Open innovation in the new context of proof of concepts: evidence from Italy

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Abstract

Purpose – The paper aims to advance knowledge by investigating the main factors that impact on innovation through the co-development process between researchers and firms at the very early stage of proof of concept.

Design/methodology/approach – The authors developed an empirical analysis on the proof of concept network project, through a mixed empirical analysis. They explored the main factors that affect the enactment of the co-development process and tested the impact of such factors on the probability for partners to enact a co-development project and generate innovation.

Findings – From the quantitative analysis comes out that the trust of the research team into the potentiality of the technology, the commitment of researchers concerning the scalability of technology and the IP value issued by external experts have a positive impact on the probability to create a match among partners and generate innovation.

Research limitations/implications – Even if all the population of technologies (108) considered in the project implementation are analyzed, the development of the empirical analysis on a specific project within a single country represents a limitation. Future analysis will concentrate on a larger panel of proof of concept experience across Europe.

Practical implications – The success of a co-development process between researchers and companies at the embryonic phase of the technology considers the opportunity to exploit the technologies into real products for the market.

Originality/value – This is an empirical analysis of the first Italian proof of concept implementation that deeply investigates which critical factors can enable innovation by enacting a co-development process between researchers and small and medium-sized enterprises (SMEs).

Keywords Innovation, Co-development, Technology transfer, Proof of concept, University-industry collaboration, Technology assessment

Paper type Research paper

1. Introduction

Technology transfer is the transition of resources (including knowledge and skills) from scientific research to the markets. This process is the result of a partnership between academic and industrial fields, whose main purpose is to make technology accessible to everyone. In the last several years, the interaction between the industry system and scientific institutions, through the exchange of knowledge and technology, has become a central issue in the field of management (Dalmarco *et al.*, 2019; Hou *et al.*, 2019).

JEL Classification — O31, O32, O34

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Several studies have analyzed the characteristics of the co-development process (Prahalad and Ramaswamy, 2004; Mallick *et al.*, 2010; Romero and Molina, 2011; Salmela *et al.*, 2011; Aarikka-Stenroos and Jaakkola, 2012; Santti *et al.*, 2017; Porras *et al.*, 2018).

In the last years, different researchers argue that the most critical phase in technology transfer model occurs between the invention and the product development phases, when commercial concepts are created and verified when appropriate markets are identified and when protectable intellectual property (IP) may have to be developed (Bradley *et al.*, 2013). This is the proof of concept phase, characterized by information and motivation asymmetries and institutional gaps between the science and technology and business enterprises. There is a kind of Death Valley related to different reasons. Proofs of concept, in fact, typically fail for two reasons: technology and market fit. Sometimes, despite all the research and financial efforts, technology does not work. Moreover, proofs of concept planned at a purely technical level are unlikely to succeed. Even If technology can be a puzzling issue, many innovation projects fail because of the lack of a market's need.

Thus, researchers and firms can decide to co-create and work together to validate (proof) scientific results (concept) from the very early stages of the innovation process (*proof of concept models*) (Munari *et al.*, 2017; Garengo, 2019), in order to reduce technology and market failure.

On this perspective, the co-development process in the proof of concept stage requires to each partner, specific knowledge, competences and skills, and it enables them to acquire external knowledge inputs, combine resources and enhance new proof of concept (Chesbrough, 2006). Thus, it implies mutual evaluation of critical elements (Wang *et al.*, 2016) among partners. In this context, very few studies focus on the critical factors that can encourage partners to enable the co-development process in the proof of concept stage (Lazzarotti *et al.*, 2017; Ombrosi *et al.*, 2019; Tsou *et al.*, 2019). This represents a relevant gap in the literature and it could be considered an emerging field of research to be strongly explored.

The motivations for our research question stem from the lacks in the literature on co-development:

RQ1. Which are the critical factors that inspire co-development between researchers and firms in the proof of concept process?

RQ2. Which kind of factors is required by the partners who decide to enact a development project in the proof of concept stage?

This paper attempts to address these questions by delineating the main factors that encourage a co-developed project, to generate a proof of concept.

In order to contribute to the literature, we conducted an empirical analysis of the first Italian proof of concept enactment, through the implementation of a mixed empirical analysis (qualitative and quantitative). The empirical analysis has the aim to explore which are the main factors that encourage co-development projects, between firms and researchers.

Our study contributes to the literature as follows: first, this study contributes to the theoretical background of co-development by offering a description of the factors that enable a proof of concept model. As both conceptual and empirical research works on this topic are still underdeveloped, our work provides fresh insights into the technology transfer literature and offers significant practical implications. Specifically, this study focuses on the factors that enable proof of concept collaborations between researchers and firms. A structured interview to a panel of technology transfer experts in Italy was conducted, in order to validate the panel of crucial factors. Third, this study explains the effect of such factors on the probability to build co-develop models in proof of concept stage. The paper is organized as follows. First, we explore the critical factors highlighted by the literature on co-development models, and then we propose the empirical investigation, by highlighting the main results. Finally, conclusions and implications are drawn from the findings.

2. Research design and hypothesis development

Several studies in the literature deeply analyzed demand-pull and technology-push models for technology transfer. Conversely, from the study of Thursby *et al.* (2001), a few studies have focused on the topic of co-developing models in the proof-of-concept stage and relevant papers in the literature are still relatively sparse (Munari *et al.*, 2017). Specifically, a relevant gap in the literature on co-development concerns the critical factors that can encourage partners to enable collaborations to generate proof of concepts. Thus, the literature described below, investigates which kind of knowledge and skills are required by the partners that decide to be involved in a co-development process of innovation. Some important issues come out. We start with the review from the analysis of some crucial papers in the field of co-development, by using *Scopus* dataset [1]; we get 22 related papers, containing relevant issues to take into account in partners selection to enact co-development processes. Shane (2002), for example, puts into evidence the importance of partner characteristics by highlighting that technologists and business people have, to trust each other and they need to have trust in the technology they are going to exploit. Gulbranson and Audretsch (2008) for example, highlighted the importance of partners' knowledge and resources, involved in the co-development of technologies. In fact, by analyzing two examples of PoCCs they highlighted the importance of the reputation and excellence of scientists involved in a co-development process. Maia and Claro (2013), focuses on the importance of the "target market and the development of additional required protectable IP" (p. 643). Lankton *et al.* (2014) highlight that technology trusting expectations influence the trusting intention of partners to be involved in a co-development process. Tsou *et al.* (2015) identify four criteria for business partner selection, such as partner reliability, partner complementarity, partner expertise and partner compatibility. Wang *et al.* (2016) highlight how the compatibility among partners influences co-development outcomes. Specifically, they underline that "goal compatibility has a positive impact on product co-development." The compatibility among partners, with respect to their outlooks, influences the extent to which they can realize the harmonic potential of their partnership. Partners' goal compatibility supports the perception that what is beneficial for one partner is also in the wishes of the other partner. Thus, goal compatibility is an important factor that encourages co-development.

