquisition (or transfer and development) of external knowledge that creates the capacity for further action*". It is reasonable to distinguish between the practical and financial benefits on business processes and the intangible benefits, such as knowledge transfer, which enable firms to acquire new skills and capabilities.

Very often, the transfer of knowledge is the real gain for a firm involved in a cooperation project. Many authors, however, have suggested that not all collaborations produce positive effects (Lei and Slocum 1992). The cost of cooperation could also be very high, both financially and strategically. Partners may take advantage of each other's core capabilities during cooperation. This problem is more likely where two firms cooperate, but the risk is also present to some extent in partnerships with universities. These also pose additional and specific coordination problems because of the different nature of the partners.

2.1 Collaborative experience and benefits

As mentioned above, a firm's ability to appropriate new knowledge and obtain sustainable competitive advantage from alliance partners depends on different factors. Collaborative experience, or the experience accumulated over time by the firm through past interactions with universities, is the first factor in our theoretical framework.

Organizations tend to replicate and perpetuate the routines established in satisfactory relationships, giving rise to path-dependency of cooperation strategies (Li and Rowley 2002; Nelson and Winter 1982). Firms involved in multiple or regular collaborations with particular types of partners can refine their organizational routines and increase their experience of managing cooperation, and therefore obtain greater benefits (Das and Teng 2000). This means that R&D cooperation could become persistent over time because of the habitual behaviours and strategies of the different partners involved. Azagra-Caro et al. (2017) posited that only a complex and persistent sequence of interactions between firms and universities over time, obtained through both formal and informal channels, leads to a positive economic impact. Rothaermel and Deeds (2006) also argued that repeated engagement in strategic alliances over time allows firms to build an alliance management capability, which in turn may be useful in new product development.

Firms that are repeatedly involved in R&D cooperation may also be considered competent and trustworthy partners by external organizations. This, in turn, contributes to their reputation as reliable and attractive research partners. This type of reputation may allow firms with past collaborative experience to cooperate with more competent partners, enhancing the outcomes of their R&D collaborations (Belderbos et al. 2015).

To obtain benefits from UI cooperation, firms need to assimilate the basic knowledge generated in the interactions with universities. This requires both a strong R&D capability and specialized staff. Under the concept of absorptive capacity (Cohen and Levinthal 1990), R&D capability is the scientific and knowledge base, both R&D investments and highly-skilled workers, that provides firms with the ability to develop new products and processes, and to absorb knowledge flows developed outside the organization (Laursen and Salter 2004). Firms that cooperate over time with universities can therefore reinforce their R&D capabilities by creating personal ties between their workers and academics through the creation of work teams (Fritsch and Lukas 2001; Santoro and Chakrabarti 1999). Sáez et al. (2002, p. 325) noted that such teams are required to "… *promote the idea or project, liaise between individuals and organizations, transfer information in the appropriate context, coordinate activities and sustain the quality of the relationship between the company and the research center*".

There is empirical evidence to support the vie$_w$ that experience in R&D collaborations can improve the probability and outcome of UI relationships. Laursen and Salter (2004), for example, sho$_w$ed that firms $_w$ith a more open search strategy, that is those that already cooperate $_w$ith other types of partners such as competitors, suppliers, or customers, $_w$ill tend to gain more from collaborations $_w$ith universities.

Belderbos et al. (2015) analysed the dynamic patterns of collaborative R&D and found that collaborations $_w$ith most types of partners are persistent over time. Persistent col- laborations bet$_w$een firms and universities have a positive impact on firms' innovative performance.

Collaborative experience also implies that there are benefits for universities. D'Este et al. (2012), for example, sho$_w$ed that previous experience of collaboration $_w$ith industry partners had a positive impact on the exploitation of entrepreneurial opportunities, provid- ing academics $_w$ith the complementary skills needed to carry out complex and risky activi- ties, such as ne$_w$ product and process development.

This set of arguments leads to the formulation of the follo$_w$ing hypothesis.

Hypothesis 1 Collaborative experience has a positive impact on the benefits (tangible and intangible) from UI interactions.

2.2 The mediating role of collaborative kno -ho

A crucial determinant of kno$_w$ledge assimilation is collaborative kno$_w$-ho$_w$, $_w$hich deter- mines ho$_w$ the collaboration is exploited and used by the firm. In Simonin's (1997) model, for example, collaborative experience is linked to the benefits obtained from collaboration through the important role of collaborative kno$_w$-ho$_w$. Simonin suggested that experience from past collaboration $_w$ork needs to be processed into kno$_w$-ho$_w$ before it is useful for business purposes. He defined collaborative kno$_w$-ho$_w$ as the ability of a firm to "*develop specialized knowledge* via *experience and then use this knowledge to obtain further ben- efits*" (Simonin 1997, p. 1150). In other $_w$ords, specific kno$_w$ledge and routines embedded in the organization are built and developed from previous experience. The experiences of past collaborations must be processed into kno$_w$-ho$_w$, by a specific capability of the firm, before it can be used effectively for business purposes. Simply possessing collaborative experience does not guarantee that the firm can benefit from collaboration. Team learning is one of the main characteristics of the firm conceived as a learning organization. Col- laborative kno$_w$-ho$_w$ is more difficult to imitate, imperfectly substitutable, rarer and more valuable than simple past experience, and is therefore a better representation of the concept of specific firm assets determining competitive advantage under the resource-based vie$_w$ (RBV) theory (Barney 1991).

The link bet$_w$een collaborative kno$_w$-ho$_w$ and the kno$_w$ledge-based vie$_w$ is easily trace- able in the literature. For instance, Miller and Shamsie (1996) and Prahalad and Hamel (1990) both recognized collaborative capability as a key resource. The difference bet$_w$een collaborative experience and collaborative kno$_w$-ho$_w$ becomes obvious $_w$hen considering the high proportion of unsuccessful collaborations and the challenge of mapping, and so easily replicating, the past collaborations of any firm. Simply engaging in collaboration, or having past experience of doing so, does not guarantee benefits for the firms involved (Madhok and Tallman 1998). It can, ho$_w$ever, allo$_w$ firms to build the expertise needed to gain from collaborative activities.

