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Opening the black box of university-suppliers' co-invention: some field study evidence

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Abstract

While there is extensive evidence that the flow of knowledge between academia and industry is important, scholars have noticed that little is known about the actual transmission mechanisms of these influences (Rosenberg and Nelson, 1994; Kenney and Patton, 2009). The paucity of research reflects the fact that university-industry exchanges are a complex process that involves many factors that are difficult to grasp. Furthermore, the practical benefits of most university research for companies stem from interactions and processes that are very much roundabout and indirect (Pavitt, 2005). For instance, a case in point of such processes consists of the technology-intensive interactions between academics and their suppliers of equipment (Perkmann and Walsh, 2007). This paper explores the emergence of dynamic complementarities among researchers' demand and suppliers' competencies and aims to identify the dynamic processes through which university labs serve as learning-environment for suppliers. We conducted field-study based on a set of instrumental devices developed in close collaboration between University of Strasbourg laboratories on the one hand, and equipment manufacturers on the other hand. Our case studies illustrate a multitude of patterns through which researchers share their technological knowledge with industrial suppliers. More precisely, our evidence shows the presence of a "procurement-led" innovation phenomenon wherein university researchers provide companies with unique insights by acting both as equipment-demanders as well as suppliers of scientific knowledge about instruments, ultimately allow firms to explore new innovative trajectories.

Keywords: University-industry interactions; scientific instrumentation; technology co-development; public procurement

JEL Classification: D22, D83, H57, O33

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1. Introduction

In 2017, the High Council for the Evaluation and Higher Education in France published an assessment report of the Institute of Supramolecular Science and Engineering (ISIS) at the University of Strasbourg stating that *"We all know that such institutions become powerhouses not only in terms of science but also in terms of economy and society."* (HCERES 2017 p. 7).

The main goal of this study is to provide a more in-depth characterization of how university research unities turn to serve as a rich learning environment for their suppliers. The contribution of this paper is complementary to our previous investigation in which we provided a quantitative evidence about the impact of academic research unities on the innovative capabilities of their industrial suppliers of instrumentation (Bianchini et al., 2019 *Forthcoming*). Although our previous study represents an original contribution to the university-industry interactions literature it does not shed light on the actual mechanisms through which universities favour learning and innovation in their industrial suppliers. Motivated by the desire to overcome this hurdle, in the present work, we thus explore in-depth these mechanisms and we try to provide evidence about *how do dynamic complementarities among researchers' demand and suppliers' competencies emerge.*

Given the exploratory nature of our inquiry, our methodological choice is to conduct an in-depth qualitative field-study based on multiple-case study design (Yin, 2014). We study three cases of technologies developed by researchers from three different research unities of the University of Strasbourg (UNISTRA) and their industrial suppliers. The cases focus on three leading biomedical and chemistry institutes of the University: an Institute in Molecular and Cellular Biology (case 2, Institute 2); an Institute in Supramolecular Science (case 3, Institute 3) and the Institute in Chemistry (case1, Institute 1). In the period May – December 2018, we have conducted 10 formal and 5 informal interviews with researchers to gather factual data about their suppliers. The main questions in the interviews relate to the background and outset of researchers' relationships with their suppliers, and to their evolution over time both inside and outside the framework of public procurement bids.

Our contribution builds on and refines previous studies in at least two ways. First, while a lot of research efforts have been directed to study the economic contribution of public research universities, most of these studies have been focusing on activities that depict technology transfer in a direct, linear-wise and unidirectional way (see e.g. Dosi et al., 2006; Perkmann et al., 2013). A common feature of these activities is that they all are mediated by formal procedures put in place by the technology transfer offices or other related institutions. Nevertheless, a closer look at how universities work in practice reveals that there is a lot of technology transfers that do not take place via “official” channels (see e.g. Schaeffer et al., 2018; Rosenberg, 1992). Essential pieces of knowledge generated by university research are often transferred to industry without having recourse to the support of technology transfer offices (TTO) or similar established technology transfer mechanisms. Instead, technologies flow back and forth between researchers and industrial firms as a by-product of other reciprocal relationships, for example, the demand for instrumentation. In addition, the technology transfer that takes place between universities and industry is depicted as a black box which creates a lot of ambiguity about how universities operate as a learning space for firms. Accordingly, scholars have emphasized the importance of greater research efforts into the study of more interactive modes of technology transfer (Lundvall, 1988; Salter and Martin, 2001; Pavitt, 2005; Antonelli, 2013); such approach is also said to provide a more rigorous evidence about the knowledge transmission processes among academia and companies. For instance, a case in point of such processes consists of the technology-intensive interactions between academics and their suppliers of equipment (Perkmann and Walsh, 2007).