Munari *et al.* (2017) focus on the "distance" between researchers and firms. In fact, when researchers and academics are involved in a co-development project, technical skills may be in abundance, but managerial and commercial skills are scarce. The authors also consider another important factor that is related to the differences in values and language between academics and firms, which may create a communication gap. Scientists generally lack awareness and understanding of business culture and the requirements of the investment process. A recent paper of Tsou *et al.* (2019) focuses on the impact of the business ecosystems, in terms of collaborative network and partner selection, on the co-development process. They argue that within a business ecosystem, partner selection (selecting partners with compatible intangible assets and market knowledge capability) has a positive effect on co-development. Specifically, they argue that similar strategy goals but different competing objectives, along with partner's culture are crucial factors in co-development enactment (Powell and Lim, 2017), such as partner's technical knowledge and trust in the market potentiality.

Following this research field, we investigate the critical issues for co-development models, related to the partners "characteristics and partners" preferences.

2.1 Research hypothesis development

Since the current literature lacks a list of factors that facilitate the co-development process in the proof of concept stage, we handled an explorative qualitative analysis. Specifically, we conducted some structured interviews to investigate the main pillars of co-development in the proof of concept stage and the characteristics asked for by potential partners. In January 2019 we launched a call for experts on LinkedIn, to involve a panel of experts (technology transfer, managers and researchers) in our explorative study. We closed the call at the end of March 2019. We get the availability from the following seven experts: two with managers of Italian small and medium-sized enterprises (SMEs) with a long technology transfer experience internationally and five with technology transfer experts working in Italian Universities. In April 2019, we carried out the structured interviews, by using Skype. The interviews lasted between 60 and 120 min to investigate which are the main element that encourages research teams and firms to be involved in a co-development innovation process (Appendix 1).

The qualitative analysis revealed some managerial and applied research practices to be adopted to enhance the co-creation process and co-development activities (see Figure 1). Moreover, the interviewer [2] proposed some possible practices as the most suitable to explain co-development. To cluster the interview data we used a thematic analysis approach (Castleberry and Nolen, 2018). After the transcription of interviews, we assigned specific codes to our data, where a code is a brief description of what is being said in the interview. We do not use specific software for coding, but we code by taking notes on a printed transcript. Then, we looked at the list of codes and their associated extracts. In this process, not all codes fit together with other codes. We selected only the codes that fit with the principal theme of the analysis. At this point, we review and refine the themes that we identified before. We read through all the extracts related to the codes to explore if they support the theme, if there are contradictions and to see if themes overlap. Some themes were split into separate themes or moved into another existing theme where they fit better. We keep doing this until we feel that we have a set of themes that are coherent and distinctive. Finally, we describe each of the themes, and we name the different items (Appendix 2). Specifically, we identified 16 items and we created three clusters that we named: endogenous, interactive and exogenous (Figure 2).

2.1.1 Endogenous factors. Interviews revealed that, at the endogenous level, the individual trust in technology and the commitment into the co-development process (Johnson, 2007) represents a crucial issue in the enactment of the relation. The level of technology potentiality and the inherent perceived risk generate trust in the technology, by increasing the commitment of researchers to be involved in a co-development relationship (De Ruyter *et al.*, 2001). In the matching activity, it is also reasonable to assume that the interest of the industrial partner will be greater if the research has great trust in the technical features of the patent/technology. Consequently, our first hypothesis is:

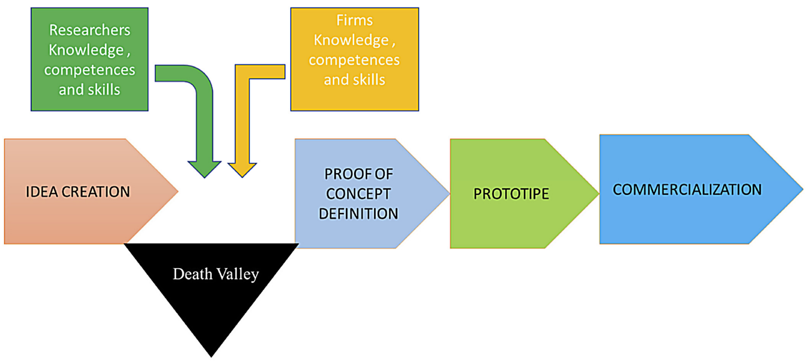

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Figure 1.
The Death Valley of Proof concept

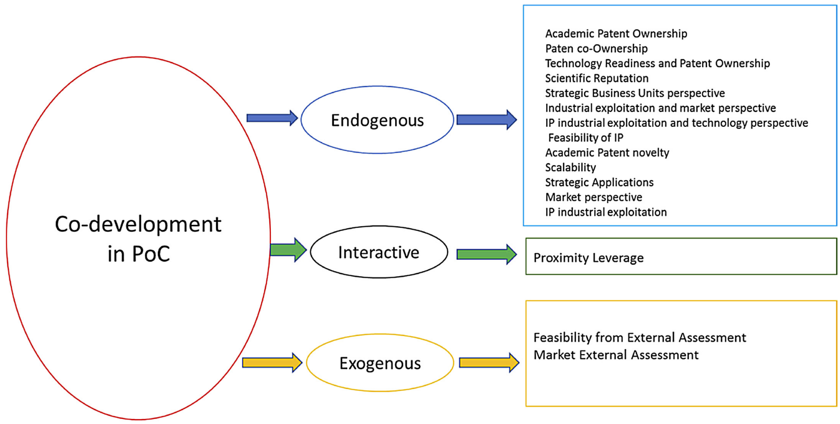

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Figure 2.
The items from the Thematic Cluster Analysis (TCA)

Hp1. A high level of commitment of the research team, related to the trust in the intellectual property potentiality of the technology, increases the probability to enact a co-development process.