Generally speaking, cooperation poses problems of coordination and requires the def- inition of specific organizational routines. The partners need to be adequately equipped to undertake effective external engagements in the $_w$ide range of open innovation prac- tices (Salter et al. 2014). Firms need to solve t$_w$o main problems: selection of the correct partners and definition of the necessary routines to coordinate their activities $_w$ith those partners. Collaborative kno$_w$-ho$_w$ organizes the interaction bet$_w$een the capabilities and

Table 1 Collaborative know-how: the phases of the collaboration cycle. *Source*: Our elaboration of Simonin (1997)

Stage	Phase	Firm competences
1	Partner identification and selection	Understanding own needs and the strategic implications of the choice; scanning external sources
2	Negotiation	Legal, tax and bargaining expertise
3	Monitoring and managing the relationship	Managing conflicts; training; renegotiating agreements; coordination; interaction and exchange abilities
4	Terminating the collaboration	Strategic view; business and technical competences

needs of the firm and external expertise to maximize knowledge transfer and benefits from collaboration. The stock of experience accumulated in the past is used to select the best external partner and then to set up effective coordination mechanisms between internal and external resources (Pisano 1988).

Simonin (1997) recognized four fundamental phases of the collaboration cycle, imply- ing the development of specific skills and organizational routines (Helfat and Peteraf 2003). The first is identification and selection of potential partners (Geringer 1988, 1991), based on different criteria such as compatibility or complementarity (Beamish 1988; Hill and Hellriegel 1994). This stage requires a clear understanding of the firm's needs and information about external sources of knowledge. The second phase is negotiation of the terms and structure of the collaboration agreement, legally, financially and structurally (Lorange and Roos 1990). The third phase is the monitoring and management of the rela- tionship, which require different competences to be translated into organizational routines to deploy the resources effectively (Helfat and Peteraf 2003). This phase requires skills ranging from knowledge management competences at several levels of the organization (Argote et al. 2003a) to the attitude required to interact with external partners (Minkler 1993), for instance, to cope with problems such as disclosure of intellectual property dur- ing the cooperation (Salter et al. 2014). Much of the information acquired by an external source is likely to be tacit, so the organization needs tools and procedures to enable it to spread knowledge effectively (Dyer and Nobeoka 2000). The fourth phase involves know- ing when and how to terminate the collaboration without negatively affecting the firm's activity and operations (Serapio and Cascio 1996; Reich and Mankin 1986), for example, because of a competency trap (Levitt and March 1988). Table 1 summarizes the different phases of the collaboration cycle, emphasizing the competences embedded and measured through collaborative know-how.

As a learning organization, the firm needs to build critical competences over time. To develop collaborative know-how, it then relies on experience accumulated through previous cooperation work. This experience is not only from direct collaboration, because any kind of contact with a university can contribute to the closure of the gaps between these two types of organizations, and therefore to better mutual understanding. Huber (1991) suggested that experience is a means of learning for firms. According to Sherwood and Covin (2008), experience of working with universities affects firms' ability to acquire knowledge from cooperation. Lyles (1988) found evidence that firms change their approach to partners because of their previous experience. Past interactions with universities therefore teach firms how to learn from their mistakes and experiments (Osland and Yaprak 1994).

Previous studies on UI collaboration have used other models to represent the entire process. Ankrah and Al-Tabbaa (2015), for example, used the Mitsuhashi (2002) model, drawing on evidence from their systematic literature review of the topic. Our perspective seems consistent with the knowledge-based theory (Grant and Baden-Fuller 1995) and the dynamic approach of the evolutionary paradigm (Nelson and Winter 1982). These approaches both consider the firm as a learning organization. Only firms that develop stra- tegic know-how are able to acquire benefits from collaboration, which explains why some firms manage external alliances better than others (Kale et al. 2002). Drawing on these arguments, we can hypothesize the following:

Hypothesis 2 Collaborative kno$_w$-ho$_w$ mediates the relationship bet$_w$een collaborative experience and the benefits (tangible and intangible) from UI cooperation.

2.3 The mediating role of trust

The most relevant dra$_w$backs for firms involved in cooperation $_w$ith universities prob- ably derive from the coordination and management of the relationships. The relationships bet$_w$een heterogeneous actors may result in specific problems of kno$_w$ledge transfer that are absent, or mitigated, in the relationships bet$_w$een more homogeneous partners, as in inter-firm collaboration. The third key factor shaping firms' benefits from UI cooperation in our theoretical frame$_w$ork is therefore the confidence bet$_w$een the partners, or trust. Simonin (1997) included trust as part of collaborative kno$_w$-ho$_w$. We argue, ho$_w$ever, that it represents a distinct and key factor in every relationship, but is a crucial aspect in UI rela- tionships because firms are more likely to trust partners that are similar to them. We there- fore isolated trust as a specific construct and suggest that trust and collaborative kno$_w$-ho$_w$ are built separately over time, affecting the benefits of collaboration in different $_w$ays.

In general, interactions $_w$ith external partners al$_w$ays have some potential risks. If a partnership is characterized by high levels of reliability and trust, ho$_w$ever, the coordi- nation bet$_w$een the partners is easier and the cooperation is more likely to be successful. Trust therefore acts as a social control mechanism and risk reduction device that facilitates interactions (Gulati 1995). High levels of trust $_w$ithin relationships reduce uncertainty and transaction costs, increase transparency, and encourage open sharing of information and kno$_w$ledge (Inkpen and Beamish 1997). Trust also affects the outcomes of cooperation. When management systems are characterized by trust, employees may $_w$ish to replicate and strengthen positive interactions, contributing to kno$_w$ledge production and dissemina- tion. This in turn may lead to more cooperation and achievement of organizational goals, such as kno$_w$ledge assimilation and innovation (Mayer and Gavin 2005).