Second, the role played by universities as fundamental actors in demand-driven innovation is a special case of the role of public procurement as a source of innovation, a topic which gained a lot of attention in recent technology policy debates (Edquist and Hommen, 2000; Edler and Georghiou, 2007; Castelnovo et al. 2018; Florio et al. 2018). The success of the public procurement procedure depends largely on user–supplier interactions which can be hampered by information asymmetries and weak dynamic complementarities (Malerba, 1996, 2006; Chicot and Matt, 2018). In the framework of public procurement, interactions between researchers and suppliers are crucial for the development of interfaces leading to innovation (Rolfstam, 2009). This study improves the above studies by exploring in depth the communication mechanisms and interactions between researchers and suppliers. By focusing on these interactions, we also shed light on the factors that hamper the collaboration between procurers and suppliers oriented towards the development of new technologies (Chicot, 2017).

Third, by discussing the strategic and technological learning opportunities offered by universities to their suppliers, we seek to contribute to previous studies focusing on big-science centres’ suppliers’ activity that have tackled both the direct (Autio et al., 2004; Nilsen and Anelli, 2016) but also the secondary financial impact of big-science procurement on their industrial suppliers (Schmied, 1982, 1987; Streit-Bianchi et al., 1984). These studies provide valuable insights about the mechanisms generating learning and innovation of big centres’ (e.g. CERN) suppliers. At the same time, they call for further exploration of these mechanisms in universities-suppliers procurement interactions as well.

The rest of the article proceeds as follows. In Section 2, we discuss some theoretical landmarks and state the research propositions that guide our analysis. We describe our research methodology in Section 3 and discuss the selection criteria of the three case studies, as well as the questionnaire used for the interviews. We briefly present the cases in Section 4. Section 5 discusses the results in light of the existing science and technology literature. Finally, Section 7 concludes with some implications for policy and pointing at the limitation and possible extensions of this work.

2. Some theoretical landmarks

Technology transfer has been outlined as a "intentional, goal-oriented interaction" (Autio and Laamanen, 1995) "between two or more persons, groups or organizations in order to exchange technological knowledge and/or artefacts and rights" (Amesse and Cohendet, 2001) and "during which the total sum of technological knowledge possessed by the parties stays stable or increases" (Autio et al., 2004).

This study is aimed to challenge some aspects of the above definition of technological transfer, namely its intentional and goal-oriented features and the idea that organizational learning can be reduced to the sum of knowledge acquisition processes of its members (Marengo, 1992). The underlying principle of our approach is that relations among different organisations, as defined by their history and socialization practices, play a fundamental role in driving and shaping collective learning processes.

Such a conception of technological innovation has interactive learning at its core and hence calls for further exploration of the interactions that unfold between firms and universities; the mechanisms through which these interactions and their respective outcomes evolve; the characteristics of inter-organizational relations and the degree of formalization and legal framework within which these relations are built.

More precisely, our study aims to explore *the emergence of dynamic complementarities among researchers' demand and suppliers' competencies and identify the (dynamic) processes leading to new technologies.* Formally, interactions between academics and suppliers take place within the framework of public procurement procedures. Since there is spending of public funds the procurement procedures represent a formalized process driven by the principles of transparency, efficiency and equal treatment. In this context communication between researchers and companies during the procedure is restricted and considered illegal since it can imply favouritism in benefit of certain candidates. Although university procurement is not specifically geared towards the generation of innovations, it has a significant impact on firms' innovative performance and represents a special case of the role of public procurement as a source of innovation wherein innovation appears as a positive by-product of the procurement process.

To analyse public procurement processes that are exclusively designed with the aim to stimulate new technologies, the literature uses the concept of Public Procurement for Innovation (PPI). Public Procurement for Innovation can be defined as the purchase "of a not-yet-existing product or system whose design and production will require further, if not completely novel, technological development work" (Edquist and Hommen, 2000 p. 5). While universities represent a common type of public procurement, public procurement for innovation "occurs when a public agency places an order for a product or system which does not exist at the time, but which could (probably) be developed within a reasonable period" (Edquist and Hommen 2000, p. 5). In this setting, the government defines the functional requirements of the expected new item leaving its practical achievement to the creativity of the suppliers (Rothwell and Zegveld, 1981; Geroski, 1990; Edler and Georghiou, 2007).

