Hurdles in University-Industry Technology Transfer: Why Research-Based Inventions are Not Transferred to the Market?

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Daniele Battaglia, Emilio Paolucci, and Elisa Ughetto

***Abstract*—Despite their importance, previous literature on university-industry technology transfer has overlooked identifying the factors and the mechanisms inhibiting the successful commercialization of research-based inventions (RBIs). In this article, we adopt an inductive approach to explore the factors inhibiting the transfer of RBIs developed within universities to the market. We do so by conducting a case study on 15 RBIs developed within a prominent Italian technical university. Our results show that three main classes of inhibitors prevent the commercialization of RBIs: institutional, interpersonal, and cultural. Although all three factors are important in preventing knowledge and technology transfer between universities and their industrial ecosystem, we find out that relational inhibitors are the most prevalent ones, whereas institutional and cultural contribute to reinforcing the effect of relational inhibitors. We discuss how such inhibitors could be tackled by technology transfer ecosystem actors to eliminate obstacles to the transfer of knowledge and technologies from universities to industry; we also discuss the effectiveness of formal policies and instruments in lowering such inhibitors.**

***Index Terms*—Inhibitors, research based inventions, science commercialization, technology transfer, university-industry TT.**

I. Introduction

UNIVERSITIES are the backbone of national systems of education and research through which the future workforce is trained, and new inventions are developed. Besides these two missions, in recent years technology transfer (hereafter TT) has reinforced its relevance following the attempt of university managers to increase the monetization of research activities. Nowadays, universities appear to be more and more "patent-centric" in order to monetize their research efforts via commercialization of science and entrepreneurship [1].

TT refers to the process through which research-based inventions (hereafter RBIs) developed within university laboratories are brought to the market by firms and other institutions [2]. TT has progressively gained momentum among university managers as the retention of patents protecting the research results coming from university labs was representing a huge cost for such institutions and could hardly create positive social benefits for both the industrial ecosystem and the society [3]. Intellectual property regimes governing university inventions have been increasingly characterized by a convergence toward a greater control of intellectual property (IP) management by university administrators. For this reason, many local and international policies have been promoted by governments and universities in order to boost the transferring of RBIs to firms and society [4], [5]. Despite this huge effort, a number of problems still affect university-industry TT. In fact, many RBIs stay trapped in the so-called "valley of death" where they cannot evolve in order to become fully commercialized products [6], [7]. According to Swamidass [3], over 75% of patents are not commercialized by universities and do not bring any value to society.

The recent literature on university-industry TT has analyzed these problems at the macrolevel, mesolevel, and microlevel [8], trying to identify the factors that may inhibit the successful transfer of technologies from universities to firms [9], [10]. Among these elements, prior studies have examined the inhibiting factors pertaining how universities are organized [11], research and commercialization is funded [11], and environment obstructs successful TT activities [8], [12]. Despite these advancements, however, the literature has overlooked the mechanisms through which inhibitors hamper effective TT and—ultimately—the commercialization of RBIs. Understanding such mechanisms is of paramount importance, given the extensive number of stakeholders involved in the TT process [13], each with different backgrounds and objectives [14]: research staff (e.g., professors), technical experts of TT (e.g., technology transfer office (TTO) staff), investors (e.g., business angels), and industry players (e.g., company managers and R&D directors).

In this article, we want to explore the relationship between the different inhibitors that affect university-industry TT through an inductive approach based upon the analysis of 15 cases of research projects with commercialization purposes developed within a prominent technical university in Italy. We extend prior works on the factors limiting the commercialization of RBIs and contribute to the stream of literature on TT to discuss possible solutions that universities may take to promote superior TT outcomes [15]. Despite a few relevant contributions [9], [16], [17], research on the factors preventing the commercialization of RBIs has been scattered and, more importantly, has underestimated the

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mechanisms linking the different kind of inhibitors at work in limiting university-industry TT.

Our results indicate that: 1) university-industry TT is limited by three factors: institutional, interpersonal, and cultural inhibitors; 2) only interpersonal inhibitors directly hamper university-industry TT, whereas institutional and cultural inhibitors reinforce the direct negative effect of interpersonal factors. Our findings depict a situation in which university researchers strive to commercialize their research because of the lack of contacts with the industrial ecosystem, such that the weakness in informal TT dominates the strengths in formal TT instruments.

The rest of the article is organized as follows. We review the literature on the inhibiting factors to TT in Section II. We introduce the methodology and the context of study in Section III. We present the results of our inductive approach in Section IV. We discuss key implications for ecosystem actors and TT activities in Section V. Finally, Section VI concludes the article.

II. Background

A. TT and TTOs

The development of TT activities has gained more and more traction in the last 30 years following the need of universities to invest in basic research projects and the contextual reduction of their budget [18]. The quest for new sources of income has pushed university managers toward a greater control of IP management [19] in order to increasingly rely on the commercialization of technologies developed within university boundaries [20]. Although this process is not frictionless (e.g., patent litigations may often occur [21]), following this gradual evolution, a TT ecosystem has started developing in most universities in developed economies [13]. One of the first steps following the raise in TT activities within universities has been the establishment of TTOs. TTOs are organizations whose main task is to provide support to the commercialization of research outputs. Among the activities in which TTOs are involved, there is the management of the IP developed within university boundaries, as well as the management of all the licensing agreements with companies willing to exploit such IP [22]. The role of TTOs also entails guiding and providing support to scientists willing to develop further their research idea (for instance by developing a patented scientific discovery into a developed product) [23], as well as fostering academic entrepreneurship [24].

At a general level, the range of TTOs' activities is very much linked with their size [25]. Previous research has found that both the kind of activities developed and their performance are a function of the number of employees hired in TTOs [26]. In the European context, TTOs have found different ways to overcome dimensional issues by organizing themselves both internally [27] and externally [28] in order to achieve scale effects that may boost their performance.