Trust also enhances learning and benefits from cooperation (Ingham and Monthe 1998; Lane et al. 2001; Nielsen and Nielsen 2009), as $_w$ell as kno$_w$ledge creation (Nielsen 2005) and dissemination (Wang and Liu 2007). This allo$_w$s firms to assimilate the kno$_w$ledge and competences of their partners. Long-term relationships $_w$ith partners are encouraged by mutual learning and a high degree of trust (Dodgson 1992). According to Argote et al. (2003b), high trust also ensures that the kno$_w$ledge provided by partners is both accurate and valuable.

Entrepreneurship research has also begun to examine the concept of trust $_w$ith a broader outlook (Slotte-Kock and Coviello 2010). Zahra et al. (2006), for example, argued that rela- tional trust, defined as trust based on social interactions among individuals, has a positive impact on organizational attitudes and behaviours, including cooperation, as $_w$ell as on organizational performance.

Tsang (1999) distinguished bet$_w$een non-competitive and competitive partnerships. The latter are characterized by a race bet$_w$een the partners to learn and appropriate kno$_w$ledge and benefits. A typical example of competitive partnership is bet$_w$een firms competing in the same product markets. The risk of opportunistic behaviours is high because the firm that first internalizes and applies the kno$_w$ledge produced by the collaboration $_w$ill acquire a competitive advantage over the other. The relationships bet$_w$een firms and universi- ties are usually considered to be non-competitive (Huang and Yu 2011). Universities and industry, ho$_w$ever, have very different missions, organizational and institutional culture, models of managing projects, and objectives (Siegel et al. 2003; Veugelers and Cassiman 2005). Universities, for example, need private research funds, $_w$hich may be crucial in ne$_w$ research fields. Academics are interested in the publication and dissemination of the results arising from research partnerships, $_w$hile private firms are less likely to $_w$ant to disclose results, because of the danger that their advantage may be appropriated by others. Firms are also more oriented to$_w$ards the commercialization of ne$_w$ technologies and kno$_w$ledge (D'Este and Perkmann 2011; Link et al. 2007).

In collaborations between firms and universities or other research institutions, different organizational cultures can give rise to conflicting attitudes and approaches to the manage- ment of the relationship (Bjerregaard 2010). Heterogeneous cultures may be a barrier to the success of UI relationships if adequate trust is not established between the partners. Some authors have suggested that trust can be built only through iterated collaborative relationships (e.g. Davenport et al. 1999). Previous contacts with universities may therefore help firms to develop confidence that their partner is not going to act opportunistically.

Sherwood and Covin (2008) recognized that trust critically affects the transfer of tacit knowledge, which is particularly relevant in cooperation focused on basic research such as with universities. Morandi (2013) argued that "*…benefits derived from industry–university joint research projects are strongly affected by the management system exploited to com- bine partners' resources and tasks*". Trust therefore facilitates monitoring and coordination of collaboration in R&D activities. Referring to innovation in science-based sectors, some authors have identified trust as the main driver of UI interactions, rather than patent cita- tions and previous collaboration (Chung et al. 2000; Sorenson and Singh 2007).

We therefore propose the following hypothesis:

Hypothesis 3 Trust plays a mediating role in the relationship between collaborative experience and the benefits (tangible and intangible) from UI cooperation.

Figure 1 shows the hypotheses examined empirically in this study. It emphasizes the crucial mediating role of collaborative know-how and trust as strategic aspects of firms' knowledge management and coordination in UI relationships.

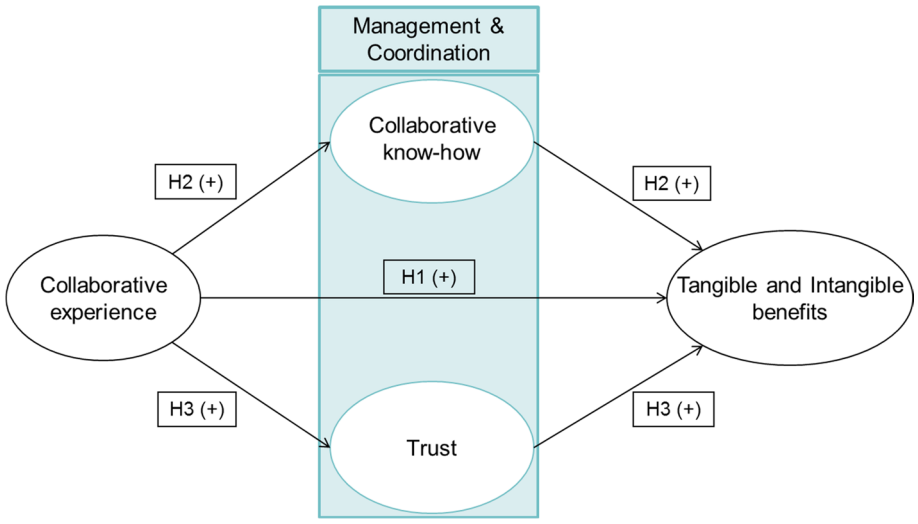

Fig. 1 From collaborative experience to collaboration benefits: the conceptual model

3 Data and methodology

To test our hypotheses, we used data collected[1] through a questionnaire sent to ICT firms. The first step of the sample selection procedure* was to use email to contact a random sam- ple of 450 ICT firms headquartered in Campania.[2] This number is approximately 20% of the total ICT firms in the region,[3] including both manufacturing and services sub-sectors. Almost 200 firms were interested in participating in our survey and were contacted by tel- ephone to provide a detailed explanation of our research. The questionnaire was submit- ted to these firms in 2009, and after two telephone reminders, 150 of them completed all required sections. Out of these 150 firms, which were consistent with the sampled popula- tion, only 50 reported collaboration with a university during the period 2006–2009 and were therefore included in the sample. More than 70% were individual company or limited liability company. In addition, there were six university spin-offs and eleven limited com- pany. All firms in the sample had their productive plants in the Campania region, excluding one case in which the firm belonged to a large company and the plant in the region was a secondary productive branch. At the time of our survey, firms were quite young, with an average age of 8 years. Their main target was the national market.

