The role of Proof-of-Concept programs in facilitating the commercialization of research-based inventions

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Abstract

In order to overcome the factors that limit the commercialization of embryonic research-based inventions (RBIs), a growing number of universities are resorting to Proof-of-Concept programs (PoCs). Although previous literature underlined the effectiveness of these programs in favoring the commercialization of RBIs, it is not yet clear what the mechanisms introduced by PoCs that enable this process are. In this paper, we seek to fill this gap with an in-depth case study regarding 12 PoC projects originating from an Italian technical university. Our results show that PoC programs create three classes of interconnected enablers (i.e., relational, structural and cultural) able to integrate inside-out and outside-in processes, and to mitigate the dichotomy between formal and informal technology transfer (TT) tools. Although only relational enablers promote the commercialization of RBIs directly, structural and cultural enablers contribute to the TT process by reducing the inhibiting effects on the commercialization of RBIs that organizational and intra-individual factors exert. Moreover, structural and cultural enablers apply a reinforcing effect on relational enablers, which facilitates the approach to industrial stakeholders by academics. We advance a new vision of the PoC as an integrated tool with a precise structure rather than a standalone instrument and we discuss implications on how universities could harmonize research and commercialization activities, shifting their TT approaches from transaction-driven to relation-focused.

1. Introduction

Despite the widespread efforts that national and regional authorities have made to develop Technology Transfer (TT) activities in order to facilitate the flow of knowledge from universities to industry, university research-based inventions (henceforth referred to as RBIs)[1] often remain far from industrial application and commercial exploitation (Passarelli et al., 2018). In fact, most of the research conducted at universities does not undergo any significant TRL[2] advancement and largely

[1] In this paper, we use the term RBI to refer to any invention, product, process or new technology that has been discovered through university research.

[2] Technology Readiness Level (TRL) is a measurement system that is used to assess the maturity level of a technology. It is based on a scale consisting of nine levels, each of which characterizes the progress made in the development of the technology. TRL 1 is the lowest (the idea) and TRL 9 is the highest (full deployment of the product in the marketplace). It was introduced by NASA for the first time in 1973 and has been certified, by ISO 2013, as a standard for evaluating technology maturity.

remains within their boundaries (about 75% of the total amount, according to Swamidass (2013). TRL advancements are crucial to transform university research into commercially viable products and technologies (Kirchberger and Pohl, 2016).

A growing number of universities throughout the world are now oriented toward the commercialization of research results and have incorporated the so-called "Third Mission" (Lockett and Wright, 2005; Wright and Phan, 2018). Despite a significant amount of effort and the introduction of new metrics, the "best practices" in TT remain limited and circumscribed to a bunch of top-tier universities. This picture reflects a state of the art that has consolidated the identification of the inhibitors to the development and commercialization of RBIs (Balven et al., 2018), but has ignored the detailed mechanisms that enable such a commercialization by universities.

Previous literature highlighted the presence of several types of inhibitors pertaining to academic entrepreneurship and, more indirectly, to university-industry TT (Ankrah and AL-Tabbaa, 2015; Ramos-Vielba et al., 2016). From this, it has emerged that one of the barriers to TRL enhancement and to the effective commercialization of RBIs is a lack of funding sources that allow inventions to be developed to a point at which they can be commercialized successfully (Benner and Sandström, 2000; Lockett and Wright, 2005; Munari et al., 2016). The inability to enhance the TRL of RBIs originates the so-called "valley of death" (Auerswald and Branscomb, 2003). The embryonic nature of university-generated inventions, and the difficulty of evaluating their applicability and industrial potential generate considerable risks for their industrialization and commercialization, which obviously limit the opportunities to attract external financing sources (Munari et al., 2018; Perkmann et al., 2013). Additional hurdles to TT concern the lack of commercial and managerial competences of university researchers, as well as the presence of communication gaps that may arise between researchers and the industrial or financial counterparts (Franklin et al., 2001; Munari et al., 2016).

In order to develop new mechanisms aimed at increasing the TRL, and thus the level of technology maturity and investment readiness of RBIs, a growing number of universities have

recently introduced Proof-of-Concept programs (henceforth referred to as PoCs[3]) (Darcy et al., 2009; Munari et al., 2018). The push toward the introduction of PoC programs in universities has reflected the efforts made by several Technology Transfer Offices (TTOs) both within and outside Europe, which have often been endorsed with the establishment of clear-cut national programs. The ultimate goals of a PoC is to bring an RBI close enough to a point at which it can be successfully commercialized (e.g. licensed to external industrial partners or sold), to raise the interest of investors and/or to fuel the growth of a spin-off (Bradley et al., 2013a; Gulbranson and Audretsch, 2008). The debate about PoCs as instruments that favor the commercialization of RBIs has centered upon the recognition of this tool as a standalone instrument in the hands of university TTOs.

Although prior studies have advanced our understanding of the different architectures that underlie the structuring of PoCs and the role played by public bodies in their design and implementation, the analysis of the micro-mechanisms induced by PoCs to favor an increase in TRL is still an under-researched dimension. Thus, the unique angle we have adopted in this paper is to investigate how and through which micro-mechanisms PoCs create enablers that mitigate the effects of inhibitors on the commercialization of RBIs identified in the extant literature. In this vein, we advance a new vision of the PoC as an integrated tool, rather than a standalone instrument, which hinges on a bunch of both formal and informal activities run by the TTO that harmonizes the university research policies.

Clearly, some research groups may be able to capitalize on their networks and approach the outside market to commercialize their RBIs without the help of structural elements like a PoC. However, the argument that we intend to put forward in this paper is that universities can make TT

[3] In this article, we consider a PoC as being a small, funded project (usually in the range of 50k) with the aim of testing the key aspects of an RBI in universities or research centers. The main purpose of developing a PoC is to demonstrate a functionality and/or to verify a certain concept or theory that can be developed. A PoC is therefore designed to determine feasibility and does not represent a commercial deliverable.

more systematic by building an overarching infrastructure around the PoC that is capable of creating a set of enhancing mechanisms that are responsible for boosting the commercialization of RBIs. We therefore depart from the idea of the PoC as a standalone tool, conceived exclusively to channel financial resources to promising RBIs, toward a more thorough conceptualization of the PoC as an instrument which is part of an integrated organizational infrastructure headed by the TTO. This is a relevant issue, from the policy perspective, because it drives decisions in universities about whether it is more efficient to allocate specific funds to a PoC as a standalone tool or to allocate both financial and organizational resources to create an infrastructure that amplifies the capacity to commercialize research outcomes. In this paper, our research question concerns this latter dimension, which is related to the mechanisms that characterize this infrastructure and that enable researchers to advance the TRL of their RBIs. In order to respond to this research question, we have focused on an embedded case study (Yin, 2017) within the context of a single university (i.e., the Politecnico di Torino, Italy). Our results show that PoC programs favor the creation of three classes of enablers (i.e., relational, structural and cultural). Only relational enablers have a direct positive impact on the commercialization of RBIs, while structural and cultural enablers work in an indirect way: they mitigate the impact of organizational and intra-individual inhibitors to TT and exert a reinforcing effect on relational enablers, which facilitates the approach to industrial stakeholders by academics.[4]

Our paper contributes to the literature on TT and on the commercialization of RBIs in the academic context in three main respects.

First, we take a step forward by revealing the mechanisms that enable the TRL enhancement and commercialization of RBIs in universities. Literature has surprisingly remained silent on this topic, even though the elements related to the contingent effectiveness model of TT (Bozeman, 2000; Bozeman et al., 2015) have been both theoretically and empirically investigated. In our study, we

[4] An enabler is meant to exert a direct effect on the commercialization of RBIs when it operates as a standalone factor; it is meant to exert an indirect effect when it operates jointly with other enablers.

complement this perspective by showing how the design of PoC programs influences the strategies and competences of universities to enhance the TRL and the commercialization of RBIs.

Second, we provide a specific contribution to the emergent literature related to PoCs (Munari and Toschi, 2021; Munari et al., 2017; Rasmussen and Sørheim, 2012) and, more in general, to "gap-funding" instruments (Munari et al., 2016). Despite the previous research, our understanding of the processes (both formal and informal) that are activated by PoCs and of their effectiveness in smoothing the obstacles faced by researchers in developing and commercializing their RBIs remains limited.

Third, our research demonstrates the role that PoCs play in creating "inside-out" processes, incentives and motivation within universities. Our findings amplify the dominance of aspects related to the creation of relational linkages and reputation, compared to mere funding. The prevalence of relational enablers over other typologies of enablers indicates that PoCs create a commercialization system which is more relational-based and inside-out than transaction-based and driven by investors (Weckowska, 2015). These "inside-out" processes rely on the management and internalization of relational and informal activities within universities that TTOs cannot manage alone, due to the complexity and plurality of the necessary knowledge domains. In this sense, we show that a gap in funding, although representing a significant element that can harm the commercialization of RBIs, is not the primary reason for commercialization problems. Finally, we highlight important implications concerning how the mechanisms of TT funding should be designed by universities and policy makers.

The remainder of this paper is organized as follows. We proceed by illustrating the conceptual background in Section 2. Section 3 illustrates the structure of a PoC. Section 4 introduces the research context. Section 5 describes the methodology. Section 6 presents the results. Finally, in section 7, we discuss the implications of our findings and we draw our conclusions.

2. Conceptual background

2.1 The origins of the problems underlying the commercialization of RBIs

The commercialization of RBIs constitutes a relevant component of the activity of modern universities (Lockett and Wright, 2005; Wright and Phan, 2018). Scholars are expected to turn their research outcomes into products or processes that address the practical needs of firms to increase their competitiveness by leveraging on cutting-edge technologies (Perkmann et al., 2013). In addition, the competition on research activities, the complexity and cost of conducting research and the limited sources of funds available for research pose new challenges on how to exploit the RBI developed in universities effectively.

The complexity of developing a technology and moving it forward on the TRL scale, coupled with the need to develop multi-layered competences, poses significant challenges for university researchers. Uncertainty and risk underpin the problems that universities face in commercializing RBIs, as investors prefer to invest in proven technologies with relatively low uncertainty and whose market risk can be managed (Rasmussen and Sørheim, 2012). For this reason, uncertainty and risk are among the first causes that limit the financing of research and keep private investors away from providing the necessary funds to turn an RBI into a real innovation (Miller et al., 2018). The consequence of such a dearth on managing risk and uncertainty is clearly depicted in what has often been referred to as the 'valley of death' (Auerswald and Branscomb, 2003), which refers to the resource gap needed to develop basic research into commercial applications.

The relevant question is therefore: how can universities best manage the risk and uncertainty associated with RBIs in a systematic way? In this context, universities and policy makers have developed targeted actions and policies to foster TT between university and industry. First, since the Bayh-Dole Act, universities have had the responsibility of the so-called "Third Mission" (Mowery et al., 2001). TTOs have been established in almost all universities throughout the world (Mowery et al., 2001) with the aim of promoting research commercialization. Second, greater emphasis has been put on academic entrepreneurship (Grimaldi et al., 2011), with an extension of the focus of researchers from patenting and licensing their research results toward the creation of spinoffs

(Schmitz et al., 2017). All these actions have been set up from the perspective that commercialization activities follow a linear path, based on a sequence of transactions between university researchers, TTOs and firms on the market (Weckowska, 2015).