2.1 Nature and varieties of scientific knowledge

In order to lay down the conceptual landmarks of the process of mutual technological learning occurring between researchers and suppliers, we begin by examining the nature and varieties of the scientific knowledge involved. Next, we discuss the mechanisms through which such knowledge can be exchanged with the suppliers.

To understand the process of technological learning unfolding between researchers and suppliers it is important to recall the central distinction between "tacit" and "codified" knowledge. Such a distinction finds its origins into a debate within the community of sociologists of scientific knowledge that emerged in opposition to the established approach of Robert Merton (Barnes et al. 1996, Collins 1985). Merton's main point was the study of "the normative *structure of science with its institutionally distinctive reward system*". In contrast to him other studies focused on the cognitive features of researchers' work and the influence of sociological notions on scientific ideas themselves (Collins 2001, Latour and Woolgar 2013). These works revealed that some varieties of knowledge in day-to-day scientific activity, for instance how to handle a new and experimental scientific instrument, are not communicated in an explicit way between researchers. For instance, in a study of a set of scientists working on the building and operating the Transversely Excited Atmospheric (TEA) laser, Collins (1974) observes that learning, skill and knowledge sharing among them does not engage any kind of written of formalized means. Other sociologists provided further evidence that knowledge diffusion comprehends something that cannot be transmitted in a written way and therefore should not be assimilated to information (Callon, 1995). Thus, sociologists have shown that scientific knowledge contains important tacit and sticky aspects (context matters, and knowledge is very localized). Consequently, to get benefits from scientific knowledge, firms should maintain close interactions with universities. Rather than distant communication via skype or videoconferences, such interactions should occur in the most natural face-to-face way. Thus, the stickiness of scientific knowledge also imposes to firms to be in physical contact with university researchers. In other words, the cost of knowledge transmission increases with the distance from its origins. Applying this argument to the domain of scientific instrumentation, knowledge about the functioning of a given technology that arises as a by-product of researchers' scientific activity has been pointed out to be intrinsically more tacit per se. The high tacit component of such knowledge is pointed out as one of the reasons manufacturers would be attracted by proximity to the place of emergence of this valuable knowledge (Pavitt 1987, Nelson 1992, Patel and Pavitt 1995).

The distinction between codified and tacit can be very superficial or even misleading for the economic discussion of the transmission mechanisms of technological knowledge. Indeed, once some of the more elaborate aspects of the concept of tacit knowledge are put forward, it becomes clear that more nuanced view of the various mechanisms and their peculiarities should be considered. Nelson and Winter's Evolutionary Theory of Economic Change (1982) emphasizes these aspects and it explores in depth the tacit aspect as a reflexion of various features related to the holder of a certain piece of knowledge, his awareness about it, his incentives to put it in words and his environment.

Drawing on the Michael Polanyi's Personal knowledge (1962), Nelson and Winter (1982) further develop and discuss the importance of tacit knowledge, providing useful insights into an alternative sphere of knowledge – that of organizational capabilities and routines approached by the analogy of individual behaviour and skills. According to Nelson and Winter, individual skills are often highly tacit such that *"a skilful performance is achieved by* *the observance of a set of rules which are not known as such to the person following them."* (Polanyi, 1962 p. 49). The rules "not known as such" even to the person who complies with them refers to the difficulty to express or to articulate them in words. This implies that the person could not provide an exact explanation of the rule itself and therefore he might not be even aware that he has been following a sequence of rules. The lack of awareness suggests that one might only be partially conscious of the rules that are followed. Besides the impossibility to articulate and the subsidiary awareness that characterize tacit knowledge, it has also been shown that tacitness is not an intrinsic knowledge feature since *"The same knowledge, apparently, is more tacit for some people than for others"* Nelson and Winter (1982, p. 78). The degree of tacitness of a certain piece of knowledge will depend on the knowledge base of each of the parties and on their incentives to communicate and articulate given know-how.

Cowan *et al.* (2001) build upon Nelson and Winter's notion of articulability and focus on the knowledge that can be articulated and encoded with the final aim of establishing the circumstances under which such knowledge will be codified (Cohendet and Steinmueller, 2001). Cowan *et al.* (2001) discuss the importance of codes, standards, models and rules under the notion of "*codebook*". The codebook can act as a reference or a repertory when all the parties are able to interpret the codes and have similar interpretations of them. Since not everybody has the same specialized knowledge, a piece of codified knowledge *"for one person or group may be tacit for another, and an utterly impenetrable mystery for a third."* (p. 10). Thus, Cowan *et al.*, (2001) join Nelson and Winter (1982) in emphasizing the importance of knowledge activities' context for the development of a solid codebook.