Most of the respondents were owners, CEOs or senior directors. Although the sample size was quite small in absolute terms, it was highly representative of the target population of ICT SMEs collaborating with universities.

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* [1] Data were collected as part of the CLUOS project carried out by the University of Sannio, financed by Regione Campania, which aimed to study the ICT sector in Campania. The sample was stratified by sub- sector and administrative province.

[2] We identified and excluded 25 large firms. To select SMEs, we used the EU definition of (i) fewer than 250 employees; and (ii) turnover below 50 million euros or balance sheet total below 43 million euros.

[3] Stores selling ICT equipment were excluded from this population of firms.

A restricted sample size is a common issue in empirical literature using structural equation modeling in this and other fields of research[**].[4] The "Appendix" shows the items in the questionnaire used in the measurement model to build the latent variables. The questionnaire collected information on firms' main characteristics (such as turnover, R&D expenditure, and number of employees), and external collaborations in R&D activities and innovation. The largest number of collaborative arrangements was with the departments of Electronic Engineering and Telecommunication at the University of Naples Federico II and with the University of Sannio.

All the items used to build the latent variables were measured on a five-point Likert-type scale. The latent variable *Collaborative experience* was composed of 10 items representing different types of collaborative channels between firms and universities. The construct *Collaborative know-how* was a latent variable built from two other variables designed using Simonin's (1997) collaboration cycle: partner selection (*Collaborative selection*) and management of the collaboration (*Collaborative management*). *Collaborative selection* (KH1) was calculated as the average value of three items reflecting the firm's ability to scan for university competence (KH1c) and select an appropriate partner (KH1a and KH1b). *Collaborative management* was measured using eight items capturing tools and strategies used to deploy internal and external resources (from KH2a to KH2h). The items concerned the use of formal or informal collaboration (KH2a and KH2b), specific managers or other workers for the management of the relationships with universities (KH2c, KH2f), formal plans of activities (KH2d, KH2e and KH2h), and software for project management (KH2g).

Trust was measured as the inverse of two items. The first one (TR1) was adapted from Lane et al. (2001) and covered protection from opportunistic behaviours by partners. The second one (TR2) used the rigidity/flexibility of the relationship as a measure of the firm's mistrust/trust in the partner.

To measure the output of collaborations, we built two constructs. *Tangible benefits* was based on three items covering the direct impact of cooperation on the firm's activities: development of new products (TB1), improvement of internal production processes (TB2), and development of business (TB3). *Intangible benefits* captured learning and knowledge transfer and was built from two items: satisfaction with the collaboration (ITB1); and acquisition of new knowledge/skills from the relationship (ITB2).

The model also included two control (observed) variables to account for firms' features. There is a rich debate about the relationship between firm size and R&D collaboration. In general, larger firms spend more resources on R&D and innovation activities, and are more likely to engage in external partnerships (Bolli and Woerter 2013). Several studies have shown that firm size is positively correlated with the propensity to cooperate with universities. Laursen and Salter (2004), for example, found that large firms were more likely to rely on external sources of knowledge and to better manage relationships with universities, because they have more resources, such as professionally-qualified staff. However, some studies have cast doubts on the positive effect of firm size on the use of external sources of information. Cohen et al. (2002) argued that while larger firms interact more with universities, smaller firms interact more efficiently. Start-ups, for example, are often considered a key vehicle for transforming university research into commercial innovations (Lee 2000). It can therefore also be argued that large firms may achieve less from collaboration than their smaller counterparts. Larger firms have a wide availability of internal resources that, in turn, may imply a robust knowledge base, so their gains from UI collaboration may be marginally very small, while those of small firms may be characterized by increasing returns. This may be especially true for small ICT firms in South Italy, as these firms may be

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** Iacobucci (2009) argued that "*If the measurement is strong (three or four indicators per factor, and good reliabilities), [and the] path model [is] not overly complex….then samples of size 50 or 100 can be plenty*".

unable to conduct their o$_w$n innovation and research projects. We therefore included the variable *Size*, $_w$hich measured the number of a firm's $_w$orkers.

Mo$_w$ery and Rosenberg (1989) underlined the necessity of having sufficient expertise $_w$ithin the firm to exploit external sources of kno$_w$ledge. Firms characterized by high sci- entific competence and specialized human capital are able to get more benefit from col- laboration. The concept of absorptive capacity (Cohen and Levinthal 1990) supports this. In-house R&D and technological competences are prerequisites to benefit from external collaboration, especially $_w$ith institutions that focus on intense basic research. We there- fore took into account the role of firms' absorptive capacity as control, measured by the percentage of employees educated at university in scientific disciplines (*R&D intensity*). Both controls used data from the first year of the survey (2006) to avoid problems of simul- taneity $_w$ith the other variables in the model[***].[5] We expected to see that *R&D intensity* had a positive impact on the benefits from cooperation, but $_w$e had no clear expectations for *Size* because of the mixed evidence in the literature.

Table 2 sho$_w$s summary statistics and correlations for the observed variables used to build the constructs and for the controls. In general, the correlation coefficients $_w$ere lo$_w$ to moderate, $_w$ith fe$_w$ cases above 0.70. All correlations met the common rule of thumb that their values should be less than 0.75 to avoid problems of collinearity, suggesting that this $_w$as not a relevant issue in our sample (Martinez et al. 2017).

Firms included in the sample had on average about 25 employees, of $_w$hom almost 60% had a university degree. This indicates that the sample consisted mostly of small firms $_w$ith specialized employees. The collaborations bet$_w$een the firms and universities $_w$ere mostly on the development or testing of a ne$_w$ technological product.

After data collection, $_w$e analysed the sample using structural equation modeling. This methodological tool offers several advantages (Hoyle 2012). Under given conditions, it is a robust method to deal $_w$ith small samples. It is a po$_w$erful tool for confirmatory analysis of predictions derived from theory, and allo$_w$s checks for possible inverse relationships bet$_w$een variables. It also allo$_w$s the definition of latent variables, or the theoretical con- structs defined by the conceptual model, through the use of observed variables.