In a similar manner, TTOs' activities are characterized by a great heterogeneity across countries. Munari et al. [4], in the context of the EU, have described how the diffusion of proof of concept (PoC) programs [29] and university seed funds is more pronounced in Nordic and Western countries rather than in Southern and Eastern European countries. Similarly, such differences have also been detected with regard to the adoption of knowledge transfer strategies [30].

B. Inhibiting Factors to TT

Despite the development of TTOs, incubators, and other actors within the local ecosystems of innovation [31], many universities still strive to commercialize research outcomes. According to Cunningham et al. [9], principal investigators (PIs) leading research projects funded by public bodies continuously seek to balance expectations from financing bodies (i.e., related to the TT dimension) with personal research interests (i.e., related to the development of new knowledge). This concept has been often named as "orientation asymmetry" [32] and refers to differences in goals and expectations that academics and their industrial counterparts have.

According to the university-industry TT literature, such asymmetry is linked to four main factors. The first aspect relates to temporal discrepancies between academics and firms. If, on the one hand, firms are concerned with short-term objectives (e.g., profits and growth), academics, on the other hand, do not fear the pressure of achieving quick results, thus endorsing a longer-term orientation toward research [33]. A second consideration is related to the different performance evaluation metrics that academics and firms adopt. While firms seek to profit from their business through their interaction on the market, academics are more interested into empirical findings, new theoretical models, and measurement techniques [34]. According to this view, industry and academia rely upon two different institutional logics: the commercial and the academic one, respectively [14]. Such logics are responsible for belief rules and assumptions that people develop by participating in one or the other organization. In this vein, academics often overvalue personal rather than organizational and societal needs when developing their research activities [35]. This has often been a huge constraint to TT activities. In fact, because academics are evaluated based on their publication track records and curriculum prestige, they rarely have the personal incentive to prefer—for instance—patenting over publishing or licensing a technology or a method over opening a new avenue of research [36].

Finally, academics are often prevented in TT activities by other two main tensions: at the organizational [16] and relational levels [17]. The first ones prevent scholars from networking with firms given professors' limited proactiveness in seeking funds for further technology readiness level (TRL) advancements of RBIs. In this vein, previous research has found that academics who are more inclined to participate in research grants are also more prone to transfer their research results to firms and society [37]. Tensions at the relational level, instead, take place because researchers are scared by the loss of academic freedom, control, and (intellectual) property on their research [38], [39]. It follows that those who want to protect their connections with the industry environment might be induced to limit their collaborations with other researchers [40]. All these factors are detrimental to the TT activity and limit the university-industry TT of universities [41].

Despite the broad understanding of such factors, we have still limited knowledge about how such factors are related one to the other. For instance, we do not know what relationship exists

between those factors hampering RBIs commercialization at the individual level (e.g., scientists) and those at the organizational level (e.g., university). The aim of this study is to provide further nuance to the attempt of disentangling such relationships.

III. Methodology

The ideal research setting for conducting our study is a university endowed with a significant capability of TT (i.e., in terms of technologies potentially transferable to industry and/or society). In this vein, we selected Politecnico di Torino (PoliTo) as a revelatory case study to identify both the restrictions and problems associated with the commercialization of RBIs [42]. This choice allowed us to exploit the in-depth knowledge of the institutional environment and accessing confidential information, which are of paramount importance in case study identification [42].

We adopted an inductive method [43] to let distinct patterns on inhibitors emerge. The inductive method is a bottom-up approach that moves from specific observations to broad generalizations and that recognizes the existence of specific patterns among observations [44]. Once patterns are discerned, a generalization of the knowledge is made to explain the phenomenon under scrutiny. This method was complemented with the adoption of the grounded theory interpretative approach [45], which allows moving from the particular observations to a more general set of theoretical propositions in a continuous interaction loop until a theory emerges [46]. Interpretative research positions the interpretation of the observed at the center of scientific explanation [47].

A. Research Context

PoliTo is the oldest technical university in Italy (it was established back in 1859) and operates in the specific domain of technical sciences (Engineering and Architecture). It has a long tradition of teaching and research, with more than 33 000 students enrolled in BSCs and MSCs courses (more than 14.5% of the students are from foreign countries), 700 Ph.D.s, and a faculty of about 900 professors.[1] In 2022, it ranked 33rd in Engineering and Technology according to the QS University Ranking by subject. About 20 years ago, PoliTo began emphasizing the importance of the "Third Mission," that is, it began to strengthen its engagement in the transfer of RBIs to industry and society. In the early 2000s, a TTO was established with the objective of supporting scholars in patenting the results of their research and eventually establishing new ventures through the creation of spinoffs. Since 2008, about 400 technologies have been patented and over 50 spin-offs have been created. Fig. 1 reports PoliTo's active patents and patents filed between 2015 and 2022.

As of 2021, about one-fourth of the active patents are actively licensed to third parties and generate revenues for the University. The University also created a Business Research Center, aimed at locating the research laboratories of local and international firms (e.g., General Motors, Pirelli, Microsoft, Vishay, etc.) within the university campus to support the cross-fertilization of knowledge from different domains. In addition, the university also created an incubator (I3P), which was recognized as the Best Public Business Incubator in the world by the World Rankings of Business Incubators and Accelerators 2019–2020. Overall, these actions were aimed at: 1) leveraging on the knowledge accumulated through applied research projects developed in collaboration with firms and 2) entering into new technological specializations to stimulate "Excellence in research," as promoted by the European Commission (e.g., nanomaterials, bioengineering, energy storage, etc.).

In the last five to ten years, these strategic decisions have been fruitful in positioning PoliTo within the upper echelon of European universities, with a particular reference to TT activities.[2] The relevant position held by PoliTo in the TT field is testified by a number of sources. First, ANVUR (the National Agency for the Evaluation of Universities and Research Institutes, which evaluates the performance and the activities of public and private universities in Italy) has recognized PoliTo as the best Italian university (out of 61 universities) with regard to the development of activities and impact of the Third Mission [48]. Second, a comparison with data retrieved from ASTP (the European Association for TT) on FY 2019 [49] reveals that PoliTo is one of the most prominent universities in TT in terms of invention disclosures (63 versus a European average of 26, and a median of 9), priority applications (38 versus a European average of 12, and a median of 6), and fraction of active patent families that are licensed or optioned (about 18%, in line with other European TTOs). Moreover, with reference to academic entrepreneurship and spin-off creation, PoliTo performed well above the average of European TTOs by creating six new spin-offs in 2019. This positions the university in the top 6% of the distribution of other European institutions. All in all, PoliTo results as a prominent university in terms of TT with reference to other Italian and European institutions.