Despite these remarkable efforts, more than twenty years of activities have not provided the expected results. Although some metrics have been identified and a few "best practices" have emerged, there are still some tight knots left to untangle. For example, although statistics indicate a growth in patenting, several patented researches still remain on the desks of TTO managers (Swamidass, 2013), and concerns about spinoffs – although growing in terms of number of firms created (Wright et al., 2007) – have been raised regarding their impact (Grimaldi et al., 2011) and survival (Prokop et al., 2019). This is because most commercialization actions require the assessment of the value of the technology on a downstream product market (Bercovitz and Feldman, 2006). This process is relatively difficult for researchers and TTO staff, due to a large degree of uncertainty and risk that is hard to mitigate. In fact, giving a value to knowledge is very difficult and complex (Ndofor and Levitas, 2004), with this complexity being greater for basic research and lower for applied research (Bercovitz and Feldman, 2006). For this reason, many universities approach firms directly to sell their RBIs, asking them to buy technologies and patents realized as if they were "off-the-shelf" products. This practice has put in doubt the detachment of scientific knowledge from market knowledge, and has encouraged the view that the commercialization of RBIs can be improved through a set of transactions among multiple stakeholders (Weckowska, 2015). Thus, universities have been spurred to design new "inside-out" instruments - with the aim of developing the market fit of RBIs- instead of "outside-in" logics aimed at channeling funds to researchers to improve the technicalities of their RBIs, leaving the duty of promoting them to firms to the TTO. In such a perspective, PoCs were conceived as instruments to bridge university research outputs with the requirements of the potential application fields (Maia and Claro, 2013).

2.2 The nature of obstacles to the commercialization of RBIs within universities

Although risk and uncertainty are among the primary causes that limit the commercialization of RBIs, the current TT literature has highlighted a more nuanced picture concerning the factors that inhibit the commercialization of RBIs. Several studies have shifted the focus of the research commercialization problem from an organizational to an individual-organizational level (Balven et al., 2018) by recognizing the key role played by individuals (especially researchers) in the commercialization process of RBIs. The aim of this shift has been to understand the micro-mechanisms that hamper academics from commercializing their discoveries. Several perspectives have been advanced on the way such factors interact and are interrelated (see Perkman et al., 2013 for a review) and multiple causes for the hampering of research commercialization have been identified (Blind et al., 2018; Davey et al., 2016; Jung et al., 2015). The commercialization of RBIs is in fact a multi-level phenomenon (Lee and Stuen, 2016; Perkmann et al., 2013) which is characterized by the interaction of individuals (i.e. the researchers), organizations (i.e. universities and firms) and institutional factors (i.e. governmental and university-related policies, market characteristics and the regulatory framework).

This complex portrait makes it difficult to identify the real set of causalities among the barriers to research commercialization. Previous literature (Ambos et al., 2008) highlighted that the tensions that limit the commercialization of RBIs are more salient at the individual level (i.e. researchers) than at the organizational level (i.e. universities). Interestingly, the way such tensions arise originates from the interaction of the researchers with the organizations and with the policies they are subject to.

Balven et al. (2018) identified three levels at which such tensions may take place. The first one is the intra-individual level, where processes are "*self-contained within the individual" (p.23)* and are associated with the phenomena that shape the behavior of a researcher. The second one is the relational level, which accounts for the set of interactions between researchers and other actors, such as entrepreneurs, industry stakeholders and investors. The third one is the organizational level, which

constitutes the set of interactions between the university, the public policies and the researchers. These levels generate a set of factors that inhibit the commercialization of research.

At the organizational level, for instance, the search for resources is one of the most important tensions. In this vein, Bozeman and Gaughan (2007) found that academic researchers with research grants and contracts are more likely to work with firms, in terms of intensive or extensive margins of collaboration. Several problems may also arise as the result of a detachment between academics and firms, as they pursue different objectives in their work. Bekkers and Boda Freitas (2008) highlighted the significant role of the knowledge content of university inventions in creating a structural barrier to TT. In this sense, the tacitness, systematicness and radicality of the technologies developed within universities often keep firms distant (Gümüsay and Bohné, 2018).

Tensions at the relational level may arise on the faculty side, as scholars may fear losing academic freedom, as well as the control and (intellectual) property on their research. Moreover, this may also occur on the industry side: as firms do not perceive the usefulness of a given research, they may not be able to integrate it within their activities or they may simply not believe in the capacity of the university team (Barbolla and Corredera, 2009). Although most tensions arise between a university, its faculty and firms, some studies have pointed toward inhibiting factors that may arise due to frictions among academics within the same university. Blumenthal et al. (1997), for instance, showed that faculty members -in their collaboration with firms- are more likely to restrict and terminate their relationships with colleagues, probably in an attempt to protect their interests with such firms.

At the same time, a "snowball effect" (in terms of additional industry contracts) may lead to research teams securing grants from firms and further boosting research commercialization. This phenomenon occurs in particular through a relational channel. Bozman and Gaughan (2007) found that scientists that resort to contracts with industry are more likely to collaborate with firms.

Finally, even tensions at the individual level may originate inhibitors to the commercialization of RBIs. Collaborations with industries often represent a discretionary choice for academics (Tartari and

Breschi, 2012), and their perception of the contingent benefits and drawbacks connected to the commercialization of RBIs may create cultural bias among them. Haeussler and Colyvas (2011) found that scientists perceive the importance and value of research commercialization in different ways. This happens as commercialization and publication activities are associated with different levels of reputation within academia and, since scholars operate within universities, they prefer to publish (Sauermann and Stephan, 2013). Similarly, Larsen (2011) showed that basic research is often cited more than applied research, and this does not facilitate academics in moving toward commercialization, as applied research is perceived to be less "remunerative" from an academic esteem perspective.

2.3 The PoC as an instrument to favor TT and research commercialization

PoC programs are among the institutional arrangements that universities are currently setting up to support translational research and to direct research toward real market needs. PoC programs have recently been endorsed in public policies throughout the world (e.g. the StartUp America Initiative, the EU Horizon 2020 Framework, ERC Proof-of-Concept grants, the Blockchain Technology Verification (PoC) Support Project in Korea; MISE PoC program in Italy; TNUFA in Israel). They are characterized by a combination of money, industrial liaisons, expertise and (sometimes) training initiatives, which are aimed at validating the technical and commercial feasibility of RBIs. This, in turn, helps to lower the technological risk of embryonic innovations, to increase their attractiveness for potential industrial partners and investors (i.e., to reduce the uncertainty related to the RBI), and, ultimately, to foster their transformation into successful industrial applications (Darcy et al., 2009; Munari et al., 2018)[5].

Despite their relative diffusion in the United States and in Europe over the last few decades and their importance for society, the mechanisms embedded in PoC programs have so far been the subject

[5] PoCs are also labeled as translational funds, proof-of-principle funds, pre-seed funds, verification funds, maturation programs, innovation grants and ignition grants (Munari et al., 2016).

of limited attention by academic researchers (Kochenkova et al., 2016). Most of the available studies are basically descriptive or are based on anecdotal evidence (Bradley et al., 2013a; Gulbranson and Audretsch, 2008; Maia and Claro, 2013; Passarelli et al., 2018; Rasmussen, 2008; Rasmussen and Sørheim, 2012). These studies describe how these measures are structured and the role played by public bodies in their design and implementation, and they have evidenced the presence of a great variety of possible solutions and architectures. For example, Rasmussen and Sørheim (2012) classified governmental financial programs in six countries into PoC, pre-seed and seed funding schemes, according to their principal goal. Gulbranson and Audretsch (2008) identified the conditions that determined the creation of two PoC centers and discussed their differences in terms of budget, initial funding, number of funded proposals and type of service provided. Maia and Claro (2013) described the critical role that a PoC plays in a university ecosystem, by looking at the case of the University of Coimbra (Portugal). Bradley et al. (2013) and Hayter and Link (2015) described PoC centers in the US, while Passarelli et al. (2018) illustrated the case of a PoC network in Trieste (Italy), financed by the Italian government.

A few other works have provided multi-country comparisons of PoC initiatives (Munari et al., 2018, 2017, 2016). Munari et al. (2017) described seven case studies of university-oriented PoCs in Europe. Munari et al. (2016) analyzed the level of centralization and decentralization of a wide variety of gap-funding instruments across Europe, relying on responses to a survey administered to 125 university TT managers. They found a curvilinear relationship between the use of centralized gap-funding instruments and the development of national TT practices, a relationship that depended on the type of instrument surveyed. In a subsequent work (Munari et al., 2018), they examined what determines the activation of these instruments and their perceived effectiveness, and disentangled the characteristics of the TTO from those of the university or from the characteristics of the ecosystem in which the university operated.

Despite the growing academic attention to PoCs, much of the current body of literature has focused on their role in contrasting resource constraint problems. Conversely, the micro-mechanisms that lead PoCs to be effective in closing the gap between university and industry in TT and how such mechanisms interact to promote research commercialization have not yet been investigated.

3. How PoC programs work

Universities and TTOs are in charge of the design of PoCs, which appear to share a similar architecture across countries (Munari et al., 2017). Their set up is critical to address the main constraints that limit the commercialization of RBIs. PoCs are structured in three different phases: i) the preparatory phase; ii) the evaluation phase and iii) the execution phase. These steps are closely intertwined and act as a bridge with the market (see Figure 1).

[Insert Figure 1 about here]

In the preparatory phase, researchers are guided in the understanding that commercialization activities have to be programmed differently from what is done with research and that new and additional dimensions have to be considered (e.g., the team, the application area, the development times, the allocation of budget and the interactions with third parties). At the beginning of this phase, researchers working on the development of the RBI often only have a vague idea about the market potential of their invention, in terms of its application domain, value and the customer segments that could be served. The action plan that researchers develop in this step helps them to clarify three key aspects of their project: i) the technical and economic facets for TRL advancement ii) the recognition of go-to market opportunities and iii) the sustainability of the business.

The first action that characterizes the preparatory phase is setting up a team and writing a technical document that contains the functioning and novelty elements of the RBI and the steps needed to increase its TRL. The second activity is the recognition of go-to-market opportunities, which requires researchers to evaluate a prospective market for the technology and to create a plan for its exploration.

The objective of this activity is to stimulate researchers to recognize their competency gap with reference to the required market sensing capabilities (Bianchi et al., 2009). The third activity consists in developing a plan in which the viability of the project is highlighted, in terms of sustainability and continuity of the business. This is coherent with Dmitriev et al. (2014), according to whom technology and market needs contribute to determining both the value proposition and the customer segments addressed by an RBI. In other words, the sustainability plan allows researchers to identify the revenue streams that may be derived from their RBI, as well as the cost structure of their business model.

During the evaluation phase, field-specific experts assess the contents of the project; they also help research teams to collect information regarding the application domain(s) and to create linkages with other relevant actors. Experts range from researchers working within the domain of the RBI, to entrepreneurs or representatives from the industry addressed by the RBI (who help assess the market potential and segmentation), to professional investors (who help assess the sustainability of the business). Altogether, they determine whether a project merits receiving a PoC grant, they provide feedback to the researchers regarding the market feasibility of their idea and give recommendations on the subsequent steps the researchers should undertake to achieve the validation of their RBI. These players, in many cases, represent a first link with the external stakeholders and help researchers to build their network. In other words, they create an informal path and work in parallel with the more formal one put in place by the TTO (Hayter et al., 2020).