Along with technical factors, the commitment of researchers increases if they are aware of the market potentiality of the technology. Specifically, researchers can increase the trust into the technology if they perceive a high level of scalability into different market segments; they also increase their trust if they perceive a large dimension of the potential market where the exploited technology is going to be placed (Tsou *et al.*, 2019). Therefore, the second hypotheses are:

Hp2a. A high level of commitment of the research team, related to the trust in the possible technology applications, increases the probability to enact a co-development process.

Hp2b. A high level of commitment of the research team, related to the trust in the dimension of the final market (where the technology can be exploited), increases the probability to enact a co-development process.

2.1.2 Interactive factors. At the interactive level of analysis, the second group of factors is related to the typology of knowledge sharing along with the locus where it is shared (Yakhlef, 2005). Different studies argue that geographical proximity is important in knowledge transfer because of the difficulty transferring tacit knowledge; they highlighted that short distances among partners facilitate communication and knowledge exchanges through face-to-face interactions, personal relations and casual and unintended meetings (Audretsch and Feldman, 1996). In addition, geographic proximity favors social interactions and trust building (Ponds *et al.*, 2007).

According to Bignami *et al.* (2019), we consider that the role of proximity is related to the type of knowledge to be shared. Considering the different phases of the innovation process in the basic research activities, knowledge is more tacit and originates from a more unpredictable process. It requires short distances and face-to-face interactions in order to be transferred. In addition, basic science knowledge is often generated by scientists within an academic setting and, for industries to get access to this knowledge, geographical proximity is necessary. Applied research, on the other hand, implies mainly codified knowledge originates from a more linear R&D process that can be controlled at a distance.

The co-development of technology for a proof of concept is related to the applied knowledge, therefore less dependent on geographical proximity than basic science knowledge areas. Our third hypothesis is:

Hp3. The match between firms and the research system for a co-development project is negatively affected by geographical distance.

2.1.3 Exogenous factors. From the interview, it was revealed that whether a new technology is feasible, or a new product is promising is always difficult to precisely predict (Jeon *et al.*, 2017). Researchers are confident with their technologies, and sometimes overly committed, so that its industrial partner may be skeptical. Moreover, it is unwise for the researchers to fully disclose the technology for the sake of convincing the potential partner because of the risk of leakage of proprietary knowledge. A skeptical partner will hesitate to fully commit and, even when committed, will be likely to withdraw the support when satisfactory results are not achieved quickly (Das and He, 2006). Therefore, to reduce such skepticism and also to have a "*super partes*" evaluation, the assessment gets by an external expert (innovation broker) is considered very useful. The previous literature suggests different crucial factors to consider in the evaluation process, such as the value of technical competence/uniqueness (Yan *et al.*, 2018), the strategic importance of the technology (Tyler and Steensma, 1995), the value of the patents and know-how (Geringer, 1991).

A positive external evaluation of the value of technology and knowledge assets can reduce the skepticism both of the researchers and the industrial partners by increasing the probability to enact a co-development project. Our fourth hypothesis is:

Hp4. A positive value of technology/knowledge feasibility issued by innovation brokers increases the probability to enact a co-development process.

Similarly, different factors in the literature underline that the industry attractiveness, the probability to enter the target market and the level of potential market power are crucial points to increase the commitment into the co-development process. Consequently, since most of the time the research team lacks the competences to evaluate the market, the need for an *ex ante* evaluation from external experts requires the involvement of knowledge brokers in the assessment of the technology (technology and market potentiality) that can offer an upper parts technology and market scenario. If the assessment from the innovation broker returns a large potential market, this encourages the involvement of industrial partners, because, it reduces the skepticism into the technology development, by increasing the commitment (Tsou *et al.*, 2019). Consequently, the fifth hypothesis is:

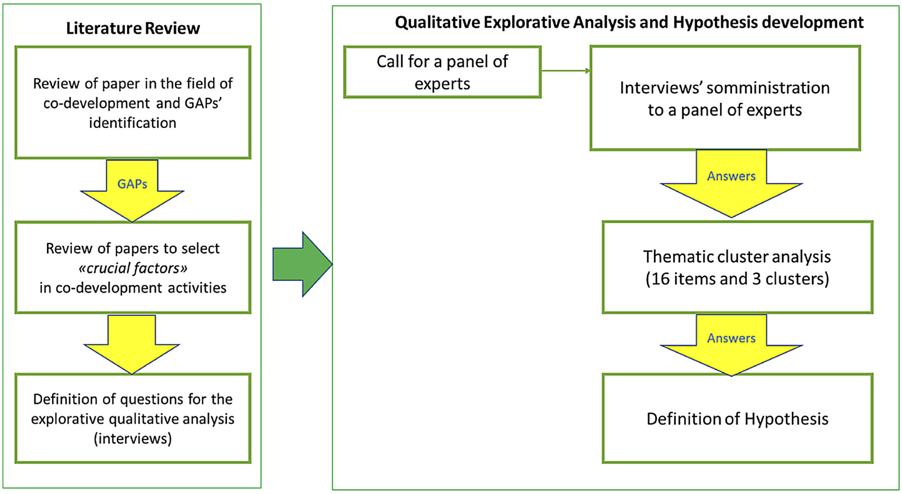
Hp5. A positive value of market applications for a new technology issued by an innovation brokers increases the probability to enact a co-development process.