Our empirical strategy used the common t$_w$o-stage procedure recommended by Ander- son and Gerbing (1988). We started $_w$ith a confirmatory factor analysis to assess the valid- ity of the constructs built by the measurement model. In the second step, after validating the measurement model for latent variables, $_w$e estimated and compared different struc- tural models to test the relationships bet$_w$een the variables (path analysis).

Table 3 sho$_w$s the results of confirmatory factor analysis for the measurement model of latent variables, $_w$hich appear to be satisfactory. Standardized factor loadings $_w$ere highly related to their respective constructs (column heading: Factor loadings) and statistically significant (column heading: z-value). All the Cronbach's α coefficients $_w$ere higher than 0.7 (column heading: Alpha), supporting the reliability of the constructs.[6] The average variance extracted (AVE) $_w$as greater than 0.5 for all the constructs, indicating adequate convergent validity. Finally, construct reliability (CR) $_w$as al$_w$ays higher than 0.7, suggest- ing internal consistency. Based on these results, $_w$e assumed that our measures consistently represented the theoretical constructs.

*** [5] In structural equation modeling, control variables should be linked to all latent variables. Ho$_w$ever, to save degree of freedom and to respect the threshold of five for the ratio bet$_w$een sample size and the num- ber of model parameters suggested by Kline (2005), $_w$e only analysed the effect of Size and R&D intensity on *Collaborative experience*, *Tangible benefits* and *Intangible benefits*.

Table 2 Descriptive statistics and correlations ($n = 50$)

Variable	Mean	SD	Min	Max	CO1	CO2	CO3	CO4	CO5	CO6	CO7	CO8
CO1	2.54	1.53	1	5	1							
CO2	2.66	1.45	1	5	0.37	1						
CO3	1.10	0.51	1	4	− 0.05	0.10	1					
CO4	1.08	0.34	1	3	− 0.01	− 0.03	− 0.05	1				
CO5	2.36	1.54	1	5	− 0.04	0.13	− 0.02	0.18	1			
CO6	1.24	0.87	1	5	− 0.04	0.26	− 0.06	− 0.07	0.12	1		
CO7	2.48	1.33	1	4	0.11	0.27	0.08	0.00	0.04	0.32	1	
CO8	2.66	1.77	1	5	0.26	0.57	− 0.01	0.25	0.41	0.32	0.22	1
CO9	2.64	1.59	1	5	0.22	0.43	0.17	0.21	0.70	0.06	0.03	0.33
CO10	1.60	1.05	1	4	0.43	0.35	− 0.12	0.21	0.19	0.11	0.43	0.22
KH1	1.75	0.86	0	3.33	0.07	0.29	− 0.18	0.07	0.05	0.49	0.39	0.30
KH2	4.12	0.73	1.71	4.86	0.13	0.22	− 0.08	0.12	0.35	0.27	0.39	0.11
TR1	3.32	1.20	0	4	0.28	0.30	− 0.29	0.14	0.43	0.16	− 0.03	0.38
TR2	2.32	1.30	0	4	0.20	0.08	− 0.11	0.22	0.16	− 0.25	− 0.04	0.15
TB1	4.26	1.08	2	5	0.06	0.43	0.14	− 0.06	0.10	0.06	0.29	0.40
TB2	2.14	1.60	1	5	0.29	0.07	− 0.14	0.13	− 0.20	− 0.20	− 0.08	− 0.22
TB3	3.34	1.66	1	5	0.27	0.52	− 0.14	0.17	0.34	0.20	0.26	0.40
ITB1	4.02	0.94	2	5	0.23	0.41	0.13	0.12	0.43	0.14	0.24	0.42
ITB2	3.88	1.24	1	5	− 0.15	0.19	0.08	0.12	0.22	0.14	0.40	0.26
Size	24.90	39.3	1	250	0.08	− 0.02	0.07	0.74	0.23	− 0.10	− 0.14	0.16
R&D Intensity	59.94	28.2	0	100	0.08	0.13	− 0.06	0.13	0.36	0.08	0.17	0.14

Variable	CO9	CO10	KH1	KH2	TR1	TR2	TB1	TB2	TB3	ITB1	ITB2	Size
CO1												
CO2												
CO3												
CO4												

Table 2 (continued)

Variable	CO9	CO10	KH1	KH2	TR1	TR2	TB1	TB2	TB3	ITB1	ITB2	Size
CO5												
CO6												
CO7												
CO8												
CO9	1											
CO10	0.48	1										
KH1	0.08	0.19	1									
KH2	0.34	0.30	0.31	1								
TR1	0.34	0.33	− 0.04	− 0.06	1							
TR2	0.14	0.23	− 0.07	− 0.08	0.31	1						
TB1	0.27	0.09	0.09	0.03	− 0.10	− 0.06	1					
TB2	0.10	0.09	0.16	0.20	− 0.16	0.40	− 0.01	1				
TB3	0.46	0.27	0.35	0.47	0.33	− 0.24	0.28	0.20	1			
ITB1	0.51	0.22	0.13	0.30	0.16	0.01	0.72	0.03	0.47	1		
ITB2	0.21	0.23	0.18	0.49	− 0.17	− 0.09	0.40	− 0.21	0.16	0.41	1	
Size	0.34	0.21	− 0.06	0.19	0.15	0.21	− 0.14	0.13	0.25	0.07	0.06	1
R&D Intensity	0.33	0.26	0.03	0.04	0.39	0.06	0.10	0.00	0.35	0.15	0.02	0.26

Table 3 Measurement model and latent variables

Latent variable	Indicator	Factor loadings	z-value	Alpha	AVE	CR
Collaborative experience	CO1	0.968	19.75	0.77	0.649	0.948
	CO2	0.795	12.63			
	CO3	0.816	11.56			
	CO4	0.611	12.76			
	CO5	0.805	16.26			
	CO6	0.859	4.692			
	CO7	0.838	2.934			
	CO8	0.699	17.32			
	CO9	0.847	33.00			
	CO10	0.774	3.777			
Coll. know-how *(selection)*	KH1	0.753	18.22	0.87	0.740	0.849
Coll. know-how *(management)*	KH2	0.956	25.44			
Trust	TR1	0.786	19.53	0.76	0.770	0.869
	TR2	0.96	48.83			
Tangible benefits	TB1	0.998	11.45	0.81	0.989	0.996
	TB2	0.994	35.33			
	TB3	0.992	26.13			
Intangible benefits	ITB1	0.987	23.81	0.78	0.926	0.962
	ITB2	0.937	17.25			

4 Empirical results

The path analysis was used to fit our conceptual model in Fig. 1. We used the reiterative procedure of the asymptotic distribution-free estimator (ADF) instead of the standard max- imum likelihood estimator, because ADF does not require the assumption of joint normal- ity or even symmetry for observed and latent variables. This makes it possible to relax the assumption of normality of the errors, which was important because of the small sample size.