The third phase is related to the execution of the plan. PoCs provide researchers with a small grant to demonstrate the viability and the functioning of their RBI. During this stage, researchers perform an initial product-market validation, and explore key aspects of the target market as well as whether the business idea is viable (Blank and Dorf, 2020). This phase allows them to extend and consolidate their network, build new connections and increase their resource availability by obtaining feedback and guidance (Kirchberger and Pohl, 2016). It is generally in this context that the research team is

asked to report the project results to the committee of experts that made the evaluation. The committee also continues to support and provide feedback in this latter phase.

4. Research context

The detailed analysis of the internal mechanisms of PoC programs requires a large amount of detailed and confidential data that cover a large time span. Such issues make the case study the most suitable research methodology to meet our goals. In the same manner, the "ideal" research setting to investigate the mechanisms of PoCs that promote the commercialization of RBIs is a university endowed with a TTO that has developed "state-of-the-art capabilities", in line with those of the main technical universities in Europe (Ricci et al., 2019). To this aim, the Politecnico di Torino[6] (henceforth referred to as PoliTo) was chosen as the setting for a revelatory case study (Yin, 2017). This choice has allowed us to leverage on our intimate knowledge of both the institutional environment and social practices (as well as having continuous access to confidential information and to researchers), which are extremely important for case study identification and interpretation purposes (Yin, 2017).

The objectives of PoliTo's TTO included the support of scholars in patenting and in co-ownership practices for collaborative research, the management of formal procedures to start research collaborations with large companies and the facilitation of the creation of spin-offs arising from research activities.

4.1 The PoC program at PoliTo

Although PoliTo's TTO achieved good results, in terms of the growth in the number and breadth of technical specializations of filed patents and spinoff creation, this did not translate into a clear ability to licence patents and in the spin-offs' ability to raise early-stage funding from investors. For this reason, in 2016, the PoliTo's Board of Directors decided to allocate 1M€/year[7] for at least three

[6] PoliTo, which is located in the North-West of Italy, is the oldest technical university in Italy. It is well known for its strong ties with the local industrial ecosystem (Colombelli et al., 2019). In 2016, when the PoC program started, it ranked 33rd worldwide in the "Engineering and Technology" QoS ranking.

[7] The Foundation Compagnia di Sanpaolo co-funded 50% of the program.

years in a row to create an opportunity for scholars to bring their RBIs closer to commercialization. Accordingly, the TTO launched the "Call for the financing of Proof-of-Concept projects" ("PoC call" hereafter). This program was implemented as a replication of some of the most famous PoCs already launched in some well-known universities (e.g. Imperial College, Berkeley, UCLA, Haifa) which had proved to be effective in increasing the commercialization of RBIs. These PoC programs (as well as PoliTo's one) reflected all the characteristics described in the existing scientific literature and in Section 3. A description of the three stages of the PoC is presented hereafter.

Preparatory stage. The PoC call was explicitly devised to fund projects with a TRL ranging from 3 to 5. The maximum eligible funding was € 50,000, which was deemed necessary to cover the cash expenses needed for TRL advancement (no further basic research activity was eligible for funding). The call was open to all PoliTo scholars and became part of the scientific evaluation of their tenure. At the individual level, it introduced incentives for the participation of young researchers (PhD students and post-docs in particular) and fostered the diffusion of entrepreneurial skills among the academic staff. The Vice Rector for TT (hereafter VRTT) coordinated the program with the other TT activities and reported to the Board of Directors.

In order to apply for the PoC call, it was necessary to own an RBI backed by a patent and to prepare a plan focused on how to increase its TRL. Such a plan had to include (i) the objectives of the project and the identification of the application domain(s), (ii) the initial and the (expected) final TRL, (iii) a GANTT chart with the expected activities and milestones, (iv) a comparison with similar existing technologies and their performances, (v) the allocation of funds.

Evaluation stage. The role of the evaluation process was to help researchers understand the market requirements to identify potential application domains. Seven field-specific committees, all of which were chaired by the VRTT, evaluated the content of the projects. Each committee included a professional investor (whose role was to evaluate the market potential and the value of the RBI), an entrepreneur with extensive knowledge of the technology application field (with the role of

introducing market insights and promoting networking with companies that were willing to explore the technology), and a professor who was an expert in the RBI domain (to make an independent assessment of the scientific validity of the proposals). Each project was evaluated using multiple criteria (e.g. accuracy of the project, team composition, market potential of the technology, budget allocation, team motivation, etc.) after a meeting of about one hour and a half with the teams (which included pitching, an open discussion with feedbacks and suggestions for the applicants).

Execution stage. The advancement in TRL had to be attained within six-nine months from the beginning of the PoC project. At least one member of the team had to be younger than 35 years old and the Principal Investigator (PI) had to be a professor or a full permanent researcher in order to ensure the continuity of the project. The PI also had to prepare an intermediate report for the evaluation committee (in order to show the on-going activities and receive feedbacks and further suggestions) and a final report summarizing the results and gaps with respect to the plan.

4.2 The results of the selection process

Out of the fifteen research teams that responded to the PoC call, twelve obtained a grant, while the remaining three projects did not achieve the minimum required score (they did not reach the minimum threshold of 60/100 points for various reasons, e.g. poor planning, issues in team composition, etc.). Table 1 describes the technological domains of the submitted and funded projects.

[Insert Table 1 about here]

Table 2 reports the main characteristics of the funded projects and the distribution of the resources among them and across different technical domains, and shows the heterogeneity of the projects in terms of team composition, research area, seniority of the researchers, TRL and application domain.

The projects all started as soon as the administrative procedures had been completed. Most of the projects were launched in the first quarter of 2017 and closed within the fourth quarter of the year; others required extra time or had to deal with bureaucratic issues and ended mid-2018.

[Insert Table 2 about here]

5. Methodology

In order to investigate the emergence of patterns concerning the key role played by PoC programs in favoring the commercialization of RBIs, we relied on the adoption of an inductive approach (Edmondson and Mcmanus, 2007).

The inductive method is a bottom-up approach that allows knowledge to emerge through observations and which is followed by the recognition of the presence of specific patterns among observations (Langley, 1999). This knowledge is gathered into an abstraction (often a theory) which facilitates the description of the macro phenomenon under study. We complemented this method with the classical interpretative approach of the grounded theory (Glaser and Strauss, 1967), which allows one to move back and forth from observations to theory and to build in a continuous interaction loop oriented toward the refinement of an emergent theory (Suddaby, 2006).

Our privileged access to all the different aspects of the PoC allowed us to manage issues related to information transparency, completeness and confidentiality that short interviews and/or questionnaires would not have allowed. We did not apply any form of opportunistic sampling (as the full sample of RBIs receiving the grant were sampled) and we did not interfere neither with the selection processes, nor with its execution (only the evaluation committee was in charge of providing help to research teams and possibly creating potential network opportunities). We were also aware of the potential biases in our analysis, and we therefore continuously checked our results -also with other TT experts within the university and with informants- to avoid this risk.

5.1 Data collection

We collected data from multiple sources. Our main informants were the applicants (i.e., professors and researchers at PoliTo), as well as the key people involved in the PoC call and its

evaluation. Moreover, as is typical of the grounded theory, we were involved in several activities related to the PoC as direct observers.[8]

Apart from direct observations, we also collected data from documents and reports made available by the TTO to perform data triangulation (Patton, 2002; Yin, 2017). We accessed such data in the form of archival documents (in written and electronic form) and databases (see Table 3 for a detailed description of these documents and their revelatory power). The PoC projects (including their mid-term and final reports) provided information about the nature of the RBIs, the required activities, encountered obstacles and budget (mis)allocation issues. Detailed evaluations by members of the seven committees helped us to understand the weaknesses and strengths of each project, from the investors and entrepreneurs' points of view, as well as the actions that the PI had to take to incorporate knowledge about the application domain. E-mails and other unstructured material were also used, while direct observations during meetings allowed us to track the intimate opinions and perspectives of the stakeholders involved in the PoC program.

We triangulated these data with semi-structured interviews with PIs. We decided to choose the PIs of each project as the key informants, because of both their long-term experience in conducting research projects and because they had key information about the constraints that may have limited their RBIs from reaching a higher TRL. For this reason, they were considered good candidates to highlight the crucial factors that could limit the commercialization of the RBIs and how the PoC helped to overcome such factors (Jain et al., 2009).

We complemented the obtained data with three additional interviews with the applicants of the PoC call whose applications had been rejected.[9]

[8] Since we could not constantly observe each team in their daily activities, we participated in and observed the meetings organized by the TTO concerning the selection and final evaluation of each team involved in the PoC call. We also had access to individual meetings between the TTO staff and the teams, as well as to the meetings between the research teams and some industrial stakeholders.

[9] Of the three projects that were rejected, one was not allowed to participate in the PoC as the initial TRL was too high, while the other two were rejected because they failed to prepare suitable development plans. The PI of one of these latter two, after the rejection, decided to interrupt the project and direct his efforts toward other research; the other one applied for a second PoC call. During the interview, he stressed that the feedbacks

[Insert Table 3 about here]

In order to avoid threats to the validity of the case studies (Yin, 2017), each interview was subject to a strict protocol. First, before the interview, one of the researchers produced a preliminary case report with the information gathered through the analyses of the archival documents provided by the TTO and through direct observations. This helped other researchers review specific issues that had to be covered prior to the fieldwork (Yin, 2017). Second, all the interviews were conducted in the presence of at least two researchers. During the interview, one of the researchers was in charge of asking questions, according to the structure reported in the Appendix, while the other(s) took intensive field notes (Yin, 2017). Each interview was recorded and transcribed verbatim.

The interview consisted of two sections. The first one was aimed at investigating the inhibiting factors that could limit the commercialization of RBIs. We did so to assess whether the cases under analysis were subject to the inhibiting factors already identified in literature. This analysis was instrumental in increasing the validity of our study; if the cases under scrutiny had had to face different inhibiting factors from the previously identified ones, the results would not have been easily generalizable. The second part of the interview concerned the enabling role played by the PoC.

In the first section of the interview, we relied on a retrospective perspective (Thomas, 2011) and asked the interviewees to discuss how the commercialization of the RBIs had been conducted before the launch of the PoC call. This question was necessary since each interview took place after the completion of the activities required by the PoC. The interviews were conducted between June and September 2018 (September and November 2019 for the three projects that were not financed), at least six months after the completion of the projects. This time span was important for our research, since it made it possible to observe the effect of the PoC on the development of each project.

received from the investor and the entrepreneur from the evaluation committee during the first application were fundamental to receive the grant in the second stage. We asked the two applicants who did not take part in the second PoC call questions concerning the factors that limited the commercialization of the RBIs. Moreover, we calibrated the questions, for the applicant who won the PoC in the second application, to identify how the first application had been instrumental to his winning in the second application.

Moreover, it allowed the interviewees to internalize and process all the events that had occurred during the PoC and to observe the most significant results of the program.