The findings of the qualitative analysis formed the basis for developing a quantitative analysis and carrying out an empirical verification in which the previously identified hypotheses were tested. The process described above is shown in the following picture (Figure 3).

3. Methodology

3.1 Sample and data

To support our theoretical developments with more practical and managerial insights, we developed an empirical analysis on the participants to the proof of concept network (PoCN) [3]. PoCN is a rewarding project implemented from 2013 to 2016 and financially supported by the Italian Ministry of University and Education (MIUR), which has recognized the high impact of the project on the industrial and scientific systems (Passarelli *et al.*, 2018).



Source(s): Author's elaboration

Figure 3. The process of research: from the literature review to the qualitative analysis

The coordinator of the PoCN project is AREA Science Park, a top-level public research institution located in the city of Trieste, whose main activities are technology transfer support and the exploitation of research results. Other partners are located throughout Italy and belong either to the industrial or the research system: Netval (the Network for the Promotion of University Research); Confindustria; CNR (the National Research Council); Elettra Synchrotron Trieste SCpA; Politecnico di Torino; the University of Calabria; the University of Padua; the University of Trieste; and the University of Udine.

We consider all the population of 108 technologies involved in the POCN project and the relationships with 67 national and international companies (79% were SMEs). Since at the end of the process, according to the criteria of appropriateness and eligibility defined by the POCN's rules, only 23 proof of concepts were developed through the financial support of AREA.

The aim is twofold. From one side our analysis is to explore which are the main factors that affect the enactment of the co-development process, identified through the qualitative analysis; moreover, our analysis tests the impact of such factors on the probability for partners to enact a co-development project. The data collected were both primary and secondary. The primary data were collected by consulting the documents made available by the support of some technology transfer experts at Area Science Parks including, for example, technology description worksheets, team background, assessment scorecards filled out by experts, publications and patents.

The secondary data on firms (size, core business and localization) were mined from the ORBIS database provided by Bureau van Dijk; all information about researchers and patents was gathered by consulting specialized websites (Thomson Reuters, Google Scholar, MIUR, Espacenet).

For a better understanding of the quantitative analysis along with the related data, in the following session, we describe the PoCN process.

3.2 The proof of concept network (PoCN): a brief description

The PoCN program starts with a training activity with the technology transfer experts belonging to the partners.

The first step of the program (Phase 1) was scouting at local and national levels. Local scouting is carried out by local partners under the supervision of the AREA. Specifically, they promoted the project in the research departments of universities and institutes and later organize interviews with research teams to identify technologies with industrial potential. Each local unit then supported academic researchers in the formulation of proposals for exploiting research results. When this stage has been completed, a set of proposals was selected by a team of technology transfer experts.

At the national level, scouting was done through three calls launched by AREA. The research groups that have already been mapped and selected by the local units, and supported by a scientific advisor, submitted a formal proposal in response to one of AREA's three national calls. In their application, the scientific advisors provided information concerning their careers (including references, roles, patents, publications and collaborations with industry) and the characteristics of the technology. In all, 108 proposals are received via the three calls (this number identifies all the population included in the empirical analysis). Regarding the field of application, every scientific advisor was asked to indicate their perception about the potential application of the technology to different business units of the market or segments within a business unit (at this stage, the indication of potential application area expresses exclusively the "perception" that scientists have about their findings).

Once the candidates have been selected, the technology and market assessment phase initiated (Phase 2). AREA SCIENCE PARK set up a group of 66 experts/innovation brokers (selected in a public competition), who evaluated the proposals and produce an assessment report, based on a set of default parameters. To carry out the assessments, the group used technology foresight and business intelligence tools. Specifically, for each technology, two dimensions were evaluated: the intellectual property and the market potentiality. For the intellectual property dimension, each technology was labeled with a synthetic indicator ranging from 1 to 100, in which values from 1 to 30 indicate low potential, 31 to 70 medium potential and 71 to 100 high potential. The market assessment focused on the potentiality to be exploited into a successful product. It was considered the size of the market, the structure and the trends, the entry barriers, the competitive benefits, the time to market. Again, a synthetic indicator was used ranging from 1 to 100, in which the values 1 to 30 indicate low market potential, 31 to 70 medium market potential and 71 to 100 high market potential.

The results of the assessment process by the innovation brokers were communicated to a panel of companies. At this stage, a network of entrepreneurs, managers and technicians selected a panel of companies that may be interested in developing the technologies already designated in the previous phase.

Different activities were carried out about the promotion and presentation of proposals to firms (Phase 3). Companies (both Italian and foreign) were asked to express their interest in one or more of the proposals by completing a form available on the web platform. Companies that expressed an interest were 67. After receiving the expressions of interest, AREA's experts, using advanced rating system tools (provided by Bureau van Dijk), verified the financial strength of each company interested in co-development. Only those companies with a financial strength – rated as sufficient – were considered eligible to sign a letter of intent with a group of researchers.

By matching the values assigned to different technologies and the ratings assigned to companies, the experts create a ranking in which the technologies are classified as adequate and adequate and fundable. A technology was considered adequate if it received expressions of interest from at least one company whose financial situation was labeled as strong (only 47 are considered adequate technologies). Technology was also eligible for financing if the total score given by the panel of experts was greater than 50. According to the criteria of appropriateness and eligibility, the AREA funded only 23 technologies in the PoCN project by enacting a matching co-development process, between firms and researchers' teams (Phase 4). The scientific research results accepted by the PoCN program were the outcomes of the work of research teams led by scientific advisors.