As PoliTo embarked on the "Third Mission," it progressively invested in "Research commercialization" activities, such as incubation and start-up support, entrepreneurship education, and funding support for technology development, licensing, and patenting. It also increasingly incentivized traditional research collaboration, networking, consulting, and face-to-face communication with industry and society—the so-called "Academic Engagement" activities [19]. In this context, several internal calls for grants targeting professors and aiming to promote the commercialization of RBIs have been launched. In this work, we focus on one of such calls—which has been launched in 2017—to assess the inhibiting factors to the commercialization of RBIs.

B. Data Collection

We collected data from multiple sources. The first source was represented by the applicants (i.e., professors and researchers at PoliTo) to an internal PoliTo call to finance the commercialization of RBIs. Second, following the dictates of the grounded theory, we acted as direct observers in several activities related

[1]Data refer to the 2017–2018 academic year. The faculty data include Full Professors, Associate Professors, and Assistant Professors.

[2]https://www.umultirank.org/ [Accessed: February 23, 2023]

Fig. 1. Active patents and patents filed by technological category (2015–2022).

to the call (for about 140 h).[3] Third, we also collected data from archival documents (e.g., e-mail and other unstructured materials), reports and databases provided by the TTO. Overall, we examined the following documents: a strategic report provided by the TTO (46 pages), the internal call documents (applications, interim and final reports, for a total of 713 pages), and the Evaluation Committee's reports (1273 pages). The projects submitted to the internal call (including mid-term and final reports) provided a description of the RBIs, of the activities foreseen to increase their TRL, as well as budget (mis)allocation issues. We levered such material to deepen our understanding of the development of each project, as well as the hurdles the research teams faced in promoting the commercialization of their RBIs.

Finally, we conducted 15 semistructured interviews with the PI of each project involved in the call. PIs were chosen as the key informants, because of their long-term experience in conducting research projects. PIs are also well informed about the obstacles hampering their RBIs from advancing the TRL and can represent a fruitful source of information on inhibitors [50]. In conducting the interviews, we followed a strict protocol [42]. First, before the interview started, one researcher provided a preliminary case report gathering the information collected through the archival documents and the direct observations [42]. Second, we organized the interviews so that at least two researchers were present. During the interview, questions were asked by one researcher entitled to this task, whereas the other(s) took intensive field notes [42]. We recorded and transcribed verbatim each interview. In the interview, we adopted a retrospective approach [51] and asked the interviewees to discuss the strategies and processes adopted to commercialize their RBIs before the launch of the internal funding call. The statistics regarding the PIs interviewed are reported in Table I.

This multilevel approach adopted through the use of several sources of information (interviews, direct observations, archival data) allowed the research team to perform data triangulation, to substantiate the theoretical framework and to enhance the understanding of the phenomenon under study [42], [52].

[3]We observed the meetings organized by the TTO relative to the selection and final assessment of the projects submitted to the call. We also participated in the individual meetings between the TTO staff and the teams. All these meetings, which took place in 2017, allowed us to collect the intimate opinions and perspectives of the actors involved.

TABLE I
SUMMARY STATISTICS ON PIS INCLUDED IN THE STUDY

Gender	Age (average)	Nationality	Previous international working experience
Male: 75% Female: 25%	44.5	Italian: 100%	Yes: 67% No: 33%

TABLE II
CLASSIFICATION OF THE THEORETICAL INHIBITORS AND ILLUSTRATIVE QUOTES

Inhibitors	Characteristics	Second-order categories	Illustrative quotes
Institutional Inhibitors	Problems related to policies, incentives, and resource allocation processes of the context in which the academics work.	Lack of resources	*"If you have an idea, you must pay for the development yourself. Very often we use the profits of research project A to subsidize the research activities of nascent research project B."*
		University-Industry misalignment	*"There is a general ignorance on the firm side, which is not a problem that is just limited to small and medium enterprises. They don't have a culture of innovation; they just look for profits."*
		Incentive mix and balance	*"Our objective is always to publish, not to design products or to offer consultancy services. [...] Research and publication are in the DNA of our research group. We have never considered the issue of designing a product or developing it."*
Interpersonal Inhibitors	Problems related to other stakeholders involved in the development and commercialization of the research.	Disconnectedness	*"We don't have systemic contacts with firms. I would say it happens sporadically. It is often a matter of chance. For instance, I set up a contact with the Alpha company because the brother of a friend of mine was working in Alpha."*
		External frictions	*"We once experienced that someone stole our work. It was an industrial partner we were working with in a European project. He knew the method since we had had an exchange of people during the project. After a while, he tried to patent the materials developed himself. Unfortunately, these risks are quite common, even for people you trust."*
		Internal frictions	*"There is extreme competition for the projects (and resources) and they often end up in unfair practices. I had to consult a lawyer to understand whether the actions of a colleague of mine were damaging my work."*
Cultural and Value-Based Inhibitors	Problems related to the beliefs of the research team that can harm research development and commercialization.	Misconception	*"It is better to do things that do 'not yet exist': it is better to simulate rather than create something. If you operate in a virtual environment, you don't face the hard problems of reality and you are perfect at everything. [...] Anyone who has tried screwing a screw has realized it is a long process. Vice versa, switching on a PC to run a simulation is quite quick, and this is polarizing research."*
		Fallacy	*"Companies do consolidate things. They don't care that we have brand new innovations to give them."*

C. Data Analysis

The analysis of the data followed an inductive approach. To identify the inhibitors to the development of RBIs, we interactively updated our emerging theoretical framework by moving back and forth between data (from interviews/archival documents) and theory [53]. In the light of the grounded theory [46], we used a comparison technique [45] to guide subsequent interviews and collection of data. To alleviate the likelihood to incur into a retrospective data collection bias[4] and to enhance the validity of our theoretical intuitions, we continuously combined the insights gathered from the interviews with archival documents and observational data [42], [54] throughout the process.