5.2 Data analysis

We adopted an inductive approach to the data analysis. During this stage, we analyzed data from the interviews in order to identify both the inhibitors to the development of RBIs and the enablers created by the PoC program. Accordingly, we moved back and forth between data and theory while we conduced further interviews. This iterative approach allowed us to continuously update our emerging theoretical framework, while new data were accessed and theoretical insights emerged (Burawoy et al., 1991). In line with the grounded theory (Suddaby, 2006), we iteratively updated our theoretical framework through a comparison technique (Glaser and Strauss, 1967) in order to determine subsequent data collection efforts, as well as the focus of further interviews. During this process, we continuously triangulated data with archival documents and observational data (Eisenhardt and Graebner, 2007; Yin, 2017) in order to mitigate the possibility of a retrospective data collection bias[10] and to reinforce the validity of the theoretical concepts that emerged.

Each round of data analysis was characterized by three phases of coding through what is commonly known as the Gioia methodology (Corley and Gioia, 2004; Gioia et al., 2013). We began the coding phase by systematically linking empirical observations through the individual and situated patterns that emerged from the interviews. We then moved toward more universal themes, and, finally, we linked them to theoretical insights. We first proceeded with a line-by-line *in-vivo* coding of the data related to the inhibitors. We then answered the question 'What's going on here?' (Gioia et al., 2013, p. 20) by grouping identified concepts into "2nd-order" theoretical levels and, finally, we reduced these dimensions into general theoretical concepts. In doing so, we paid particular attention

[10] Although this is a possibility (Eisenhardt and Graebner, 2007), we believe this bias does not apply to our research setting for two reasons: first, university fellows strive to transfer research toward society on a daily basis; second, the PoC - in the analysed context – was a spot policy initiative that could not be used for any other of their research projects. Therefore, difficulties in transferring research results toward society are currently still experienced by professors, thus making them a reliable source of information.

to identifying the concepts that explain *why* RBIs are difficult to transfer from academia to society (Flick, 2009). Although this topic has already been studied in the literature, we used an inductive approach to avoid confirmation bias in the identification of the factors that limit the commercialization of RBIs in our context, and to reinforce the external validity of our case study (Yin, 2017).

As suggested by Gioia et al. (2013), we managed first-order and second-order themes and aggregated theoretical dimensions in a data structure tree. Whenever new data (e.g. interviews) were added, we iteratively proceeded to update our data structure. We proceeded analogously with respect to our main research question (i.e. related to how the PoC intervened in alleviating the inhibiting factors to the commercialization of RBIs). In this case, we determined first- and second- order categories related to the enabling function of the PoC instrument (i.e. the smoothing of the barriers that could hinder the successful commercialization of the RBIs) and we connected them to the theoretical dimension in an analogous way to those identified for the inhibitors.

6. Results

As previously mentioned, we first assessed the validity of the inhibiting factors to TT identified by the literature for the 12 cases under scrutiny and then analysed the enablers that were activated through the PoC programs. The obtained results highlighted that, in line with the previous literature, three factors inhibited the commercialization of the RBIs, namely: relational, organizational and intra-individual factors[11]. We then turned to investigating the PoC as an instrument that would be able to alleviate the obstacles that prevented the RBIs from achieving commercialization. Our results show that inhibitors may be tackled by a corresponding set of enablers. Through data triangulation, we identified three categories of factors that enable the commercialization of RBIs: (1) structural enablers, (2) relational enablers and (3) cultural enablers.

[11] A comprehensive description of the inhibiting factors is available from authors upon request.

These factors operate at the organizational, relational and intra-individual level, respectively, in mitigating the corresponding inhibiting factors.

In the following sections, we report what has emerged from triangulating the interviews, as well as the archival and observational data collected throughout the development of the PoC. In the first sub-paragraph, we provide a general overview of the enablers, while we show the results in the second sub-paragraph, specifying how the enablers emerge and through which mechanisms they interact to favor the commercialization of RBIs. On the basis of these findings, we discuss the theoretical implications of our results and we explore how our theorizing can inform and advance the literature on university-industry TT.

6.1 Enablers of the commercialization of RBIs

Table 4 and Figure 2 describe the data structure of the PoC enablers that have emerged from the interviews and the data triangulation, as well as some exemplary quotes on each enabler.

[Insert Table 4 about here]

[Insert Figure 2 about here]

The first set of enablers operate by mitigating inhibiting factors at the relational level and, therefore, are labeled as relational enablers. We identified three second-order categories: trust and commitment, network creation and communication. These enablers refer to those factors that help researchers close the relational gap that exists among the stakeholders involved in the development of an RBI, the potential users and the research groups. Relational enablers emerge over all the PoC stages and favor the development of trust and commitment between parties, because the university provides a signal to external stakeholders that the risk associated with an RBI is reduced (see Q1 in Table 4). Relational enablers help research groups to access a consistent network of relationships (see Q2 in Table 4) and to improve communication skills with external stakeholders (in particular by favoring contact between researchers and firm managers; see Q3 in Table 4). In other words,

relational enablers play the key role of mitigating the detachment between academics and other stakeholders, due to the lack of direct relationships between parties.

The second set of enablers (i.e. structural enablers) are grouped into three second-order categories: availability of funds, reduced University-Industry (U-I) mismatch, and new research opportunities. At the organizational level, structural enablers are factors that indirectly encourage scholars to be more effective in both TT and in research development. They lower commercialization barriers by supporting TRL advancements (e.g. by creating the conditions for the realization of prototypes aligned with the investors' requirements; see Q4 and Q5 in Table 4) and the definition of milestones to increase the fit between the RBI and the market requirements. Researchers, through structural enablers, mitigate the level of uncertainty RBIs are subject to in terms of market value assessment. The provision of funds from the university helps researchers to collect advice from investors without entering into any negotiation with them and to quickly develop early versions of the product aligned with the market requirements (see Q6 in Table 4).

The last set of enablers (i.e. cultural enablers) help researchers overcome the prejudices and cultural barriers that can hamper the development and commercialization of RBIs. They can be distinguished into two second-order categories: the effective identification and the translational approach. They operate at the intra-individual level by changing the beliefs of researchers about the practical needs of firms and about the necessity to balance theoretical and applied research.

Participation in a PoC in fact allows researchers to identify the potential of their RBI early on in the process (see Q7 in Table 4). In this vein, a PoC allows scholars to overcome cultural barriers by giving them the opportunity to align basic research (in line with publication objectives) and, at the same time, to translate basic principles into more applied concepts closer to the market needs (see Q8 in Table 4).

6.2 Activation mechanisms and the interaction of enablers

Since one of the objectives of this study was the investigation of the mechanisms that determine the commercialization of RBIs funded under PoC schemes, we exploited data triangulation to identify the relationships that exist between the first-order categories of enablers discussed above and the second-order categories, that is, the mechanisms that link and reinforce the effect of each enabler. These results are summarized in Figure 3 and described in detail hereafter.

Relational enablers. As far as relational enablers are concerned, we found that they directly contribute to the commercialization of RBIs by promoting existing TT activities, such as the licencing of a patent or the creation of a spin-off. These enablers lower the negative effects of relational factors that hamper commercialization by means of three mechanisms: (1) the trust in and commitment of third parties to the research team, (2) the communication skills developed by the research team, and (3) the creation of a network that connects research with the market domains.

During the interviews, the informants recognised that the PoC was a valuable instrument to build and facilitate relationships with actors outside the academic environment, and that the PoC reassured stakeholders about the value of their RBI. In some cases, the interviewees reported that the PoC helped them increase the credibility of the research group in the eyes of third parties, regardless of the concrete possibility of commercializing the RBI. As one professor mentioned:

"We understood that if we went on the market with our idea, we would have created trouble for some of the companies we work with. There are market equilibria that cannot be modified. However, the PoC offered us the opportunity of showing them our competencies and they now know who we are and how reliable we are."

A second important aspect refers to fact that the PoC can reinforce the commitment of third parties toward the development and commercialization of RBIs. In fact, as proved by the e-mails we had access to, the frequency of the contacts between researchers and other parties greatly increased once they had shown the prototype of their RBI. Other secondary sources (i.e. e-mail exchanges between the TTO and the research groups) revealed that the commitment of the research teams increased once the external stakeholders started to be more committed. As one PI mentioned, the PoC

created "*a virtuous cycle of commitment*" from which all the involved parties could benefit. For instance, we observed, in several cases, how the youngest members of research teams (often PhD students) were fully committed to the development of the RBI after the termination of their educational path. In some cases, the PhD student received a post-doc grant with the specific purpose of continuing the development of their RBI. In a couple of cases, some PhD students quit academia to work full time on the development of an academic spinoff based on the results of the PoC.

The improvement in the communication skills of the research team can also favor the commercialization of RBIs. This aspect allows researchers to manage their relationships with external stakeholders more effectively, thanks to the creation of a shared language, whose effect is to smooth communication barriers. We identified two different ways through which communication enablers operate. First, informants reported that the PoC was instrumental in adapting their own language to that used by firms. One scholar also emphasized that the PoC was an opportunity to rethink about how to communicate the content of a patent related to an RBI:

"The PoC has been an opportunity for us: we have learned how the contents of our patent could be communicated more clearly and in a more 'structured' manner."

Second, the informants reported that they understood how to approach their counterparts in an appropriate manner, in particular those that were less technically skilled, as one of them reported:

"It is a matter of language. After five minutes of too scientific talks, your counterparts are bored. They don't care about all the nerdy stuff you care about; they want to see what conclusions and value you bring to the table".

An improvement in the communication skills was evident during the meetings of the research groups with the PoC evaluation committees. The entrepreneurs who were part of the committee emphasized the improvement PIs had made, in terms of communication skills. This evidence is corroborated by the fact that, although just three out of twelve research groups clearly stated the value

proposition connected to their RBI in the application documents prepared for the evaluation committee, ten research groups clearly did so in the final documents.

A recurrent theme that emerged from the interviews (deemed as one of the greatest benefits of the PoC) is that academics were able to access a wide network of actors involved in the relevant business environment (in the same domain as the university or from other domains). In some cases, the first point of contact for the creation of the network was the evaluation committee, who played the role of bridging the gap between researchers and some of their industrial contacts; in other cases, the TTO created the conditions necessary to establish such linkages. Thus, the PoC enabled research teams to get in touch with a variety of stakeholders interested in the commercialization of their RBIs.

More importantly, this mechanism of network creation allowed research groups to create a set of durable relationships that could be exploited not exclusively in an attempt to commercialize PoC-funded RBIs, but also for further developments or new RBIs. In this vein, a PoC reinforces the team's ability to attract new matching funds from external stakeholders, since the advancement of a TRL boosts the interest of firms (i.e., they understand the application of the technology more and become more willing to participate in future developments). In this respect, one PI said:

"The PoC gave me the resources necessary to improve the TRL of the technology. After the development phase, i.e. during "phase 2", it allowed us to sit around a table with firms and jointly discuss the potential application of the technology and the future directions of its evolution".

In short, relational enablers and the associated mechanisms directly promote commercialization activities by lowing the detachment between external stakeholders and researchers[12].