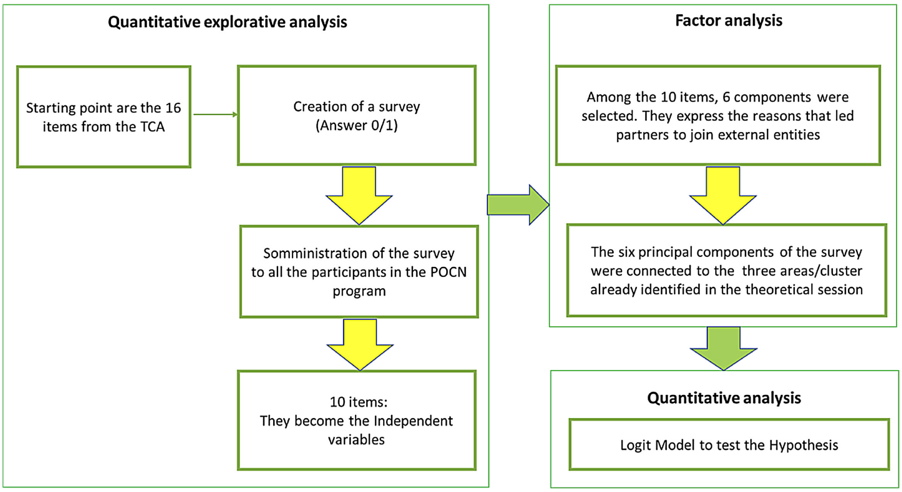
The 23 firms involved in the co-development are mostly Italian (only 4 are foreign companies). Besides, 18 of them are micro-companies or SMEs , while 5 are large companies. Only 1 is a spin-off. Most firms are between 5 and 15 years of age. Most belong to the "clean" technologies, industrial process technologies and medical technologies sectors. At this point, for each technology a co-development project was drawn up; each of them was tested and approved by the AREA experts, who also defined the amount of financing and the project champion to assign to the project.

Each co-development matching program ended with the implementation of a proof of concept, an industrial prototype after a development process shared between researchers and companies that last up to nine months.

3.3 Quantitative analysis

Since the co-development technology transfer process at the proof of concept stage is a phenomenon recently observed and still poorly understood, we focus on an exploratory analysis to obtain a better understanding of the object of study. Specifically, starting from the 16 items that come from the TCA, we created a survey with binary responses (Appendix 3). We involved in the survey, all the participants in the POCN program. The survey aimed to attempt to measure the main factors that impact on the matching between research and industrial contexts at the proof of concept stage. From the survey, we get 10 items that explain our research topic. Then we run a factor analysis to select the principal components that led each partner to join external entities. Given the binary outcome of the dependent variable, we carried out three logit models based on generalized linear model (GLM) estimation and following a cross-sectional approach. The aim is to test the three-item sections, applying the variables coming from the factor analysis. All the process is shown in the following picture (Figure 4).

3.3.1 Factor analysis. We consider a dichotomic dependent variable that is equal to 1 if the partner enacts a co-development project and is equal to 0 if not. Then, to meet our research



Source(s): Author's elaboration

Figure 4. Quantitative analysis: all the steps

hypotheses, we considered such ten items (Table 1) that we assigned into different five categories of independent variables.

The first group of empirical factors (academic patent ownership and patent co-ownership) belongs to the intellectual property category and points out whether the ownership of patents comes from the academic context or there are industrial patent applicants who co-funded the research proposal.

The second category (technology readiness and scientific reputation) focuses on the new technology readiness to the proof of concept and how the scientific community acknowledges the reliability of inventors' research activities.

The third category gives the business perspective of inventors, detecting the technical and market feasibility of the new technology. The fourth factor considers the geographical proximity between university and firms as leverage to foster their matching in the co-development process.

The last category relies upon a double external assessment issued by (1) IP experts in regards to technical feasibility and (2) industrial experts through their opinion about the industrial exploitation of the new technology.

Among these factors, we selected six components expressing the reasons that led partners to join external entities. Hence, before performing our analysis models, we screened the factor items through an explorative factor analysis based on principal components analysis (PCA), aiming to identify which driving components can explain the most variability of the surveyed items. Each component, whose eigenvalues result greater or very close to 1, ranks into the first six ones and describes the essential information of the survey. Indeed, the overall six factors express the 80% of the cumulative variation of the original ten-item survey.

The results of the factor items analysis are reported in Table 2. The first factor drives the proximity leverage section, the second and third factors embrace the external assessment section, and the fourth, fifth and sixth factors fit into the section of technology and market feasibility.

Factor	Variable	Measure
Academic patent ownership	AC_PAT	Number of patents whose applicants are only the academic inventors
Paten co-ownership	Ind_pat	Number of patents whose applicant/co-applicant is a firm
Technology readiness	TRL	Technology Readiness Level which estimates the maturity of a new technology according to European Commission
Scientific reputation	CIT	Number of citations of publications relating to the specific technology of which the team or part of it is co-author
Strategic business units perspective	SBU	Number of potential Strategic Business Units within the business, identified by inventors
Industrial exploitation and market perspective	Buss_Ass	Number of target markets of the new technology, identified by inventors
IP industrial exploitation and technology perspective	TECH AREA	Number of technical classifications related to the new technology, considered in the patent (https://www.epo.org/searching-for-patents/helpful-resources/first-time-here/classification.html)
Proximity leverage	DIS	Geographical distance (in km) between a firm and University Research Centre/Department
Technology feasibility from external assessment	IND_IP_exp	Rating issued by IP experts (innovation broker) about the feasibility of the new technology
Market external assessment	Ind_exp	Rating issued by industrial experts (innovation brokers) about the market potentiality of the technology and the sectorial competitive advantage

Table 1.
Empirical factors of survey-driven analysis

The scientific reputation and credibility of the inventors – expressed through their amount of citations by the scientific community – does not explain their marketability toward the industrial environment, showing a low eigenvalue (0.17). In addition, according to the same analysis in Table 2, even the technology readiness and patent ownership items seem not expressing the matching variable of our survey, given their weak eigenvalues.

We considered the first six principal components of our survey, embracing the three areas identified in the theoretical session:

(1) *Interactive* factor of the entities involved in co-developing [DIS],

(2) *Exogenous* factors issued by outsider evaluators (innovation brokers) [IND_IP_exp, IND_exp] and

(3) *Endogenous* factors [SBU, Bus_Ass, Tech_Area].

We summarized in Table 3 all the variables of the study, the underlying measurements and the related research hypotheses; whilst Table 4 describes the statistics of industry-university matching as well as its factor variables.