Table 4 shows the results and the diagnostic tests of the estimated models. We estimated four different model specifications based on different theoretical assumptions. Model A was the most comprehensive and included the direct path from *Collaborative experience* to both *Tangible benefits* and *Intangible benefits*, as well as the mediating variables and the controls. Model B excluded the direct relationships between *Collaborative experience* and the benefits, but considered the mediators and the controls. Model C assumed that *Col- laborative know-how* was positively related to *Trust*, as in the paper by Nielsen and Nielsen (2009). Lastly, Model D considered only the direct path from *Collaborative experience* to the dependent variables, and the effects of the control variables.

The diagnostic tests showed that Model B fit the data most accurately. The comparative fit index (CFI), which is specifically designed for small samples (Tabachnick and Fidell 2007), was 0.944. The Tucker-Lewis index (TLI) was 0.925 and the coefficient of deter- mination (CD) was 0.892. The root mean squared error of approximation (RMSEA) was 0.008 and the standardized root mean squared residual (SRMR) 0.074. The deterioration in the diagnostic tests for the alternative models A, C and D suggested that Model B should be preferred. The estimates for Model A, however, were similar, and the preference for Model B indicated by the diagnostic tests may therefore be a result of the low number of variables.

To investigate the mediating effect of *Collaborative know-how* and *Trust* on the relation- ship between *Collaborative experience* and the benefits from UI cooperation, we followed the method proposed by Baron and

Kenny (1986). The first step of the procedure is to sho$_w$ that there is a significant relationship bet$_w$een the dependent variable and the independent variable of interest. In the second step, the independent variable must have a significant effect on the mediators. In the third step, the mediating variables must have a significant impact on the dependent variable. In the last step, the effect of the independent variable of interest on the dependent variable has to be lo$_w$er $_w$hen the model includes the mediating variables.

Table 4 Alternative structural models

Consequent variable	Antecedent variable	Model A	Model B	Model C	Model D
Tangible benefits	Collaborative know-how	0.001***	0.002***	0.118	–
Tangible benefits	Trust	0.587***	0.892***	1.060***	–
Intangible benefits	Collaborative know-how	0.332***	0.722***	0.596***	–
Intangible benefits	Trust	0.867***	0.544**	1.081***	–
Collaborative know-how	Collaborative experience	0.161***	0.217*	0.032	–
Trust	Collaborative experience	0.366	0.492***	0.569	–
Tangible benefits	Size	− 0.053	− 0.078**	− 0.815	− 0.283***
Intangible benefits	Size	− 0.107***	− 0.069***	− 0.148	− 0.085***
Collaborative experience	Size	0.196	0.221***	0.206	–
Tangible benefits	R&D intensity	− 0.008	− 0.022	− 0.044	0.004
Intangible benefits	R&D intensity	0.029	0.065***	0.018	− 0.85
Collaborative experience	R&D intensity	0.762	0.116	0.160	–
Tangible benefits	Collaborative experience	0.624**	–	–	0.945***
Intangible benefits	Collaborative experience	0.512***	–	–	0.775***
Trust	Collaborative know-how	–	–	− 0.529	–
	CFI	0.890	0.944	0.901	0.980
	TLI	0.803	0.925	0.812	1.230
	CD	0.344	0.892	0.510	0.881
	RMSEA	0.025	0.008	0.018	0.000
	SRMR	0.123	0.074	0.096	0.447

Standardized total effect

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Our estimates met these four conditions, supporting Hypothesis 1 on the positive effect of *Collaborative experience* on the benefits from UI cooperation, as $_w$ell as Hypotheses 2 and 3 on the mediating role of *Collaborative know-how* and *Trust*. Step one required a sig- nificant relationship bet$_w$een *Collaborative experience* and benefits. Model D sho$_w$ed that *Collaborative experience* $_w$as significantly related to both *Tangible benefits* (β = 0.945, $p < 0.001$) and *Intangible benefits* (β = 0.775, $p < 0.001$). Step t$_w$o, $_w$hich requires a sig- nificant relationship bet$_w$een *Collaborative experience* and the mediators, $_w$as fulfilled in Model B, $_w$here the coefficients $_w$ere 0.217 ($p < 0.05$) for the effect on *Collaborative know-how* and 0.492 ($p < 0.001$) for the impact on *Trust*. The third step, requiring the mediators to have a statistically significant impact on the dependent variable, $_w$as also sat- isfied. In Model B, *Collaborative know-how* positively influenced both *Tangible benefits* (β = 0.002, $p < 0.001$) and *Intangible benefits* (β = 0.722, $p < 0.001$), and there $_w$ere simi- lar results for *Trust* on both *Tangible benefits* (β = 0.892, $p < 0.001$) and *Intangible benefits* (β = 0.544, $p < 0.01$). Lastly, our point estimates $_w$ere consistent $_w$ith step 4, for the dif- ferent effect of *Collaborative experience* on the dependent variable, depending on $_w$hether the mediating variables $_w$ere included in the model. When the mediators $_w$ere considered in Model A, the direct impact of *Collaborative experience* on *Tangible benefits* $_w$as 0.624 ($p < 0.01$), $_w$hich $_w$as lo$_w$er than in Model D, but still statistically significant. The direct impact on *Intangible benefits* $_w$as also still positive and significant (β = 0.512, $p < 0.001$), but lo$_w$er than in Model D. These results support our Hypotheses 2 and 3, and indicate that

Collaborative know-how and *Trust* have a partial mediating role on the relationship bet$_{w}$een *Collaborative experience* and benefits from UI cooperation.