Apart from directly favoring the commercialization of RBIs, relational enablers can also reduce the impact of the intra-individual factors that limit the commercialization of RBIs. In fact, a lower

[12] The validity of this mechanism is also supported by additional evidence: after concluding the PoC, participants in the program declared they were more focused on patenting their RBIs than before. Moreover, the PoC participants who licenced their patented research earned 1.5 times more, in terms of revenues, than those who did not participate in the program.

detachment from firms that are active in the local environment leads researchers to think about the potential applications of their technologies earlier on in the research process. This reduced detachment may also change the way researchers convert basic research into applied research. In this vein, network development - as a consequence of the participation in the PoC program - was found to facilitate a better matching of the subsequent research developed by PoC participants with the requirements of the industrial environment, as well as to stimulate a continuous flow of market knowledge from firms to researchers. The interviewees specified that, even without renouncing rigor and theory, thanks to their new network, they began to approach new research lines by considering what problems firms really needed to solve. In this regard, one PI remarked:

"*We still begin our studies with literature and theory, but we are more aware of what people in industry really need. Sometimes, even when we perform basic research, if I have a doubt about the potential of an experiment, I call some of my industrial contacts to ask for their opinions. We now start collaborating with firms from the very beginning."*

Structural enablers. As far as structural enablers are concerned, our case study informed us about the indirect impact they have on the commercialization of RBIs. The analysis of the data did not, in fact, evidence any direct mechanism that favored the licencing of the patent underlying the RBI or which led to the creation of spinoffs. Conversely, what emerged is that structural enablers, apart from reducing the impact of organizational factors, also contribute to limiting the impact of both the relational and intra-individual factors that hamper TRL advancements and the commercialization of RBIs. This happens through three distinct mechanisms: the availability of well-targeted funds, a reduced U-I mismatch and the development of new research opportunities.

Limited access to funding is a well-known obstacle to the development and commercialization of RBIs, and the small amount of money made available by the PoC is apparently of little help in moving a development ahead or in the commercialization of RBIs. Nevertheless, the interviews with the PIs highlighted that the benefit of the PoC is the quick and targeted provision of funds made available specifically for the development of RBIs. All the applicants already had research funds available, but administrative rules blocked their utilization for TRL advancement; at the same time,

the negotiations for funds with investors was an endless and time consuming process. PoC funding (granted on the basis of the judgment of investors and entrepreneurs) provides a positive signal to external stakeholders about the potential value of the RBI, thus enhancing the probability that they will co-fund its development. In this regard, one professor commented:

"We visited [firm name] and said that PoliTo was investing in our technology. The company became more confident about the development of the RBI, started to believe in us as a team and became more open to co-financing its development."

Moreover, a recurrent feature that emerged from the interviews was that the money raised with the PoC was undoubtedly insufficient to complete the advancement of the TRL. Nevertheless, it was very useful to timely hire the young researchers needed to develop the project, to overcome the structural issues of recruiting in universities and to speed up TRL advancement and prototype creation. It also helped the PI to remain focused on the relational and commercial aspects of the project. In this vein, it is not surprising that the teams used 40% of the total PoC budget (out of about €430,000 granted) to hire young research assistants. In short, rather than directly favoring the commercialization of RBIs, structural enablers- through the availability of funds- indirectly reduce the relational factors that inhibit it. This was clearly described by a professor, who remarked:

"[…] It was an opportunity to stay away a little from doing dirty work down in the lab. Before, even calibrating the test bench could be a task that took a lot of time, now with [name] it takes a bit more, but I am freer to spend this time looking for partners".

Structural enablers can also lower the effect of relational factors through the reduction of the U-I mismatch, thereby closing the existing gap. According to our data, this happens in two ways. First, a PoC enhances alignment with the industry demand. The informants stressed the role that the PoC played in moving an RBI from a homespun and unsophisticated prototype to something closer to a product. This allowed them to obtain a better understanding of the technology and, in turn, to enhance the willingness of industrial stakeholders to invest in it (e.g. see quote Q2 in Table 4). A PoC gives research groups a new ability of correctly seizing the potential market demand and aligning the features of a prototype to the market needs. The informants outlined how they developed and revised

their prototype by incorporating both the technological aspects developed through basic research and the features they discovered during the analysis of the needs of real customers. Therefore, in some cases, researchers modified their original idea accordingly and aligned technology "newness" with the customers' requirements in order to tackle the problem connected with the scarce interest firms had shown in the past toward their technology, as this quote reveals:

> *"Thanks to PoC funds, we participated in three tradeshows and interviewed more than 150 people. We realized that nobody was willing to pay a single cent for our technology as it was. They were not even aware of the problem. So, we had to change our approach to meet the customers' demand."*

More in general, according to the TTO's data, part of the money granted to 10 out of 12 RBIs funded under the PoC scheme was used to assess their product-market fit through the collection of the preferences of potential customers. This translated into a change in the way the researchers usually approached the development of RBIs.

Second, when an RBI becomes more understandable to industry stakeholders and to investors, it lowers their related perception of its technological risk (i.e. concerning the future adoption of the technology) and increases their willingness to collaborate or invest in further developments (e.g. they start asking questions like *"What are the key benefits?"* instead of "*Does it work and how?"*). In this sense, structural enablers originating from a reduced U-I mismatch help to mitigate the impact of the relational factors that inhibit the commercialization of RBIs.

A last mechanism through which structural enablers alleviate the impact of intra-individual factors is the emergence of new research opportunities that arise from enhanced interactions between firms, research groups and potential users. As reported in quote Q6 in Table 4, such interactions facilitate the identification of new market opportunities that are "adjacent" to the existing RBI (from a technological viewpoint) and help researchers to identify the real commercial potential of the RBI. Hence, participation in the PoC enables research teams to scout the technological environment more extensively.

In our specific case, this activity sometimes allowed researchers to detect the presence of technological solutions that were already available on the market and which performed better than theirs did. However, researchers outlined that they were able to perform an intimate exploration of both the technological and the market environments and thus to reposition their research in order to solve technological and market problems that had not yet been addressed, in part thanks to the role played by the evaluation committee. For instance, one participant highlighted that she had the possibility of understanding that the problem she had been trying to solve had already been addressed by means of a molecule which was at the last stage of evaluation by the FDA. Thus, as she understood the limited chance of the success of her molecule, she also identified the limits of this product and developed a new research project to fill these gaps. The new research project was very successful at an international level and she received an ERC grant. In this sense, the opening of new research opportunities allows research groups to limit the impact of the intra-individual factors that inhibit commercialization, as they mitigate erroneous beliefs that harm research development and commercialization.

Cultural enablers. The third dimension of enablers activated by PoCs is the cultural one. However, like structural enablers, the evidence that emerged from our data collection did not highlight any direct impact on the advancement of TRL for RBIs or on their commercialization. Cultural enablers emerged in the form of two mechanisms (effective identification and translational approach) which -on the one hand- limit the impact that intra-individual factors may have on research development and commercialization, and -on the other hand- indirectly reduce the relational factors that hamper the commercialization of RBIs. An interesting aspect that emerged was the systemic method that the research teams gained (after participation in the PoC program) to design their future research with a "stage gate" approach (with precise milestones) in order to obtain TRL advancements and commercialization. This theme frequently recurred in the final set of colloquia between the evaluation committee and the PIs and was one of the most frequently cited take-aways from the

researchers who participated in the PoC initiative. In this sense, professors highlighted that by following this "stage gate" approach, it was immediately possible for them to classify new basic research (post-PoC) as "*with potential for the market*" or "*with potential for publication*". Finally, the interviewed scholars reported that, in the post-PoC phase, participation in the program significantly lowered their prejudices toward the potential application and commercialization of their RBIs and created new motivation to work on TRL advancement and (eventually) on the commercialization of the RBI. This emerges from the following comment made by one of the interviewees:

"None of us had ever thought about developing a project beyond the research stage for a paper. After having participated in the PoC, we now consider the possibility of fully developing the new technologies. […] We think about it more and more, at least to licence them."

Our analyses highlighted that both of the mechanisms associated with cultural enablers played significant roles in reducing the impact of the relational factors that hamper the advancement and commercialization of RBIs. The effective identification, together with the translational approach, put the research teams in a condition of becoming more attractive to industrial stakeholders. The effective identification also stimulated research teams to overcome their prejudices about the feasibility of the application of their research, thereby giving them more confidence to take valuable research projects to a higher TRL. The translational approach gave researchers the mental scheme needed for an early assessment of the validity of the research project, thus helping them to present relevant RBIs to the industrial stakeholders. The functioning of this mechanism is clearly depicted in the words of one professor, who highlighted that:

"After the PoC, [name of the person] -who is my usual contact in [name of the company]- was enthusiastic about all the projects I presented to him. Did this mean I was better at doing research? I do not think so, but my impression was that the projects I was bringing to him were more valuable than before."

[Insert Figure 3 about here]

7 Discussion

Previous literature has provided a complex portrait of the factors that hamper the commercialization of RBIs (Balven et al., 2018). In particular, it has advocated that elements that

inhibit TT can depend on organizational, intra-individual and relational factors. At the same time, it has also highlighted that PoCs are viable instruments to promote TRL advancements of RBIs (Munari and Toschi, 2021; Munari et al., 2017), but has failed to explain the mechanisms that lead to their successful commercialization.

Based on these premises, we have identified three classes of enablers (relational, structural and cultural) that a PoC activates and the way they work in favoring TRL advancements and the commercialization of RBIs. Our findings have a number of implications for TT strategies in universities and, in particular, for the role and organization of TTOs. Such mechanisms are summarised in the following paragraphs and the implications are illustrated.

7.1 Toward a model of the enabling relationships activated by PoCs

Building on the evidence we have collected, our results depict a situation in which only relational enablers directly enhance the commercialization opportunities of RBIs, by means of an increase in the set of relationships PIs and research teams activate. On the other hand, we find that structural and cultural enablers smooth the inhibiting effect of organizational, intra-individual and relational factors.

Our study unveils that PoC programs are effective in favoring the commercialization of RBIs via relational factors, as this set of enablers increase the possibility of simplifying and strengthening the connections that researchers have with the external environment, thereby creating more trust and transparency. Although the availability of funds and/or the correct identification of the potential applications of the RBI in the design phase are crucial elements for TRL advancements (Munari et al., 2016), the mechanism through which this happens is only realized by means of relational enablers. In fact, their occurrence allows PIs to increase their connections with industrial stakeholders. Such connections are directly responsible for TRL advancements, since they guarantee the access to resources that cannot be acquired but that are fundamental to start commercialization. For instance, like entrepreneurs do (Blank and Dorf, 2020), researchers can conceive an application for their RBI earlier on in the process. However, until they test the existence of the real market needs, they cannot

understand its value or start commercializing it. We argue that PoCs help TTOs integrate formal and informal mechanisms (Gilsing et al., 2011; Schaeffer et al., 2020) and bridge the gap between RBIs and the "market" according to an "inside-out logic" (i.e. researchers acquire market information inside the university to approach the outside market). This process is in contrast with TT paradigms based on "outside-in logics" (Bradley et al., 2013b), whereby the market is brought inside universities to evaluate and select RBIs as if they were "off-the-shelf". Our results, which are generalized in Figure 4, offer a new lens under which TT through PoCs can be read.

[Insert Figure 4 about here]

The portrait that emerges from our study, which shows a complex set of relationships and connections between enablers, explains the scarce results of several TT instruments that work on single enablers through formal mechanisms (such as university controlled seed-capital funds or official incentives for commercialization; Rasmussen et al., 2006). In other words, our results suggest that the unique provision of money to academics (like patents or other formal activities) is not enough to achieve the commercialization of RBIs, because of the crucial importance of building ties with the industrial environment. This evidence is in line with early results on informal mechanisms of TT (e.g. advisory services; Rasmussen et al., 2006) which had proven valuable in promoting the commercialization of RBIs. However, the PoC instrument-as it results from this study- appears to be more powerful than formal and informal mechanisms per se (i.e, taken in isolation), because it orchestrates such mechanisms.