Surveyed items	Eigenvalue	Difference	Proportion	Cumulative
Dis *	2.13	0.47	0.21	0.21
IND_IP_exp *	1.66	0.46	0.16	0.37
IND_exp *	1.19	0.03	0.11	0.49
Bus_Ass *	1.16	0.08	0.11	0.61
SBU *	1.07	0.26	0.10	0.72
Tech_Area *	0.81	0.12	0.08	0.80
TRL	0.68	0.07	0.06	0.87
Ind_Pat	0.61	0.13	0.06	0.93
Ac_Pat	0.48	0.30	0.04	0.98
Cit	0.17	0.00	0.01	1.00

Note(s): *identifies factor items applied to research analysis

Table 2. Factor analysis – principal-component factor

Level	Label	Proxy	Measures	Hypothesis
Dependent variable				
	Matching	Industry–University interaction	0.1	
Factor variables				
Interactive	Dis	Is a proxy of the geographical distance	Km (ln)	Hp3
Exogenous	IND_IP_exp	Is a proxy of the technology Feasibility level issued by external innovation brokers	1–100 scale (ln)	Hp4
Exogenous	IND_exp	Is a proxy of market applications level issued by external innovation brokers	1–100 scale (ln)	Hp5
Endogenous	Tech_Area	Is a proxy of the commitment of the research team, related to the trust into the number of potential technology fields	No	Hp1
Endogenous	SBU	Is a proxy of the commitment of researchers related to the applicability of technology (in different segments within a specific business unit where the new technology will be deployed)	No	Hp2a
Endogenous	Bus_Ass	Is a proxy of the trust of the research team in the dimension of the market (where the technology can be exploited)	No	Hp2b

Table 3. Variables description and measurement

Variables	N. Obs.	Mean	Standard Dev.	MIN	MAX
Dependent variable					
Matching	108	0.36	0.48	0	1
Factor variables					
Dis	108	1.33	2.30	−2.30	7.36
IND_IP_exp	108	4.06	0.37	3.09	4.59
IND_exp	108	4.22	0.23	3.55	4.60
Bus_Ass	108	1.18	0.49	1	3
SBU	108	1.19	0.52	1	3
Tech_Area	108	2.01	1.57	1	12

Table 4.
Descriptive statistics

3.3.2 The logit model and the main results. Given the binary outcome of the dependent variable, we carried out three logit models based on GLM estimation and following a cross-sectional approach, whose formulation is described in Table 5. The aim is to test the three-item sections, applying the variables coming from the factor analysis. Hence, we aimed at analyzing contingencies in a more complex causality relationship, to explore the matching practices in a multi-stage complementary context, based on a wider perspective and by testing contextually several variables.

Specifically, we developed three regression models basing on factor items of Table 2: (1) in model 1 we measured the impact of the "interactive" factor of the entities involved in co-developing [DIS]; (2) in model 2 we verified the effect of "exogenous" factors issued by outsider evaluators [IND_IP_exp, IND_exp]; and (3) in model 3 we explored how "endogenous" factors can affect the interaction between universities and firms [SBU, Bus_Ass, Tech_Area].

We ran the equations in Table 5 from model 1 to model 3, gathering significant parameters as reported in Table 6. In addition, we applied to our analysis the *White-Huber correction* in order to avoid a biased estimation due to the inconsistency of standard errors' heteroscedasticity. We do not take into consideration control variables, given that we based our study on a multi-stage analysis, testing the factors' odds ratios for each stage and checking how the models' goodness (Δ Adj. R^2) improved, once we move from one stage to the next one.

The findings from model 1 to model 3 show strong empirical evidence, taking – stage by stage – the impact of each category of factor items on the matching probability. The empirical analysis shows that some research items affect significantly the interaction between industry and university.

The regression analysis of the factor related to the *interactive dimension* points out that the matching is significantly and positively affected by geographical dimension (i.e. Dis). This implies on one hand that the higher is the geographical distance among academics and

Models[1]	Models formulation[2]
Model 1	$\text{Log}\,[\text{Pr}_i/(1\text{-Pr}_i)] = \alpha + \beta_1\,\text{Dis}_i + \varepsilon_i$
Model 2	$\text{Log}\,[\text{Pr}_i/(1\text{-Pr}_i)] = \alpha + \beta_1\,\text{Dis}_i + \beta_2\,\text{IND\_IP\_exp}_i + \beta_3\,\text{IND\_exp}_i + \varepsilon_i$
Model 3	$\text{Log}\,[\text{Pr}_i/(1\text{-Pr}_i)] = \alpha + \beta_1\,\text{Dis}_i + \beta_2\,\text{IND\_IP\_exp}_i + \beta_3\,\text{IND\_exp}_i + \beta_4\,\text{Bus\_Ass}_i + \beta_5\,\text{SBU}_i + \beta_6\,\text{Tech\_Area}_i + \varepsilon_i$

Note(s): [1]A logit regression is underlying each model
[2]In the notation, "Pr_i" is equal to "$\text{Pr}\,(\text{MATCHING}_i = 1 \mid x_i)$"

Table 5.
Logit models formulation

Factor variables	Model 1 Odds ratios[1]	Model 2 Odds ratios	Model 3 Odds ratios
Dis	6.58*	4.32**	4.26***
IND_IP_exp		1132.79***	1225.20****
IND_exp		8.95	11.91
Bus_Ass			0.94
SBU			8.01***
Tech_Area			0.12***
Constant	0.10****	0.0015****	0.00025****
No. obs.	108	108	108
Wald test χ^2	3.08*	35.80****	44.34****
Adj. R^2	0.60	0.74	0.77
Δ Adj. R^2	0.60	0.14	0.03

Note(s): *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, ****$p < 0.001$
[1]The odds ratios are estimated through a robust analysis (*Huber-White Sandwich* estimator). Because it is a logit method, the odds ratios are calculated as exp *(β)* and replace in the table the β coefficients for a better interpretation of the effects of the independent variables
[2]Overall estimation testing all research hypotheses simultaneously