Looking at the estimates of Model A and Model D, $_{w}$e can conclude that Hypothesis 1 on the positive effect of *Collaborative experience* on *Tangible and Intangible benefits* is also confirmed. In both models, the coefficients $_{w}$ere positive and statistically significant.

The magnitude of the estimated coefficients suggests that *Trust* is the major driver of tangible benefits, $_{w}$hile *Collaborative know-how* is more important for learning and intan- gible benefits. These results are consistent $_{w}$ith previous studies: Ple$_{w}$a and Quester (2007) and Ple$_{w}$a et al. (2013), for example, found that trust $_{w}$as a significant mediator bet$_{w}$een firm capability and satisfaction/outcomes in collaboration $_{w}$ith universities.

Our results also suggest that collaborative kno$_{w}$-ho$_{w}$ has a $_{w}$eaker effect on tangible benefits and a stronger effect on learning than $_{w}$as found by Simonin (1997). These differ- ences could be explained by the inclusion of trust as a specific mediator in our model or by the peculiarities of the ICT firms in our sample. Using a sample of 66 S$_{w}$edish firms col- laborating $_{w}$ith universities, Broström and Lööf (2008) found that the indirect benefits (i.e. learning) $_{w}$ere at least as important in the creation of ne$_{w}$ R&D results.

The controls sho$_{w}$ed mixed results. The effect of firm size $_{w}$as negative and statisti- cally significant, sho$_{w}$ing an inverse correlation $_{w}$ith both tangible and intangible benefits. This result is consistent $_{w}$ith the explanation that small firms, despite their lo$_{w}$er internal capabilities, gain greater benefits from UI cooperation. Large firms are better managed and organized, $_{w}$hich allo$_{w}$s them to exploit the opportunities of cooperation, but are also able to conduct complex research and business development independently. A similar effect of firm size $_{w}$as found by Fındık and Beyhan (2015), studying the impact of collaboration on firm innovation performance in Turkey. Our result is also consistent $_{w}$ith Santoro and Chakrabarti (2002), $_{w}$ho noted that smaller firms in technology-intensive industries build their problem-solving ability in core technological areas mainly upon technology transfer and cooperative research relationships.

R&D intensity, $_{w}$hen statistically significant, had the expected positive sign. The vari- able, ho$_{w}$ever, sho$_{w}$ed a $_{w}$eak explanatory po$_{w}$er, and had a statistically significant impact only on *Intangible Benefits* in Model B (β = 0.065, $p < 0.001$). This may be because the firms in our sample $_{w}$ere mainly small, $_{w}$hich in turn may imply a lo$_{w}$ intensity of in-house R&D. Innovation strategies in small firms often rely on both internal and external sources of information.

5 Discussion

The engine of innovation is no longer rooted $_{w}$ithin individual firms. Instead, it lies in innovation net$_{w}$orks that encompass different types of partners, including industry, uni- versities and government. UI cooperation is therefore a crucial factor in enhancing firms' innovation and competitiveness. The aim of this study $_{w}$as to advance understanding of the benefits accrued by small and medium-sized ICT firms from R&D collaboration $_{w}$ith universities. Building upon the kno$_{w}$ledge-based vie$_{w}$ and organizational learning per- spective, $_{w}$e proposed a theoretical frame$_{w}$ork encompassing the concepts of collaborative experience, collaborative kno$_{w}$-ho$_{w}$ and trust in the context of UI interactions.

The model $_{w}$as empirically tested on a sample of ICT firms from the Campania region of Italy. All these firms had established relationships $_{w}$ith universities during the period 2006–2009. The results support the theoretical assumptions that collaborative experience has a positive effect on the benefits from UI cooperation, and sho$_{w}$ed that collaborative kno$_{w}$-ho$_{w}$ and trust are significant mediating mechanisms bet$_{w}$een collaborative experi- ence and gaining benefits from cooperation $_{w}$ith universities. These findings suggest that repeated interactions over

time contribute in building collaborative kno$_w$-ho$_w$ and trust, $_w$hich in turn can be used by firms to fully benefit from future collaborations $_w$ith universi- ties. Collaborative kno$_w$-ho$_w$ is therefore a distinct capability, and not the same as experi- ence in collaboration, although the latter is useful and necessary to develop the former. Our study also emphasizes the critical role played by trust in ensuring the effectiveness of UI relationships.

We found empirical evidence of heterogeneous effects on t$_w$o different types of benefits: tangible and intangible. Trust $_w$as the major driver of tangible benefits, $_w$hile Collabora- tive kno$_w$-ho$_w$ $_w$as more important for learning and intangible benefits.

Our study contributes to the theoretical literature on UI alliances in t$_w$o $_w$ays. Previ- ous studies mainly looked at collaborative kno$_w$-ho$_w$ and trust in the context of inter-firm cooperation, but $_w$e hypothesized and tested that these factors also have a crucial role in the relationships bet$_w$een firms and universities. The management of interactions $_w$ith external partners is a critical activity because of the complexity and uncertainty of projects carried out across organizational boundaries, especially in science-based industries such as ICT. These tasks are particularly difficult in the context of UI relationships, $_w$hich involve partners $_w$ith different organizational cultures, objectives and kno$_w$ledge bases.

We also sho$_w$ed that collaborative kno$_w$-ho$_w$ and trust have heterogeneous effects on different types of benefits from UI collaborations. This supports the vie$_w$ that firms can benefit from partnerships $_w$ith universities in several $_w$ays (Crossan and Inkpen 1995; Pucik 1988). We distinguished intangible benefits, $_w$hich pertain to learning via kno$_w$ledge acquisition, and tangible benefits, $_w$hich include product and process innovations. We have therefore advanced organizational learning theory by sho$_w$ing the dual and distinct role of collaborative kno$_w$-ho$_w$ and trust in the process of kno$_w$ledge assimilation and application, $_w$here previous studies considered trust as just one aspect of collaborative kno$_w$-ho$_w$ (e.g. Simonin 1997).