7.2 PoCs and their impact on TT activities in universities

Our results, as well as the derived model, provide a number of implications on how universities and TTOs could enhance their capability to commercialize RBIs. At a theoretical level, the fact that the TT process undergoes a hybridization, becoming more relation-focused than transaction-focused (Weckowska, 2015), implies that even TTOs have to rethink their role. A long-standing mantra among TT scholars is that universities should be able to promote dual structures that entail

ambidexterity in TT, thus favoring both the promotion of basic science and the exploitation of intellectual property rights (Ambos et al., 2008). TTOs, through PoCs, can create a further option for researchers, in addition to the traditional academic activities of research and teaching. In this sense, PoCs reduce the need of a dual structure to manage tensions in TT (Ambos et al., 2008) by perfectly aligning research and commercialization objectives.

The enabling factors we have identified, as well as the way they work, provide a nuanced picture that informs us about five aspects universities should pay attention to when implementing PoCs to promote TT.

The structure of PoCs is crucial for TRL advancements. The fact that enablers do not emerge together in a specific phase of the PoC, but along all the three phases (i.e. preparatory, evaluation and execution), highlights that the structure and the objectives of PoC programs are crucial to ensure the reach of the desired outcome (i.e. TRL advancements and commercialization)[13]. We suggest that, in order to efficiently reap the most benefit from PoCs, universities should keep the preparatory, evaluation and execution phases as cornerstones, and introduce frequent and shared feedbacks from external stakeholders. In this light, we argue that, although the size of a PoC may vary (i.e., the amount of money granted can change across different PoC programs; Munari et al., 2018), its structure should not and the sequence of the preparatory, evaluation and execution phases should become standard when PoCs are conceived.

The effectiveness of PoCs depends on informal ties and processes. An important outcome of our research concerns the mechanisms through which the commercialization of RBIs takes place. Previous literature (Rasmussen et al., 2006) highlighted that TT instruments (e.g. university-controlled seed capital, external service providers for commercialization, business plan development

[13] More specifically, it appears that any specific phase of the PoC is important for its success: i) the preparatory phase allows academics to elaborate communication skills about the value proposition of their RBI; ii) the evaluation phase provides them with preliminary industry contacts; iii) the execution phase provides them with money, additional industry contacts and a more throughout understanding of how their RBI can be of interest for the industry.

programs and advisory services) promote the commercialization of RBIs by means of either formal or informal mechanisms (Gilsing et al., 2011). Conversely, our study unveils that although PoCs are set as formal TT mechanisms -as the selection of RBIs is based on formal rules - their effectiveness depends more on relational enablers which are recognized as informal mechanisms (D'Este and Patel, 2007).

PoCs stimulate network building and facilitate communication with the entrepreneurial ecosystem. PoCs help scholars access business networks and create reputation, which are at the basis of an active engagement in TT activities (Lai, 2011). TTOs, through PoCs, can selectively share their network with research teams, thereby reducing transaction costs and creating new business opportunities. In addition, the researchers involved in PoC programs learn to communicate with investors and non-technical managers. This ability is crucial when dealing with companies that are interested in the functioning and applicability of an RBI to their business rather than in its technicalities (Li et al., 2013).

PoCs reshape the innovation and entrepreneurial culture of universities. PoCs activate cultural enablers that stimulate scholars to change their beliefs and reduce their distance from industrial stakeholders, thus enhancing their capability of building new relationships. In addition, they enhance the capacities of research teams to recognize market opportunities and to be more effective in providing valuable solutions to real problems. In this perspective, we speculate that PoCs could help reshape the innovation and entrepreneurial culture of a university by "legitimating" the development and commercialization of research (Stuart and Ding, 2006).

TTOs act as "explorers" with external stakeholders. The results of the study highlight a new role for TTOs, based on the design of the PoC call and the offering of constant support to research teams (in particular during the execution phase). The allocation mechanism of PoC funds on a competitive basis and following the judgement of a selected committee of investors and entrepreneurs, increases transparency and bridges formal and informal TT practices (Weckowska, 2015). TTOs should not

simply promote the competitive selection of PoCs (i.e, by choosing evaluation committee members and by setting the program requirements) but also accompany research groups to explore application alternatives and create new business contacts for researchers. In this way, TTOs can promote research commercialization by aligning research excellence with research commercialization.

7.3 Further implications for research

Our study has enriched the literature on TT by delving deeper into the micro-mechanisms that allow TT instruments (such as the PoC) to favour the commercialization of research developed within university boundaries. In doing this, we provide further support to those early studies which have tried to open the black box of PoC programs (McAdam et al., 2009; Rasmussen et al., 2011; Rasmussen and Rice, 2012). Moreover, our research provides further nuance by showing that effective TT instruments as PoCs rely on more complex mechanisms than money (Munari et al., 2017).

Previous literature suggested that the support to university TT may occur through funding schemes promoting: i) a superior engagement of academics in commercialization activities (push model); ii) a superior attention of investors toward university RBIs (pull model); and iii) the intervention of intermediaries able to foster both technology push and pull (Rasmussen and Rice, 2012). Our results show that funding schemes stimulating academics to push their technology toward the market increase the technology pull by investors and firms as well, by aligning the objectives between them. Our micro-level analysis uncovers a finer-grained mechanism through which the development of relational enablers in academic teams acts as a catalyst for industrial players, as scientists are better able to communicate with them and align the value proposition of their RBIs to market needs. This result further complements early perspectives on PoCs about the effectiveness of such instruments as conditional on the ex-ante commitment of an actor to receive the technology before the grant is given (Rasmussen and Rice, 2012). In particular, it shows that PoCs are a viable instrument also in conditions in which the industrial partners are not committed ex-ante.

Beside relational enablers, we also recognized further internal mechanisms activated by the PoC as responsible for reinforcing relational mechanisms. Although previous studies have advocated the necessity to create an entrepreneurial culture within universities to improve TT and commercialization (Bercovitz and Feldman, 2006), scarce evidence of the underlying mechanisms has been provided. Our study shows that propelling a TT culture within the university through PoCs facilitates the communication between academics and industrial partners that, in turn, supports the commercialization of RBIs.

The emerging mechanisms highlighting the relevance of relational enablers reinforce previous evidence on the entrepreneurial competences of academic staff. Rasmussen et al. (2011) have highlighted that three main competencies (i.e., opportunity refinement, leveraging and championing) are a requirement for professors to gain credibility and then create new ventures departing from their RBIs. Although the acquisition of such competences in the form of human capital appears a viable option (Rasmussen et al., 2011), our results demonstrate the possibility of creating them through a learning-by-doing process stimulated by the PoC. Our findings suggest that the attrition that limits academics to "get out of the universities" searching for industrial partners can be overcome by means of formalized schemes as PoCs. A summary of the main theoretical contributions of this work is reported in Table 5.

[Insert Table 5 about here]

7.4 Implications for universities and policymakers

Our results have implications regarding the design and implementation of funding mechanisms aimed at effectively connecting academic research and innovation processes in industries, since they introduce a deeper understanding of the mechanisms that could enable this process.

Our findings suggest the importance of widening the perspective used to analyse the commercialization of RBIs and, more in general, university TT strategies and activities. Far from

being frictionless, the effective commercialization of RBIs requires a complex setting, designed to fully recognize and manage the effects of inhibiting factors (Balven et al., 2018). In this sense, the design of funding instruments, such as PoCs, should address the creation of enablers aimed at mitigating the effects of inhibitors and at creating the right conditions for commercialization.

A fundamental implication for policymakers concerns the importance of allocating a greater amount of funds to PoCs and of recognizing the importance of their role in sustaining innovation processes. PoCs could also help avoid the misallocation of the funds needed to increase the TRL of RBIs, as they are more effective at the initial stages, in order to commit a smaller amount of funds over a broader array of selected projects and to have a more comprehensive selection process. This is consistent with our finding that relational factors are fundamental antecedents for the commercialization of RBIs, since they help complement policies directed toward the creation of incentives for both organizations and individuals to promote TT (Kenney and Patton, 2009). Failure to understand the importance of the complex micro-mechanisms that operate at an individual level and block the commercialization of RBIs could lead to policy makers and universities investing in policies and incentive schemes that are not able to fully address such issues. Indeed, the inefficiency of past policies has resulted in limited TT being transferred from universities to industry through licencing (Swamidass, 2013) and academic spinoffs (Fini et al., 2017).

Our findings also have a number of implications for universities, as they offer a more comprehensive perspective on the effects and role of the mechanisms that TTOs can leverage on to mitigate inhibitors and increase the impact of research activities. For example, although the amount of financing given in PoC programs is often limited (Gulbranson and Audretsch, 2008), such programs facilitate research teams in accessing a wide array of resources that cannot be bought or exchanged on a market (e.g. network, reputation, culture and beliefs), thus lowering the real financial needs and removing the effect of inhibiting factors.

PoCs could also help universities introduce mechanisms aimed at managing tensions at the intra-individual level, which are needed to create connectedness and fit with the external environment, and which are mainly based on a "clan" logic (Ouchi, 1979). Such mechanisms are essential to focus the attention of young researchers (mainly PhD students and post-docs) on TT activities, as well as to foster the diffusion of soft entrepreneurial skills among the academic staff and to mitigate the "publish-or-perish" imperative. This is possible since bureaucracy (rules) and market mechanisms (i.e. ex-ante setting the price of a patent outside any application context) do not work at the intra-individual level in the TRL stages, where investors and firms do not have sufficient knowledge or competencies to assess the value of a new technology.

Finally, in order to obtain an effective allocation of funding, universities must be able to internalize additional knowledge regarding both market and production processes. The composition of committees in charge of evaluating RBIs that are eligible for funding is a key aspect; such evaluation committees require external experts from different backgrounds in order to assess RBIs contemporaneously from different viewpoints (regarding technical aspects, market potential as well as the entrepreneurial and organizational capabilities of the research team).

In short, our findings contribute to identifying the limits of TT approaches focused exclusively on formal activities and highlight the importance in universities of financial resources to guide the initial stages of development of RBIs and the complex balancing that is necessary between transaction-focused and relational-focused models of TT (Ambos et al., 2008; Weckowska, 2015). In a similar way, the implications regarding the structure and objectives of TTOs concern the acquisition of the new competences that are needed to perform a broader set of activities, as well as the need to take on a more proactive role in investing in RBIs, in order to bring them to the next TRL stage as quickly as possible, while identifying the best partners and the most promising market.

8 Conclusions

In this paper, we have investigated how and why PoC programs can favor the development and commercialization of RBIs, and the profound changes they can introduce to TT policies and mechanisms in universities. We have found that a PoC program limits the effect of inhibiting factors on TT by favoring the emergence of several enablers which enhance the development and commercialization of RBIs. We have classified these factors in three categories (i.e., structural, relational and cultural enablers) and we have identified the mechanisms through which they work.