Table 6. Logit regression analysis of predictors, co-development between academics and practitioners toward a proof of concept

industrial partners, the greater is the matching probability to co-develop innovation. Then, given the innovation process in the phase of applied research, it is not important for a partner to be in the same territory, but other factors matter (Hp3). Accordingly, for example, to Ombrosi *et al.* (2019, p. 611), "*the commitment to the relationship among the mechanisms needed in developing trusting OI relationships*" is a very crucial factor. Moreover, for what concerns the relational dimension, a lot of researchers highlight that co-development "*often occurs in trustful long-term relationships when a fruitful match is found*" (Lehtimäki *et al.*, 2018, p. 1). In the co-development step to generate a proof of concept, codified knowledge is higher than tacit knowledge. Then, as suggested by Yakhlef (2005, p. 231): "*The more companies able to codify the knowledge underlying certain activities into tools, the more outsourceable to customers or partners these will tend to be. Codification enables information and knowledge to circulate between producers and consumers. This way, codification will speed up the process of transferring explicit knowledge from consumers to companies and vice-versa*".

Concerning with the second model of *exogenous variables*, the measure of market applications issued by external innovation brokers and related to the market potentiality of the technology and to the sectorial competitive advantage (i.e. IND_exp), appears in models 2 and 3 with an unknown effect, not supporting the fifth research hypothesis (Hp5). The analysis of the *exogenous* dimension, related to the role of external innovation brokers, shows that an external positive evaluation of intellectual property value and technology feasibility (novelty, patentability, etc.) – issued by external experts (IND_IP_exp) – significantly increases the commitment of firms and researchers in joining proof of concept exploitation (Hp4).

Going to the last logit model, at the *endogenous-level*, hypothesis 2b (Hp2b) dealing with the trust in the dimension of the market (where the technology can be exploited), perceived by the research group (i.e. Bus_Ass), has an unknown effect in models 3. Moreover and with respect to the same factors category, the first hypothesis (Hp1) is related to the trust of the research team into the specific IP potentiality of the technology (i.e. Tech_Area); and the hypothesis 2a refers to the commitment of researchers regarding the scalability of technology across different segments within a specific business unit where the new technology will be deployed. Our remarks in model 3 show that the trust of the research team into the new technology seems to inhibit the matching probability, being the odds ratio significant and lower than 1; whilst the business commitment of research team (i.e. SBU) can foster the co-development process between academics and firms, supporting the hypothesis 2a (Hp2a).

Overall, model 3 has a foreseeable and high level of significance ($p < 0.001$) as well as a non-negligible value in explaining the matching variability, given the higher adjusted goodness of the overall estimation ($R^2 = 0.77$). Therefore, the first two factors impact immediately and significantly on the matching probability (Model 1 and Model 2), explaining the most variability of our study on the second stage.

4. Limitations of the study and suggestions for future research topics

Although the paper analyses in deep the first proof of concept project implemented in Italy, by focusing on the whole population of 108 technologies, the development of the empirical analysis on a specific project within a single country represent a limitation. Therefore, further studies should focus on a larger panel of proof of concept experiences across countries.

5. Conclusions

From the analysis of the literature comes out the opportunity to deeply investigate which factors encourage the co-development process between researchers and SMEs, in the proof of concept stage. This represents a critical stage where the probability to fail is very high. Then, researchers and firms can get the opportunity to work together and co-create a new technology or a new product, as well as a new process, to validate (proof) scientific results (concept) from the very early stages of the innovation process (*proof of concept models*) (Munari *et al.*, 2017; Garengo, 2019). Co-development requires each partner, specific knowledge, competences and skills, thus a mutual evaluation (Wang *et al.*, 2016) among partners is spurred. From this perspective, the empirical analysis had the purpose to identify which are the crucial factors evaluated by researchers and firms, that encourage collaboration from the preliminary stage of development.

From a theoretical perspective, this paper tested some hypotheses and provided directions to scholars interested in the study of the co-development innovation process in the proof of concept stage. To accomplish these aims, we adopted an empirical mixed method with a qualitative-quantitative analysis.

The results can suggest some implications for all the innovation systems (researchers, firms and policy makers) asked to invest in some crucial assets.

The trust of scientists in the potentiality of their technologies needs to be channeled and supported in applied research by their parent organizations, to increase academics commitment in collaborating with firms (Schulze-Krogh and Calignano, 2019). In doing so, they should exploit the research outcomes out of the ivory towers, meeting companies that are interested in collaborating with public research. Indeed, once the researchers are aware of all possible applications of their technology and they know the high level of scalability of the technology, they increase their commitment to the collaboration process. On the other side, companies, become more interested in developing a powerful technology.

Another relevant factor to be evaluated is the typology of knowledge offered by the partners and the locus where technology is shared. The empirical analysis shows that the higher the physical distance between partners the greater the matching probability. It comes out that rather than focus on local proximity, in the proof of concept development, it is important to focus on social and cognitive proximity (Breschi and Lissoni, 2009). Costabile (2000), for example, highlights the importance of relational closeness, based on the interconnection of relationships between heterogeneous stakeholders as a vehicle for the generation and dissemination of innovation. To develop innovation, SMEs, research centers, universities and other institutions must work together to form an open network.

The success of a co-development process between researchers and companies at the embryonic phase of the technology considers the opportunity to exploit the technologies into real products for the market. Technology is the core resource in the co-development process; therefore, firms look for a scientific partner with a high level of commitment due to the high level of perceived technology potentiality. Since it is difficult for a researcher to make a complete assessment (especially about the market), the involvement of an external innovation broker is crucial for an "*ex ante*" and "*super partes*" evaluation of the technology. Such a positive evaluation of the factors related to the technology, such as the technology turbulence and the technology perspective/foresight, offer to the partners clear feasibility of a specific technology. On the contrary, our analysis highlights that there is not any relevance of positive external market analysis. The findings suggest also several implications especially for the research system and the policymakers.

Since the quality of applied research is strictly related to basic research, universities have to invest in top scientists. This is related to the strategic orientation of the university. In fact, according to Giuri *et al.* (2019), prestigious research tends to facilitate the creation of a wide and robust pool of technologies available for commercialization, increasing the propensity of researchers to exploit their inventions and capture the income flows generated through their intellectual capital (O'shea *et al.*, 2005).