We followed the Gioia methodology [55], [56] to analyze data along three phases of coding. We first linked empirical observations on why RBIs are difficult to be transferred from academia to society by means of the single patterns that emerged from the interviews. The first step was in fact a line-by-line in-vivo coding of the data on inhibitors. We then converged to broader categories, grouping the identified knowledge into "second-order" theoretical levels [56, p. 20]. Finally, we linked such general concepts to theoretical insights. Following Gioia et al. [56], first-order and second-order themes were aggregated into a data structure tree, which was iteratively updated whenever new data (e.g., interviews) were added.

We classified inhibitors into three theoretical categories, namely institutional, interpersonal, and cultural-value-based inhibitors. Table II and Fig. 2 describe the data structure of the results that emerged from the interviews and from data triangulation with the inclusion of illustrative quotes.

IV. RESULTS

A. Institutional Inhibitors

Institutional inhibitors concern recurrent problems that research teams face to increase the TRL of their RBIs. They also reflect policies, incentives, and resource allocation processes that create permanent obstacles to meeting such goals. Institutional inhibitors negatively affect the advancement of the TRL. For instance, they can prevent scholars from developing specific research projects due to the unsuitableness of the available funds to target an advancement of TRL, to the misalignment of objectives (between the research team and firms willing to explore the technology) and to the absence of an appropriate incentive mix and balance within the academic context. Institutional inhibitors are thus composed of three second-order categories: "Lack of resources," "University and Industry misalignment," and "Incentives mix and balance."

[4]In principle, this bias [54] should not apply to our research setting because: 1) academics—especially in engineering faculties—are constantly devoted to transferring the results of academic research toward society and 2) the internal call for funding RBIs was a unique policy initiative that could be applied just to some research projects sharing certain characteristics. Therefore, university fellows still face difficulties in bringing research to reach a commercialization outcome.

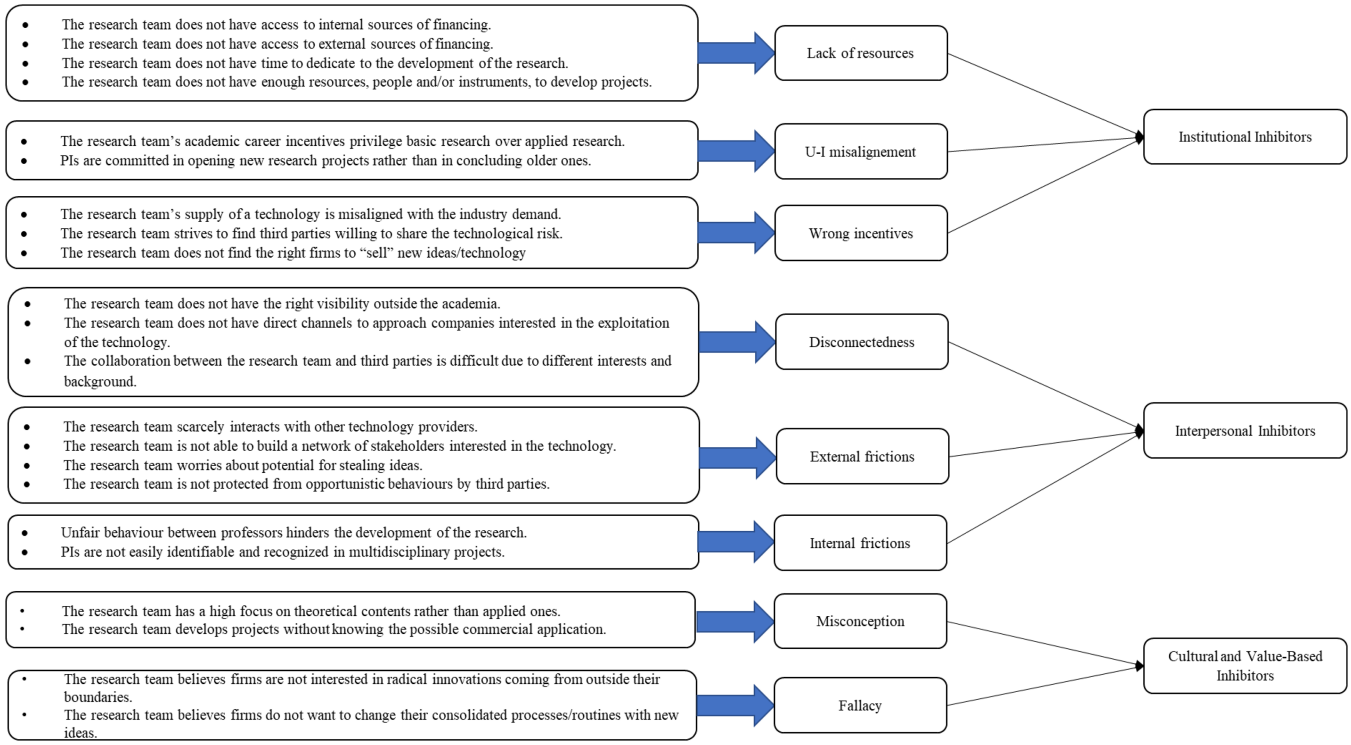

Fig. 2. Data structure.

1) Lack of Resources: Limited access to funding is an obvious obstacle for scholars pursuing an advancement of TRL and the commercialization of RBIs. The lack of resources specifically targeted for TRL advancement was a recurrent issue raised by the interviewees, even though the research teams had no specific complaints about the general shortage of research funds (e.g., the average annual research funds available to the interviewed teams ranged between 100 000 and 500 000 Euros).