This research has important implications for practice. ICT firms, and more generally high-tech firms, should develop strategic competences to fully benefit from interactions $_w$ith universities. Past experience alone is not sufficient to maximize the benefits from UI collaboration. This $_w$ill enable them to gain from learning and kno$_w$ledge acquisition, as $_w$ell as improve their ability to develop product and process innovations. This is consist- ent $_w$ith other studies sho$_w$ing that small high-tech firms need to establish a $_w$ide range of partnerships $_w$ith the external environment to remain competitive in their rapidly changing markets (Fukuga$_w$a 2013; Martinez et al. 2017).

In recent decades, the public sector has dedicated increasing resources to supporting research collaborations bet$_w$een firms and universities, based on the assumption that tech- nology transfer $_w$ill occur. Despite the increasing importance that public programmes have attached to UI cooperation, ICT firms still report a lack of institutional support and strin- gent regulation as major barriers to innovation. Our results suggest that public programmes should not support single collaborative projects bet$_w$een firms and universities, but focus on the development of enduring collaborative relationships over time. They should also put in place effective controls to prevent opportunistic behaviour and contractual violations, as $_w$ell as an adequate regulation of intellectual property rights, to create favourable condi- tions for alliance learning and the development of innovations. Effort is therefore needed to build channels and tools facilitating the interaction bet$_w$een universities and industry, and especially to support small firms. Some studies have sho$_w$n that universities prefer to cooperate $_w$ith large, $_w$ell-established firms (e.g. D'Este and Perkmann 2011), so it may be important to formulate appropriate incentive schemes to foster UI collaboration involving small and medium-sized firms. Our other empirical findings sho$_w$ that benefits from UI collaborations are greater for smaller firms, suggesting that interaction $_w$ith universities is a po$_w$erful means to overcome some typical limitations for innovation in SMEs, such as uncertainty and financing constraints.

6 Limitations and future research

This study has expanded knowledge about university–industry relationships, but it also has some limitations that call for future research. The existing literature on knowledge transfer and learning in alliances has emphasized the important role of collaborative know-how and trust, but other elements may also influence the relationship between collaborative experience and the outcome of UI cooperation. Our results show that collaborative know- how and trust have a partial mediating effect on this relationship. Martinez et al. (2017) showed, however, that also human capital is a fundamental driver of firms' innovation performance in high-technology industries because it strengthens the positive impact of alliance partner diversity. Similarly, specialized human capital within firms operating in science-based industries could be an important resource in translating external knowledge and previous collaborative experience into stronger benefits from cooperation with univer- sities. In addition, Nielsen and Nielsen (2009) argued that partnerships' governance mode may be relevant to the benefits achieved by firms. Therefore, a promising avenue for future research would be to explore other possible channels through which collaborative experi- ence increases the benefits from UI cooperation.

We considered the relationships between industry and university only from the point of view of firms. Future research should investigate the university perspective, as this has received less attention (Boardman and Ponomariov 2009). Indeed, the success of UI col- laborations could also be affected by the previous experience of researchers in the various channels of knowledge transfer to industry (D'Este and Patel 2007), and by the entrepre- neurial orientation of the university concerned (Bellucci and Pennacchio 2016; Bruneel et al. 2010).

Our research design suggests that the results should be generalized with caution. The sample for the empirical analysis was small and, although alternative configurations of the model were considered and tested, this could limit the external validity of the analysis. The low number of observations limited the complexity of the proposed model, which ulti- mately responded to the need for parsimony. Our analysis also used data from only one region of Italy, and only one sector. Further investigation of other technology-intensive sectors, and different regional and national contexts, might help to develop a more robust picture.

In spite of these limitations, we believe that our analysis provides an empirical verifi- cation that was previously lacking in the literature on learning and interaction processes in university–industry cooperation. Our results add to understanding about how firms can manage interactions with external partners to maximize their benefits.

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Appendix

Measurement items for latent variables using a five-point Likert-type scale

Latent variable	Items (items code)
Collaborative experience	Contracts (CO1)
	Joint research (CO2)
	Patents (CO3)
	Copyright licenses (CO4)
	Direct recruitment (CO5)
	Temporary exchange of staff (CO6)
	Advice (CO7)
	Informal information exchange (CO8)
	Theses and dissertations (CO9)
	Research publications and reports (CO10)
Collaborative selection (KH1)*	We use specific tools to monitor universities' areas of expertise (KH1a)
	We have internal staff dedicated to the selection of universities for collaboration (KH1b)
	We have a defined process to select universities to work with (KH1c)
Collaborative management (KH2)*	There is a formal document for the specifications of the project in collaboration with university (KH2a)
	To develop innovations in collaboration with a university, we activate a formal collaboration process (KH2b)
	We identify a project manager for any collaboration with a university (KH2c)
	We define a formal plan of activities (e.g. timing diagram or budget of activities) for collaboration with a university (KH2d)
	We check the progress of the plan during the joint project and regularly update the estimates of time/cost and/or specifications (KH2e)
	We identify resources for the joint project and formally allocate a portion of their time (KH2f)
	We use software for project management (e.g. Microsoft Project) in collaboration with the university (KH2g)
	We define plans for long-term collaboration with universities (KH2h)
fTrust	We feel that we need to protect ourselves from possible opportunistic behaviours (TR1)
	We specify rigid objectives and constraints for university activities (TR2)
Tangible benefits	We have used the results of joint projects with universities to develop new products (TB1)
	We have used the results of joint projects with universities to improve internal production processes (TB2)
	We have used the results of joint projects with universities to develop our business (TB3)
Intangible benefits	Do you feel satisfied with your collaboration with universities? (ITB1)
	We have acquired new knowledge/skills from the relationships with universities (ITB2)

*Collaborative selection and Collaborative management are used to build the construct Collaborative know-how

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