With the diffusion of the proof of concept models, also the strengthening of the technology transfer office (TTO), are becoming even more crucial in the universities. They are called to explore the university bundle of research results, to make a previous assessment, by choosing the best in class for the applied research. The TTOs must offer the researchers' assessment support; specifically, they have to propose the assessment reports to identify the potential of the technology in terms of sectorial, market and intellectual property feasibility. Moreover, they must alert researchers on the technology transfer opportunities, on firms' innovation requirements, on the potential market needs along with the potential networks' creation. Therefore, along with the traditional activities, the TTO is called to give support in terms of assessment. Then, the hiring criteria for TTO employees require new competencies, with strategic and management backgrounds. Furthermore, the educational university system should propose to scientists, *ad hoc* educational programs to enhance the competences of researchers on technology transfer, management of technology, intellectual property rights and strategy.

Policymakers should explore the opportunity to invest in POC programs. A synergic collaboration in the proof of concept process, where a co-creation process among heterogeneous actors is enacted, can offer advantages to all the actors involved. The research team can have the advantage to persist in its core mission by keeping its research soul with high-level performance while at the same time it can become more and more conscious of market and industrial needs. On the other side, SMEs can develop new products and processes through cooperation with experts having a strong scientific competence, offering specialized skills that are not available internally.

Notes

1. The main criteria used for paper selection in Scopus dataset were the followings: TITLE-ABS-KEY ("co-development" AND "partner") AND (LIMIT-TO (SUBJAREA, "BUSI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (EXACTKEYWORD, "Co-development") OR LIMIT-TO (EXACTKEYWORD , "Innovation") OR LIMIT-TO (EXACTKEYWORD , "Open Innovation")) AND (LIMIT-TO (LANGUAGE, "English")).
2. Since in the qualitative research reflexivity is a crucial issue throughout all phases of the research process, one goal is to monitor the reflexivity effects. To enhance both the accuracy of the research and "the credibility of the findings by accounting for researcher values, beliefs, knowledge and biases" (Cutcliffe, 2003, p. 137) and research's trustworthiness (Buckner, 2005), we involved an

eternal interviewer. Moreover, we compared the analysis of the content by all the researchers involved in the paper.

3. We propose the analysis of POCN experience, as the first multisector national project on POC, in Italy and supported by the MIUR. The empirical analysis considers all the population of technologies, not just a self-selected sample of technologies.

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Appendix 1
Questions for the interview to experts

(1) What do you think about the co-development process for your firm/research group?

(2) How is important the co-development of technology between a firm and a research team?

(3) How is important to have the collaboration of a "complementary partner" in a development of a new process or product?

(4) Do you agree if we try to formulate a definition of proof of concept as "the process by which the matching between research and industrial systems occurs in the early stages of the innovation process (mainly basic and applied research)".

(5) What is the difference between traditional models of technology transfer (demand pull and technology push) and co-development?

(6) Do you agree if we associate co-development process with "researchers and teams' characteristics" (reputations, value, commitment, propensity, etc.).

(7) Do you agree if we associate co-development process with the characteristics of technology (TRL, intellectual property, patent, etc.)?

(8) Along with researchers' features, teams' characteristics, technology's peculiarities, what else can you suggest (at least 3 more items, please)?

(9) As long as you decide to be involved in a co-development process with a firm, which of these variables influences your decision:

Driver	Value (1 = very low to 5 = significant)
Scientific reputation	
Propensity of researchers to applied research	
Proximity of technology to the market	
Level of technology feasibility	
Intellectual property value	
Geographic distance between partners	
Relational distance between partners	
Skepticism/commitment of researchers	
Market potentiality	
Intellectual property potentiality	

Table A1.

Appendix 2

n	Items	Description
1	Academic patent ownership	We want to collaborate with scientist having applied research competences
2	Patent co-ownership	We want to collaborate with scientist that have previous relations with firms
3	Technology readiness	The level of readiness of the technology is very important
4	Scientific reputation	We want to collaborate with scientist having a high level of Reputation in the scientific community
5	Strategic business units perspective	We want to collaborate with scientists that are aware to develop a technology with market and industry appeal
6	Industrial exploitation and market perspective	We want to collaborate with scientists that are a low level of skepticism in terms of target market to penetrate. They have to trust into the technology
7	IP industrial exploitation and technology perspective	We want to collaborate with scientists that develop technology for different technological areas
8	Feasibility of IP	We want to collaborate with scientists that develop technology with real intellectual property novelty
9	Academic patent novelty	Collaboration with scientists that are devoted to the research activity and that are able to make discovers on the frontier of the science is important
10	Scalability	Scalability of technology and number of applications
11	Strategic applications	The technology should have different applications in different business unit
12	Market perspective	Trust of the scientists in the market potentiality of the technology to answer several market needs
13	IP industrial exploitation	Commitment of the researchers about the potentiality of a technology
14	Feasibility from external assessment	We want to collaborate with scientists that satisfy the real needs of the market, by offering new products embedding frontier technologies
15	Market external assessment	I want to be sure about the Novelty of technology for the market and the potentiality of the market and the competitive advantage
16	Proximity leverage	We can collaborate to develop the applied research that can be controlled at a short distance

Table A2.
Items from thematic cluster analysis

Appendix 3

n	Items	According to your experience, say which of these items is necessary to create a collaboration at the proof of concept stage (Yes = 1; No = 0)
1	Academic patent ownership	
2	Patent co-ownership	
3	Technology readiness	
4	Scientific reputation	
5	Strategic business units perspective	
6	Industrial exploitation and market perspective	
7	IP industrial exploitation and technology perspective	
8	Feasibility of IP	
9	Academic patent novelty	
10	Scalability	
11	Strategic applications	
12	Market perspective	
13	IP industrial exploitation	
14	Feasibility from external assessment	
15	Market external assessment	
16	Proximity leverage	

Table A3.
Survey for POCN's participants

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