However, our research is not free of limitations. The main issue is related to the generalizability of the results. We have deliberately focused attention on a PoC program developed within a single university to remove all the heterogeneous sources of variation we would have encountered if we had considered different universities. Such sources could have led to confounding effects (Gehman et al., 2018) with respect to the identification of the factors that enable the development and commercialization of RBIs. At the same time, the focus on a single university allowed us to have access to confidential data that could instead have hampered this type of study in other settings. We also recognize that the identified factors could depend, to a certain extent, upon the context in which a university operates. Moreover, other local cultural factors may partially drive the identified enablers. In this sense, as we did not observe any direct effect of cultural and structural enablers on RBIs commercialization, as well as any link moving from cultural and relational enablers to structural enablers, we strongly advice future research to test the generalizability of the model we propose.

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Another promising avenue for future studies could be to test the relationships we have advanced in our study by adopting a larger sample and, possibly, a quantitative methodology. In this vein, we call for the development of ad-hoc scales that would be able to measure the mechanisms we advanced and the relationship among them.

Future studies could also explore the effect of PoC programs on different commercialization outcomes. The previous research on TT was largely focused on licencing and spinoff creation as

outcomes of TT activities (Di Gregorio and Shane, 2003; Thursby and Thursby, 2002). We propose that future studies could explore whether such competing options are still viable after the implementation of the PoC instrument. Our study seems to suggest that when enablers are activated, licensing is no longer the principal outcome desired by research teams. Instead, we have collected some informal feedback from interviewees who, as they increased their capabilities of entering into later stages of the development of RBIs, considered the establishment of a spinoff as a more viable option. We believe this point is particularly relevant as it could have important implications for academic entrepreneurship and universities.

Future research may also address how to design effective TT programs based on PoCs and the role that universities could play in planning and governing TT processes. We argue that universities could have a systematic advantage, in this respect, over other organizations, since they can manage individual and organizational aspects through mechanisms that investors and companies do not possess. In this vein, we also propose that future studies could explore the causal impact of a PoC and of its characteristics on promoting the commercialization of RBIs. Our study was conceived to analyse several PoC projects funded under the same scheme. However, PoliTo's PoC was characterized by some particular features that other PoC schemes may lack (Munari et al., 2017). For instance, participants in PoliTo's PoC received ad hoc mentoring, specific education on patents and spinoffs, and participation in a program with companies that involved one-to-one meetings. These elements, together with the mandatory inclusion of at least one young researcher within the research team, seemed to be important aspects for the success of the program. Similarly, the inclusion of external stakeholders, such as VCs and entrepreneurs, within the evaluation committee, seemed to favor the connection between external stakeholders and academics. Thus, we call for future research to explore the impact of the characteristics of PoCs on their effectiveness in fostering the commercialization of RBIs.

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10 Appendix

Interview structure

Part 1:

Consider the perspective of how you and your team usually conduct research projects (think about projects not involved in the PoC and, if possible, projects you developed before your participation in the PoC).

- What are the contents of your research activities? Are they oriented more toward developing new theories or new technologies?
- On a basis of 100, how important is it for your research group to publish and how important is it to develop/commercialize new technologies? Why?
- What is the usual starting point of your research?
- On a basis of 100, how many times can you fully fulfil all the different tasks professors are required to accomplish (e.g. research, teaching etc.)?
- When you develop a new research line, do you already know the market needs?
- How is your research perceived within and outside the academic environment?
- How often do firms call upon your research group to develop new research projects?
- How extensive is your network of firms?
- Where do you look for competences/technologies that are complementary to your research team?

- What are the main barriers to collaborations with other partners?
- Are your partners willing to share the technological risk of a technology?
- How do you finance your research projects? Where do you obtain the money?
- How do you promote your technology once you have developed it? Do you face issues in doing this?
- Who are the usual potential customers of the technologies you develop? How do you approach them?
- What are the channels you usually use to get in touch with the potential customers and partners for the development of your technology?
- Do you have any further observations on the problems you may face while developing a research project?

Part 2:

Now consider the perspective of when you and your team participated in the PoC with your technology. Think about its development during and after the project.

- From the perspective of the problems we highlighted in the first part of the interview, did you perceive anything different in the development of the project at the basis of the PoC? If so, what?
- Do you believe it has been an effective instrument? Why?
- Did you achieve the initial objectives you and your team decided on at the beginning of the project?
- Do you perceive that the average value of your project has grown?
- During and after the PoC, did and does your project receive the attention of firms? If so, in which way?
- Did you arrive at an agreement with any firm?

- What is the current state of development of the project?
- Are you still missing something that would allow it to move forward? If so, what?
- What was the role, during the PoC, of the other team members?
- Do you have any further observations on the PoC and the development of your research project under this scheme?

11 Tables and Figures

Figure 1
Phases of PoC programs

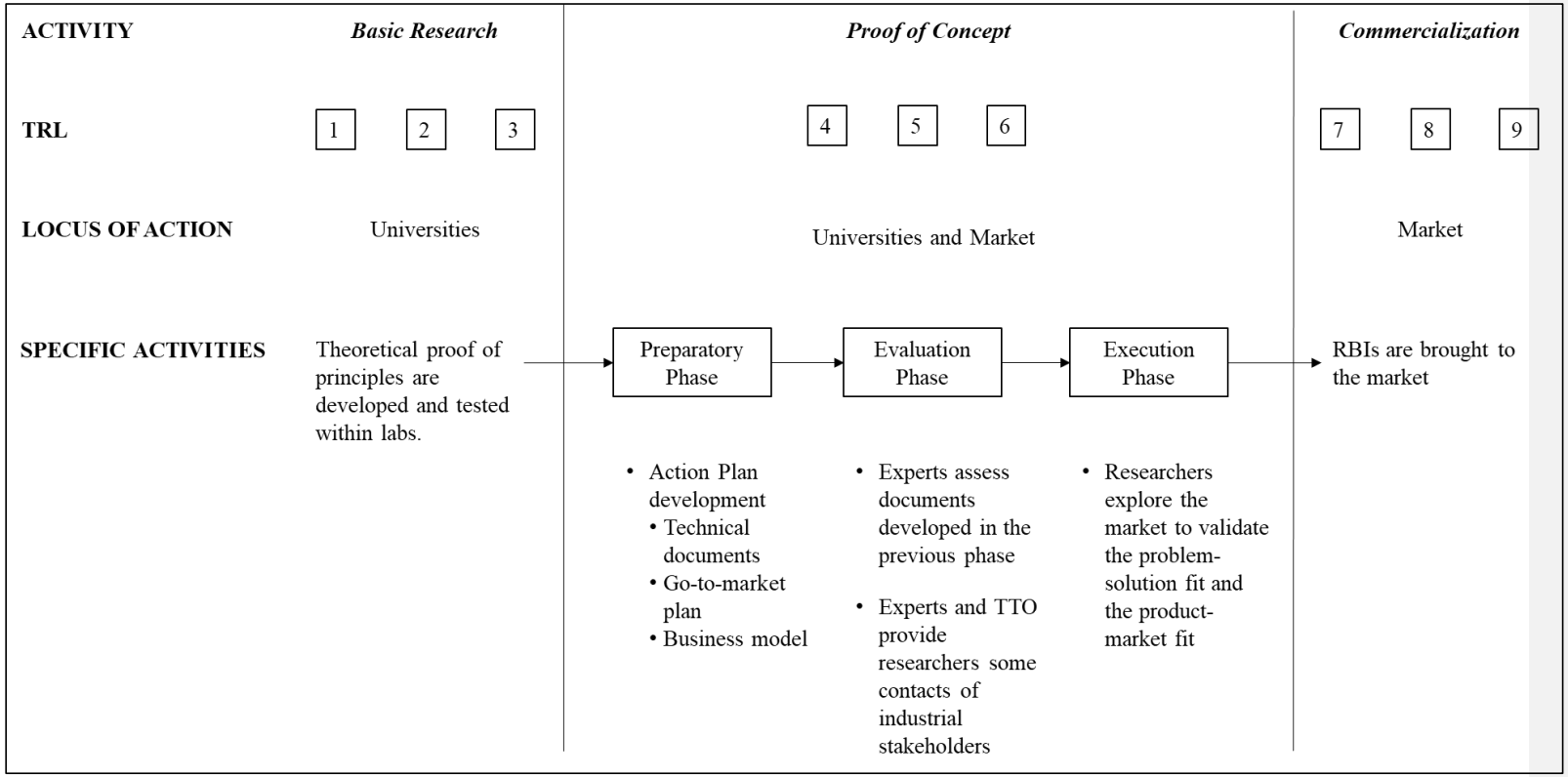

Table 1
Technological domains of the applicant and funded projects.

Technological Domains	*No. of applicant projects*	*No. of funded projects*
Mechanical, Automotive and Aerospace Engineering	4	3
Biomedical and Chemistry	3	3
Civil construction and Environmental	2	2
Industrial Engineering	1	1
Energy	2	1
ICT, Electronics and Telecommunications	2	1
Design and Architecture	1	1
Total	**15**	**12**

Table 2
Description of the cases

Project Number	Team size	Professors	Research Fellows	PhDs	Others (e.g. Students/External Members)	Research Area	PI's position	Starting TRL	Final TRL (Supposed)	Actual TRL (Earned)	Approved Grant	Score Received by the Evaluation Committee
1	3	1	1	1	0	Mechanical Eng.	Full Professor	4	6	6	€ 36.500	76
2	3	1	1	1	0	Telecommunication	Associate Professor	4	7	6/7	€ 36.500	83
3	6	3	0	2	1	Automotive Eng.	Associate Professor	2/3	4	4	€ 47.500	70
4	3	1	2	0	0	Civil Eng.	Associate Professor	3	4	5	€ 43.000	82
5	4	1	0	2	1	Biomedical Eng.	Associate Professor	4	6	6	€ 36.000	87
6	4	2	1	1	0	Energy	Associate Professor	3/4	5	5	€ 39.700	96
7	3	1	2	0	0	Industrial Eng.	Research fellow	3/4	6	5	€ 11.500	74
8	3	2	0	1	0	Chemical Eng.	Associate Professor	3	4	4	€ 40.000	73
9	3	1	2	0	0	Mechanical Eng.	Full Professor	4	7	6	€ 41.500	79
10	6	2	3	1	0	Biomedical Eng.	Associate Professor	3	5	4	€ 41.000	84
11	5	3	2	0	0	Design and Architecture	Associate Professor	6	7	7	€ 14.000	71
12	4	2	0	2	0	Civil Eng.	Associate Professor	3	5	4	€ 43.000	93
13	4	2	2	1	0	Aerospace Eng.	Associate Professor	5	7	n.a.	€ 16.100*	54
14	2	1	0	1	0	Energy	Associate Professor	3	6	n.a.	€ 49.000*	55
15	4	1	1	2	0	Telecommunication	Full Professor	3	5	n.a.	€ 45.600*	59

Note: The data reported in the Table refer to the status of each project at the time of application (except for the actual TRL). The research team may have included internal faculty members (e.g., professors, fellows etc.) but also external faculty members (e.g., professors from other universities, people working in firms etc.), who are identified in the "Others" column. "Research Area" refers to the main research domain of the PI. "Starting TRL" is the TRL at the beginning of the PoC (evaluated by the TTO). "Final TRL" is the TRL expected at the beginning of the PoC (evaluated by the research team) and "Actual TRL" is the TRL achieved at the end of the project (evaluated by the TTO together with the Evaluation Committee). "Approved grant" refers to the grant assigned to each project (*amount required but not assigned to rejected projects). Each professor participating in each project has an average H-index above the median of other Italian professors in the same position.