Three additional aspects, related to the lack of resources, emerged from the interviews. First, limited funds are available to target increases in the highest levels of TRL. Second, increasing a TRL by just one level (from TRL 3 onward) could require more resources than those provided by the university (or acquired by competitive funds) to support "standard" research activities (this is particularly evident for biotech research activities). Moreover, even in the presence of promising technologies, firms are sometimes not willing to finance the development of RBIs when the level of TRL is lower than 6, since they do not want to face technological risks that they are not able to manage.

Research teams try to overcome these constraints by cross-subsidizing their research projects: they can use the "residual funds" associated with other projects to finance the first stages of development of their RBIs in order to obtain the preliminary results needed to apply for larger grants (e.g., European projects) or to start collaborations with industry.

The research groups also complained about the lack of other types of resources (i.e., time and people). These factors were in particular stressed by informants and are clearly connected to the scarcity and timing of available funds. On the one hand, it is in fact difficult to engage young people to work full time on a project for a two-third-year period when there is uncertainty about the availability of funds to hire them after that period. On the other hand, relying on temporary staff—although being advantageous in terms of costs—is likely to lower the speed and continuity of developing RBIs.

The interviewed scholars also emphasized their overwhelming workload in addition to research (due to teaching, fundraising, and administrative duties), which often prevents them from providing an RBI with efficient guidance and from continuing its development until commercialization. In addition, existing academic incentives indicate that staying focused on funded research projects is much more rewarding and simpler than increasing the TRL of existing RBIs (especially if the uncertainty of funding is high and negotiations are time-consuming).

2) University-Industry Misalignment: This inhibitor is about the difficulty that universities and firms face in aligning their objectives and sharing risks and investments when the TRL of an RBI ranges from three/four to six. The PIs we interviewed reported their direct experiences about how difficult it is to transfer RBIs to firms. This may depend on a misalignment of the objectives between academics and practitioners that often causes a bad planning of how to advance the TRL. In fact, academics have limited knowledge of the application domain of their RBIs and/or are not able to explore alternative fields of application, as it is very hard and expensive for them to collect such knowledge. Accordingly, academics do not seem to be interested in the segmentation of the needs of industry on a specific topic. They work according to a "push logic" on very general problems, assuming that the developed research will eventually be adopted by firms without any problems.

Two other key elements influence university-industry misalignment. The first one is related to how the risk of failure can be shared: the university needs to cover all the marginal costs of TRL advancement, while firms are not willing to invest in research projects that foresee a high risk in terms of market application. The second one deals with the fact that it is difficult for research teams to "sell" their new technology to firms by explaining how they can enhance existing products and/or create new ones. Under such conditions (which are more familiar to VC-like investors), it is hard for firms to understand the content of RBIs and to allocate the investments needed to work together with the university.

3) Incentives Mix and Balance: The last feature that characterizes institutional inhibitors is related to the incentives scholars have to transfer research results toward industry and society as a whole. A recurrent pattern in each interview was related to the rewards academics obtained from TT activities with respect to research activities. The informants highlighted the role of the "publish or perish" imperative since career advances are mainly evaluated on narrow research productivity parameters. The PIs also underlined the fact that researchers may have more incentives to develop basic research projects than applied ones since their results are more suitable for publication.

Another relevant issue related to incentives concerns the reasons PIs begin new projects. It emerged, from the interviews, that many PIs are more interested in showing colleagues their ability to manage and develop several projects rather than in finalizing and concluding them. This is because, within academic departments, senior professors informally value the capability of their colleagues by considering the number of projects they manage rather than to the results they achieve. This is a wrong incentive for PIs, who are pushed to start new projects as much as possible, and to squeeze their collaborators (e.g., Ph.D. students, researchers) over multiple and different activities. Clearly, younger resources have more incentives, for career reasons, to work hard on just a few projects in order to achieve a valuable result, rather than to move continuously from one project to another. This creates a tension within the research groups that often constraints the development of RBIs.

B. Interpersonal Inhibitors

Interpersonal inhibitors refer to the problems academics have to face to build connections with other stakeholders, whose involvement is key for the development and commercialization of RBIs. Academics generally lack business experience and have difficulties in signing contracts with firms, due to the high complexity resulting from the technological uncertainty of RBIs and the attribution of property rights. The entity of these problems is also magnified by the opportunistic behavior of firms, which reduces the willingness of scholars to disclose information and knowledge, thus creating a vicious circle that limits the possibility of any type of collaboration. These inhibitors, taken together, prevent researchers from reaching the stakeholders that could, in principle, introduce the right complementary resources needed to advance and commercialize RBIs. Interpersonal inhibitors emerge from three second-order categories, namely, "*disconnectedness*," "*external frictions*," and "*internal frictions.*"

1) Disconnectedness: A major issue in the development and commercialization of university-based research is the distance that academics perceive from the industrial domain, which ultimately leads to research projects and their expected results being disconnected from "real world" challenges. The informants identified four main issues from which disconnectedness may arise. The first one concerns the fact that research teams may have a weak reputation outside the academic environment. In this situation, trust between firms and research teams cannot be the base for negotiating a funding agreement aimed at increasing the TRL of an RBI. This issue is particularly relevant since research groups often maintain relationships with a very small set of firms; thus, the exploration activities needed to assess the potential of RBIs are limited.

A second issue is that relationships are generally established and maintained by the PI of a research team. This fact has two important implications, which may magnify the disconnectedness between research groups and firms. On the one hand, relationships tend to take on the form of personal links. Once a PI moves away from one university to another one—or once he/she retires—the link is simply lost. On the other hand, this limits the impact of new ideas from young researchers, since they do not have any direct personal contacts with firms.

The third aspect of disconnectedness concerns the way research groups approach companies that may be interested in the exploitation of RBIs. The informants reported that they are rarely able to identify interested firms in order to discuss the commercial value of an RBI, since they have little information about its economic potential, and they lack adequate business skills. In this vein, a difficulty they usually face is related to their capability of explaining the key aspects of RBIs to businesspeople.