In our study we aim to explore knowledge activities and interactions between researchers and suppliers and we are thus interested in how the above-mentioned codebooks are developed initially – i.e. at the beginning of interactions between two parties; in a new discipline; for a new technology. In the beginning, there will be no codebook. So, in order to create it, all the participants will start to codify relevant pieces of knowledge to express models and create elements for the codebook. However, the starting codification requires the establishment of a specialized dictionary and language between participants. The dictionary consists of a specific vocabulary by the means of which participants will describe the models. At the beginning of the emergence of new technology, the establishment of a standard language is an essential part of the collective activity of codification (Cowan et al., 2001). In such a framework, knowledge can be taxonomized according to the existence or not of the codebook. When knowledge is articulated and codified, it is recorded in a standard codebook and serves as a reference. When knowledge is unarticulated, instead, it is not explicitly referred to during knowledge activities. In this case, two possible instances should be considered.

At the beginning, the knowledge is unarticulated and truly tacit, because it is not embodied in devices or has not been described and therefore it cannot be recorded in any type of codebook. In the second phase, although knowledge is unarticulated, it is embodied in instrumentation, artefacts and thus a codebook exists. However, in the course of knowledge activities and interactions, the codebook has not really been mentioned as a reference by the parties. Since from an outside perspective the codebook is not obvious, it looks like the people involved in the interactions are relying on truly tacit knowledge even if no codebook is available at all. This situation is called by Cowan, David and Foray (2001) "*displaced codebook*" and it involves a codified background knowledge, even if this knowledge is not evident, manifest. A reference codebook does exist, but it is imperceptible because it is almost never indicated. Therefore, participants in activities building on this type of knowledge use advanced terminology, technical language and disciplinary jargon and still understand each other without any reference to manuals or codebooks. In this setting, the participants often have taken the codes and models of the underlying codebook as given. Accordingly, in order to penetrate their group and have a worthwhile interaction with them, one should be able to overcome the need to rely on the codebook and show that he has the same internalized perspective of it.

The displaced codebook represents an instance in which background knowledge is codified although its codification is not evident because of the existence of other norms between individuals operating within the same domain of knowledge. According to Cowan and al. (2001) this type of codified (in general) but not articulated (in the specific context) knowledge corresponds to the scientific endeavour as described by Kuhn's concept of normal science (Kuhn, 1962). In this framework, researchers explore various theoretical and experimental trajectories within a given *scientific paradigm* or *explanatory framework*. They draw upon and contribute to a codified body of knowledge. However, the underlying content of that knowledge remains tacit among community members. It can be questioned and challenged in the event of a debate on its substance, storage and recollection. Similarly, a technology that emerges in such a framework is codified although the content of its codebook is not evident.

The finer distinction between different types of knowledge beyond the dichotomy of simple codified and tacit knowledge allows one to refine the analysis of the communication mechanisms that are engaged in the processes of learning and transfer of such knowledge.

Furthermore, such a distinction allows one to get a more complete and nuanced vision of the various channels and ways through which knowledge is created and diffused among researchers and their suppliers and, ultimately, on how the latter can significantly benefit from it.

2.2 Researcher-Supplier interactions as focal point of public procurement procedures

Researcher-supplier interactions' can also be approached as a special case of public procurement as a source of innovation. User-supplier interactions are at the heart of the successful outcome of public procurement of innovation (see Rolfstam, 2009). Accordingly, scholars have studied the role of procurement procedures in the intermediation between demand and supply (Edler and Yeow, 2016) as well as the failures that can inhibit collaborations between public users and suppliers such as the lack of sufficient interactive space (Chicot, 2017). On the one hand, these failures might take place because an essential factor necessary to trigger off dynamic complementarities is deficient or too weak. It might be related to a lack of competencies and to low absorptive capacities. On the other hand, too loose or inexistent connections among heterogeneous agents and/or the lack of complementary activities among them might be at the origin of user-supplier failures. In this case, public procurement can be seen as a policy tool to tackle user-supplier interaction failures.

The Public Procurement for Innovation literature has identified some guidelines for the interactions that are essential for the effective learning between users and suppliers in the generation of innovation within the public procurement framework.