Table 3
Data Inventory

Data Type	Quantity	Original data source	Original (intended) data audience	Insights in particular for
Interviews	12 on funded RBIs 3 on not funded RBIs 22 hours approximately and 128 pages of transcription	Informants	Analysis for this study	Inhibitors, Enablers
Strategic report	46 pages	TTO	University Board of Directors	Inhibitors
PoC call and related documents: applications, funded PoC reports (on-going and final)	713 pages	TTO and PoC call applicants	TTO	Inhibitors, Enablers
Archival records: reports of the Evaluation Committee, e-mails, etc.	1273 pages	Vice Rector for Technology Transfer (VRTT)	VRTT, PoC participants and TTO staff	Inhibitors, Enablers
Final Evaluation Reports	208 pages	TTO	TTO and VRTT	Enablers
Meetings minutes and direct observations	244 pages and 140 hours approximately	TTO, VRTT, Informants	TTO, VRTT, Evaluation Committees	Inhibitors, Enablers

Table 4
Classification of theoretical enablers and illustrative quotes

Enablers	Characteristics	Second-order categories	Illustrative quotes
Relational Enablers	Factors that enable TT by closing the relational gap between the stakeholders involved in the technological development, potential users and the research group	Trust and commitment	*"You gain credibility with respect to external partners only once you provide something close to a product, and the PoC gave us this opportunity. They now trust us completely" [Q1]*
		Network creation	*"The PoC has been a great experience, and the higher value added has been achieved from bringing people we had never met before around the table" [Q2]*
		Communication	*"I think that another important achievement of the PoC has been to put us in contact with people with decision-making power within firms, and not only with technical experts. We have now learnt how to approach them" [Q3]*
Structural Enablers	Factors that indirectly favor scholars to be more effective and successful in TT and eventually in research development. They lower specific barriers to the context in which they operate.	Availability of funds	*"The PoC has given us the right amount of money we needed to build a prototype, with the right timing" [Q4]*
		Reduced U-I mismatch	*"Through the PoC, we have had the opportunity to discuss matters with our potential users, and it has allowed us to let them understand the technology. We are now working on reducing the number of sensors in the product, since the firm told us that they create complexity and reliability issues. We are now bringing a more credible product to the market" [Q5]*
		New research opportunities	*"I realized immediately that there were two different markets with different needs. The first one needs a more complex product and new research, the other one a simplified version of what we had" [Q6]*
Cultural Enablers	Factors that enable scholars to think about external applications and overcome old beliefs that can harm RBI commercialization	Effective identification	*"I tried to win a competitive research project and I was told by the evaluation committee that it was unfeasible. Now, with the PoC, I know we can do it. What I learned is that I should pursue my idea in future research projects that are not just limited to its conceptual development" [Q7]*
		Translational approach	*"[…] substantially, my basic research is always the same and there are few marginal differences in how I conduct basic research now. Conversely, there are many differences in what I do after basic research is conceived. For instance, I immediately divide projects with a 'publication scope' from projects with a 'commercial scope'. This allows me to decide where to put fewer/more resources and to program the tasks over the subsequent months" [Q8]*

Table 5
Summary of the main contributions to the literature

		Stream of literature			
		PoCs *(e.g., Munari et al., 2017; Rasmussen and Rice, 2012; Gulbranson and Audretsch, 2008)*	**Formal vs. informal models of Technology Transfer** *(e.g., Weckowska, 2015; Gilsing et al., 2011)*	**Tensions in university-industry Technology Transfer** *(e.g., Ambos et al., 2008)*	**Role of the TTO in Technology Transfer** *(e.g., Bradley et al., 2013)*
Main Findings	**Relational, structural and cultural enablers are the underlying mechanisms of the commercialization of RBIs through PoC programs**	• PoCs are not mere funding schemes promoting TT. Instead, they rely on more complex mechanisms than the provision of money to favor the commercialization of RBIs. • PoCs overcome pull models of TT by promoting an "inside-out" logic: researchers "get out of universities" to search for industrial partners and investors, rather than the opposite.		• PoCs reduce the need of a dual structure to manage tensions in TT by perfectly aligning research and commercialization objectives for academics. This happens through the emergence of cultural enablers.	
	Relational enablers directly impact on the commercialization of RBIs. Structural and cultural enablers indirectly impact on it through relational enablers.	• The development of relational enablers in academic teams acts as a catalyst for industrial players, as scientists are better able to communicate with them and align the value proposition of their RBIs to market needs.	• Informal TT mechanisms promote the commercialization of RBIs (relational enablers). However, informal mechanisms emerge by means of formalized schemes as PoCs. • PoCs, thanks to the support of a team of external evaluators and the provision of money, allow PIs to get free from technical development duties and to devote more time to build up network relations with industrial partners. • PoCs favor the culture of commercialization by stimulating PIs to collaborate with industrial stakeholders		• TTOs are no longer required to act as guarantors of the reliability of the technology for industrial stakeholders, as PoC overcomes pull models of TT. • TTOs remain in charge of the formal aspects of PoCs (e.g., its design) and are responsible of accompanying research groups along the execution phase.

		even during the basic research phase.

Figure 2
Data structure for PoC enablers

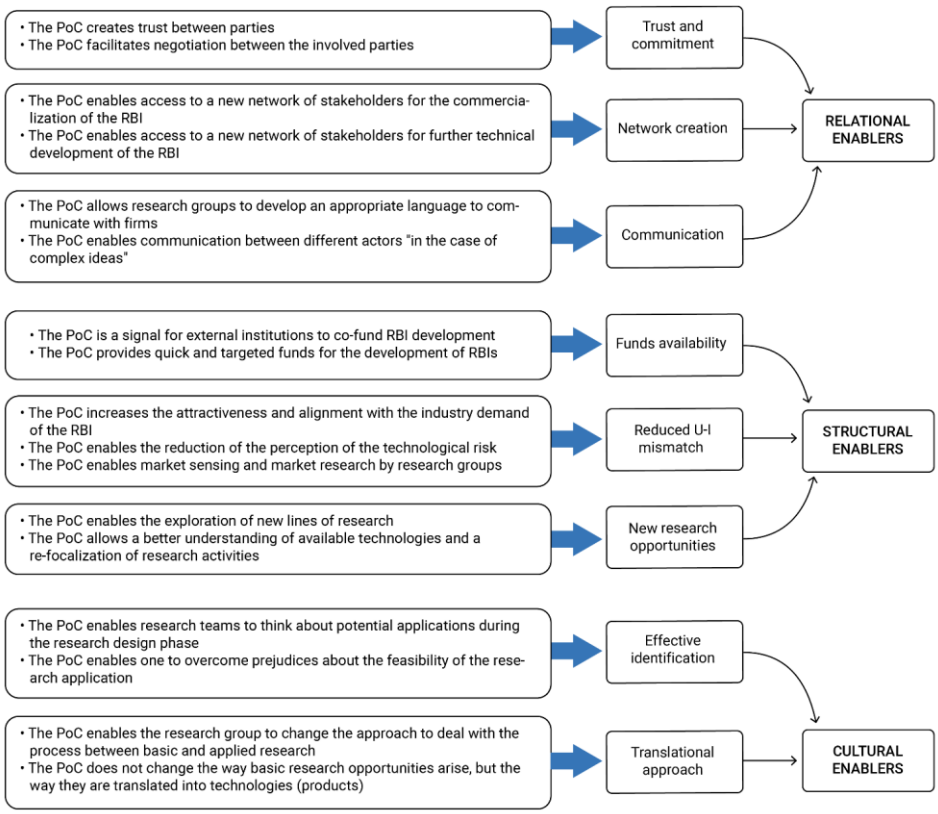

Figure 3
Relationships between inhibitors, PoC-induced enablers and the related enabling mechanisms

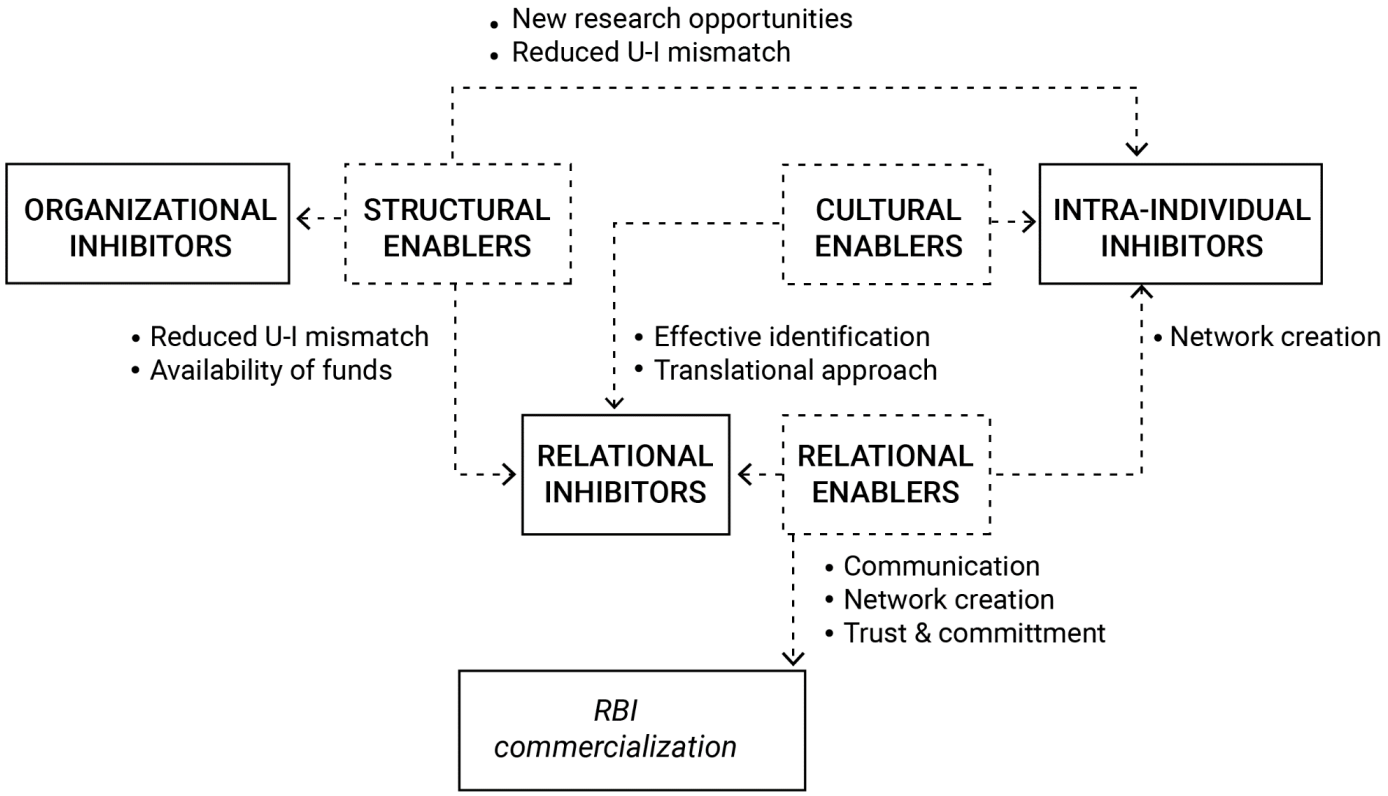

Figure 4
An enabling model for the commercialization of RBIs