A fourth problem that causes disconnectedness between academics and practitioners is that the two groups have different interests and backgrounds. Practitioners live in a context that is focused on creating new streams of revenues and/or cutting costs and have the chance to explore a broad space of technological solutions. Both groups operate at different levels of abstraction and strive to find a common ground to discuss problems and solutions. This—in turn—hinders communication between the two parties.

2) External Frictions: Research teams face two other kinds of interpersonal inhibitors, which we have named "external and internal frictions." External and internal frictions are related to the relational impediments that are particular of academia (internal frictions) or which arise from the external environment and from the stakeholders that are part of it. The latter reflect the difficulties that research teams have in creating stable relational and contractual ties with external stakeholders. Differences in languages and culture create communication barriers that lead researchers to prefer to interact with people who have technical roles in firms, rather than managerial ones.

External frictions also arise due to concerns of the research team about the potential theft of ideas from external stakeholders. This is a somewhat harmful problem because firms (especially larger ones, which have the financial power to develop large R&D projects) may use an RBI as a source of ideas that they may then further develop internally; moreover,

any presentations of RBIs made without paying attention to confidentiality issues may invalidate patents or create leakages of intellectual property. This issue emerged quite often during the interviews. Moreover, this problem is linked to the fact that it is difficult, at this TRL stage, to protect research teams from the potential opportunistic behavior of third parties. In fact, they often maintain contact with firms and other stakeholders through informal contacts that are beyond the jurisdiction of a contract, and firms are likely to exploit such contractual weaknesses.

This problem is amplified by the fact that, in order to stay competitive, firms create incentives for their employees (in the form of career advancements, bonuses, etc.) that make them "greedy" to scout and capture opportunities originating from academic RBIs. At the same time, at lower levels of TRL, it is difficult to define the boundaries of an RBI and then allocate property rights accordingly. The informants mentioned several times controversies arising from the possibility of patenting a technology/method since firms want to be the exclusive holders of the intellectual property rights.

3) Internal Frictions: Internal frictions are the last dimensions that characterize interpersonal inhibitors. A recurring theme that emerged during the interviews with the informants is related to the opportunistic and unfair behavior between scholars from the same university. Such behavior may hinder the development of research, as well as the possibility of taking on research projects that are the most suitable for the characteristics of the research team. It has been highlighted that some research teams strive to attract resources, even in areas that are not really in their specific domain of competence, in order to maintain the integrity of the staff (e.g., to fund temporary positions over time) and to legitimate their visibility within the university.

Other relational problems have been reported, at a more microlevel, concerning leadership within research groups. This issue is in particular related to multidisciplinary research teams, where an exchange of complementary knowledge between researchers is required, since none of the team members can have all the technical skills necessary to manage the project. During interviews, the informants reported problems in the coordination activities of the research projects, due to the difficulty of clearly identifying a PI for the project. The interviews showed that formal hierarchical mechanisms do not satisfactorily mitigate this problem for two main reasons. First, even though there is a hierarchical difference between scholars (e.g., Full Professor versus Associate Professor), the difference in the technical knowledge between the two parties implicitly allows them to act as PIs due to the specific contribution they make to the project, and due to the lack of specific knowledge of the other researchers. Second, in many projects, there is no clear hierarchical difference among the participants as a result of the small number of tenured positions available (in the Italian case, only Full and Associate Professors). In fact, many research groups employ Associate Professors as the PI, and other members of the research group hold the same academic position. In these cases, participants in the research group may be more reluctant to recognize the coordination role of PIs who have the same academic position as they do. In other words, hierarchical dynamics are not very effective in such situations.

C. Cultural and Value-Based Inhibitors

Cultural and value-based inhibitors refer to the problems that originate from the misleading beliefs that research teams have, or from their fallacy in interpreting and processing some signals from firms. These problems prevent researchers from successfully converting the effort put in the development of the research project into a commercially viable innovation. More specifically, they are related to problems that arise when the development of an RBI is pushed toward a direction that the market will not consider as valuable (such as a more theoretical—rather than applied—RBI), or which prevents PIs and researchers from interacting with firms and their representatives (as happens when some researchers and PIs self-create false beliefs about potential collaborating firms). Cultural and value-based inhibitors emerge from two second-order categories, namely, "*misconception*" and "*fallacy*."

1) Misconception: It emerged from the interviews that the theoretical and applied contents of research projects should be correctly balanced so that the scientific field may advance, and research findings may be transferred toward industry and society. However, it clearly emerged that scholars often care about complex and disregarded problems, which are not completely connected with the real needs of industry and society. The fact that their research is often too theory-oriented (and this is reinforced by the *publish-or-perish* imperative) and does not embed a vision about future applications has caused, from the very beginning, limited opportunities for the future commercialization of RBIs.[5] This problem is amplified by the fact that research teams often start developing a research project without knowing the potential of the technology under scrutiny to display a real application.

2) Fallacy: A relevant theme emerging from interviews refers to a wrong perspective scientists have of what firms need and what they look for in terms of innovation. We named this problem as fallacy. Fallacy refers to the wrong beliefs scientists have about the nature of innovation processes in companies, being incremental rather than radical. Academics believe that firms are conservative in their innovation routines and likely obstruct the introduction of radical innovations originating from outside their boundaries. Interviewees confirmed that the belief that companies may not be interested in radical RBIs completely discouraged them from interacting with firms.

V. Discussion

A. How Do Inhibitors Block the Commercialization of RBIs?

When analyzing the several hurdles faced by the research teams in transferring their RBIs to the market, it emerged that not all the three classes of identified inhibitors harmed the commercialization of RBIs in a direct way. Although a direct relationship for interpersonal inhibitors was found [57], it emerged that both institutional and cultural and value-based inhibitors had an indirect effect on the commercialization of RBIs (i.e., increasing the magnitude of interpersonal inhibitors) and self-reinforced each other in a vicious loop. Based on our

[5]Please note that interviewed researchers were not purely theoretically oriented (although their H-index is above the average of other Italian professors).

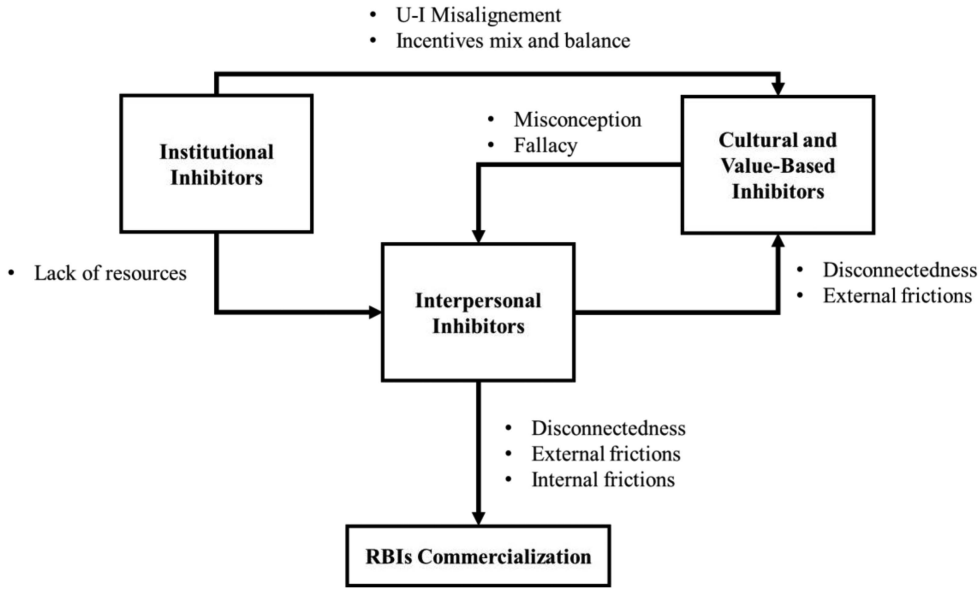

Fig. 3. Relationships between different inhibitors and the related mechanisms.

analyses, we represented these linkages in Fig. 3, in which the mechanisms that cause such relationships are represented on arrows.

We found that interpersonal inhibitors have a central position in limiting the commercialization of RBIs. The lack of adequate channels to approach potential adopters and other stakeholders who may be useful in bringing an RBI to the market (such as venture capitalists) represents a primary factor in blocking their development. Researchers often pursue the development of their RBI without receiving feedback or guidelines from the market and they face the risk of entering into a vicious cycle that moves them away from the potential market demand [58]. Some more audacious PIs may try to break this cycle by directly contacting companies. However, in such cases, they may target the wrong stakeholders (i.e., they run the risk of having their RBI stolen or ignored), or they may receive wrong indications about further developments of their RBI. Additionally, research teams may face opportunistic behavior by the involved parties, who may try to steal their ideas to develop the project internally. PoliTo's strategic report, for instance, reports that, between 2013 and 2017, around half of the professors who applied for the internal university procedure to obtain a patent had fears about an external company collaborating in the development of the technology stealing their idea. Such "external frictions" may in fact impede or slow down the development of the technology and, consequently, its commercialization and transfer to the market. While professors may fear opportunism from external partners [59], another interpersonal inhibitor that can impede TT is represented by the set of frictions that may develop within the faculty. A large portion of PIs we interviewed reported potential conflicts with other faculty members as an obstacle to the development and transfer of an RBI. Other professors could hinder the development of the research to limit the career progress of the research teammates or of the PI. This could happen to maintain power and status within the department and the university, which could guarantee them superior visibility outside academia.

Concerning institutional and cultural and value-based inhibitors, we found that they work "indirectly" in limiting the commercialization of RBIs, in the sense that they enhance the magnitude of interpersonal inhibitors and create decisional loops, thus worsening the effect of other inhibiting factors.

Institutional inhibitors are related to the problems that arise with policies, incentives, and resource allocation processes of the context in which academics work. Although such problems could be connected with the commercialization of RBIs [4], we found that the lack of resources or ineffective policies developed within the university do not impact directly on the commercialization of RBIs, but rather enhance the magnitude of interpersonal and cultural and value-based inhibitors. In other words, institutional inhibitors prevent the development of a valuable visibility of the research team outside academia and the building of a network between the research team and industrial partners, thus favoring more disconnectedness and external frictions that, in turn, constitute an obstacle to the commercialization of RBIs.

Insights from the interviews revealed that the lack of funds did not necessarily prevent the development of RBIs. It was reported that a lack of resources prevents PIs and research teams from being in touch with industrial counterparts, as it precludes PIs from marketing their RBIs, or from building new contacts with industrial stakeholders. Several informants reported that existing funds were too "rigid" and it was not possible to use them for objectives other than research (for example, to use them to acquire specific resources or skills needed to participate in tradeshows and/or industrial events to make contacts with industrial partners). This aspect often forced PIs to stay focused on laboratorial activities instead of concentrating on finding partners interested in acquiring/codeveloping their RBI.

Although, on the one hand, institutional inhibitors contribute to the devolvement of interpersonal inhibitors, on the other

hand they also contribute to reinforcing cultural and value-based inhibitors. In this sense, the incentive mix and balance and U-I misalignment may increase the extent to which cultural and value-based inhibitors have an indirect impact on the commercialization of RBIs. The system of incentives at a university (i.e., the academic evaluation system based on publications to establish the career advancement of professors) favors cultural and value-based inhibitors [60], thus increasing the misconception of scholars who are focused on their research. In other words, the fact that the development of more basic rather than applied research is incentivized shifts the focus of research toward more theoretical than applied contents. Similarly, U-I misalignment—and more in particular the difficulty research teams experience in finding third parties who are willing to share the technological risk of the RBI—contributes to the reinforcement of the idea that academics have, i.e., that firms are not interested in the development and the adoption of radical innovations originating from academia or—more in general—outside the industry environment.

Finally, we detected a relationship between cultural and value-based and interpersonal inhibitors. We found that cultural and value-based inhibitors contribute to the reinforcement and development of interpersonal inhibitors since misconception keeps research teams from finding out about the real needs of firms. More specifically, the fact that researchers develop their RBIs without explicitly knowing the possible commercial application of the projects increases the distance between industry and academia, thus reinforcing the disconnection and the external frictions that may arise between these two worlds. Moreover, the belief of researchers that firms are not interested in the radical innovation they are developing also contributes to limiting their capability to create contacts with industrial stakeholders.

In a similar way, even interpersonal inhibitors, apart from directly harming the commercialization of RBIs, may contribute to reinforcing cultural and value-based inhibitors. This happens since disconnectedness and external frictions promote misconceptions and fallacy among academics, thereby strengthening their idea that firms are not interested in radical innovations from outside and that research groups should perseverate in their development of theoretical projects rather than applied ones.

B. How Does the TT Ecosystem Could Relax Inhibitors to Promote TT?

The prevailing nature of relational inhibitors in hampering the transfer of RBIs from universities to firms questions the role and the future development of the actors populating the TT ecosystem [13]. Our research depicts a situation in which professors—who are crucial elements of the TT ecosystem [23]—require support in building a network of contacts to further proceed in the development of their RBIs. While TTOs have been broadly set with this mission [61], they often play a minor role in cultivating business relationships with firms (an inside-out logic [62]) and operate as administrative facilitators in order to lower the burdens of bureaucracy that bound many universities [31]. The necessity of lowering disconnectedness and external frictions calls, instead, for more proactive TTOs. TTOs should operate as anchor tenants [63] in the development of a TT ecosystem, enhancing stakeholders' connection within and outside universities [64]. This view is akin to Hayter [31] who foresees for TTOs the role of advisors and connectors in the development of spinoffs, from opportunity recognition to entrepreneurial commitment and credibility building within the industry [65].

Besides TTOs, our findings call for a rethinking of the role that other actors (such as university incubators and science parks) within the TT ecosystem might have in promoting TT [13], [66], [67]. The fact that institutional inhibitors do not directly hamper the development of RBIs puts in the forefront the need to alleviate relational inhibitors. Stakeholders within the TT ecosystem (such as university incubators and science parks) should better adapt the services they provide to technology-based firms by helping start-ups, academics, and industry players build mutual relationships and knowledge sharing. This could result in the set-up of new collaborations that would ease the transfer of technologies developed by university professors to the market.

VI. Conclusion

This article aimed at further understanding the links between the factors that inhibit the transfer of technologies from universities to firms. While the previous literature highlighted several factors hampering the successful transfer of RBIs developed within the universities to their industrial counterparts (e.g., [9], [16], [17]), it overlooked through which mechanisms inhibitors hinder a successful commercialization of RBIs.

Our findings on a case study on 15 RBIs developed within a technical university in Italy highlighted that RBIs are limited in reaching successful commercialization mainly because of relational factors that impede a successful alignment of intents, activities, and objectives between university professors and their industrial counterparts. Moreover, we also uncovered that institutional [17] and cultural inhibitors [35] limit the transfer of RBIs through a more indirect mechanism, namely by enhancing the relational inhibitors. These results contributed to the literature investigating the factors limiting successful university-industry TT (e.g., [15], [68]). In fact, by highlighting the crucial role of relational inhibitors in hampering the commercialization of RBIs, it also recalls for the necessity to rethink the whole TT system currently implemented in many universities. Most TTOs and incubators, in fact, operate by promoting their technologies and patented RBIs to firms as if they were "off-the-shelf" products, according to formal procedures. Rather, our results highlighted the need to overcome a transactive view of TT for a more relational view of TT [64], which entails the involvement of companies and firms since the very beginning of the research (i.e., when the TRL is very low). This has clear implications for academic entrepreneurship and universities: the design of effective TT programs, whose governance was aimed at helping PIs create relationships with actors active in the relevant ecosystem, may lower the effects of inhibitors to the commercialization of RBIs. Moreover, university managers should be aware that operating exclusively on the alleviation of institutional inhibitors (e.g., by providing researchers with more money to overcome

the valley of the death) can only partially relieve hurdles in TT. In this vein, our research points out the need to operate on all the three factors identified or to massively break down the link between interpersonal inhibitors and commercialization of RBIs. Which of the two strategies could be more effective (or less costly) still remains an open issue upon which future studies might shed further light.

This research is not free of limitations. The main issue is related with the generalizability of our results. Our objective has been to understand the factors inhibiting the development and commercialization of RBIs. We have concentrated on a single university in order to avoid confounding effects that would have emerged when comparing different universities and to ensure the access to confidential information that would have been prevented if the focus was extended to other settings. However, we recognized that the identified factors could depend, to some extent, upon the context in which a university operates. Moreover, other local cultural factors may partially drive the identified inhibitors. For instance, we discussed in Section III-A the primary position of PoliTo in the European landscape with reference to TT. Therefore, the results we found might be driven by the relatively excellent positioning of the university against other competitors. To be more specific, this research might have overlooked and overrated at the same time some possible inhibitors connected to resource availability. Small universities in rural areas, with scarce connections with the local ecosystem (or with a scarcely developed ecosystem), might suffer the issue of resource scarcity as more pronounced than universities like PoliTo. At the same time, resource scarcity at PoliTo might be less evident than what discussed by our interviewees, as the high level of the university research and TT activities might increase the competition for funds among different PIs. Therefore, the analysis here conduced could be replicated in similar settings, where a technical university with a significant (lower) TT capacity is embedded within a more (less) dynamic local entrepreneurial ecosystem. All these points need further exploration by future research. A second issue concerns the fact that we have deliberately taken the perspective of PIs. Findings could be improved by considering the viewpoint of TTO managers, entrepreneurs, and investors as well. Moreover, future studies could also consider the perspective of Ph.D. students and early-career academics (like postdocs or untenured professors). Recent literature is pointing out the increasing relevance of such figures for successful TT [69], [70]. Thus, we believe that different perspectives about inhibitors could be a valuable complement to the theoretical framework we have advanced in this study.

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