Chicot and Matt (2018) analyse user-supplier interaction failures in two cases. First, the "simple" case in which the researcher-supplier interaction does not aim to establish a durable collaboration (co-development) but it ensures the communication of public needs to producers. In this context, public procurement procedures frame the identification of the need and the precise communication to the possible suppliers by means of formal call of tenders. Formal procurement procedures are assumed to be enough in reducing informational asymmetries, related to firms' lack of knowledge about public needs and in triggering a demand-pull effect (Edler and Georghiou, 2007). Next, Chicot and Matt (2018) address user-supplier interactions when they must refer to each other as co-developers of a technology. In this case their smooth and rich communications are central to the process in which users provide companies with valuable knowledge about their experience with products and opinion about future possible developments, this, in turn, allows suppliers to adjust their products. In this case, procurement serves as a frame where both actors can communicate, enabling users to exert an important effect on suppliers innovation behaviour and performance (Chicot and Matt, 2018). This process of learning and reinforcing each-other technological knowledge base is referred to as *dynamic complementarities* (Malerba 2006, 1996). It follows that public procurement for innovation (PPI) can provide the space and time for the emergence of dynamic complementarities between users and suppliers. To ensure such an environment of awareness and frequent interactions within the formal procurement process, there are practices such as competitive dialogue (Uyarra 2016), which "allows the contracting authority to have discussions with the candidates during the procedure so to better define its needs and the appropriate means to achieve its objectives" (Telles, 2010, p. 1)[2].

The establishment of formal contractual agreements among procurers and suppliers for the definition of contractual terms as milestones; deliverables and intellectual property is shown to have a negative influence on their collaborations (Matt et al., 2012). Therefore, another body of possible malfunctions stems from users' and suppliers' collaborative norms i.e. the respective willing of users and suppliers to commit in reciprocal collaboration (Chicot, 2017; Schiele, 2006; Walter *et al.*, 2003). Considering the degree of information exchange and level of cooperative norms between users and suppliers in a 2x2 matrix, Wang and Bunn (2004) discuss four groups of user-supplier interactions. Intensive information change and norms correspond to a "frequent, intensive and open" way of communication (Wang and Bunn 2004 p. 95). On the contrary, when norms and information sharing is not valued and practised, the procurement parties' relation is qualified as "arms-length" type whereas no particular cooperation and communication take place. Besides these two extreme cases, Wang and Bunn (2004) introduce "supervisory relationships" and "recurrent relationships". These four categories completely echo to the notions of relational embeddedness as highly intensive and rich relations versus arms-length transaction type contacts that we discussed earlier (cf. Section 3.2.2). A further group of collaboration failures refers to the daily communication between users and suppliers within the frame of the competitive dialogue and it can manifest as lack of knowledge exchange (Wang and Bunn, 2004) and coordination among parties (Rolfstam, 2009).

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[2] also cited by Chicot (2017)

Besides analysing failures occurring in various stages of the procurement process, the PPI literature stresses the role of trust (and the lack of it) in the success (and otherwise in the failure) of user-supplier interactions. Trust is a transversal concept that affects all the aspects of user-supplier collaboration. Since confidence, trust and trustworthiness form progressively with experience and involve "socio-psychology bonds of mutual norms, sentiments, and friendships" (Ring and Ven, 1994, p. 93), it is unlikely that it will develop in standard procurement procedures (Chicot, 2017). Within the formal framework, trust is only based on contractual arrangements and the confidence in institutions. Since at the university, procurement procedure does not include competitive dialogue and is delicate to combine with collaborative R&D projects, early interactions, that would allow for trust-building between researchers and companies, are rather difficult to sustain. Emphasizing the essential role of trust in inter-organisational collaboration, procurement scholars (Rolfstam, 2009, Chicot, 2017) call for the in-depth exploration of the trust-building processes in the context of limited interactions by formal rules.

3. Field-study methodology

To explore the direct and indirect learning processes that unfold among researchers and companies in our original dataset, we interacted with university staff at various administrative levels in order to be able to identify the most appropriate contacts to interview among researchers' that have purchased equipment in the period 2011-2017.

The analysis of researchers-suppliers' interactions is done in the course of a fieldwork conducted in three research unities at the University of Strasbourg in the period May-December 2018. In the following sections we spell out our research protocol – we explain our baseline methodological choices in conducting the field-study such as sampling techniques; data collection and analysis approaches.

3.1 Case study as a tool of social sciences

To explore how dynamic complementarities, emerge between researchers and their suppliers we employ a multiple case study approach. To identify practices, their corresponding underlying mechanisms and how they are conducive to knowledge-intensive interactions between researchers and suppliers from the researchers' perspective, we conducted qualitative interviews with researchers as a primer data collection method. Our methodological choice is motivated both by the characteristics of the interactions under study and by the precise research question we strive to tackle. Technological learning between researchers and suppliers is a complex phenomenon, as it involves many processes and patterns of relations between the processes and the individuals evolved. A multiple case study looks as an appropriate empirical tool to analyse in depth such a phenomenon because it allows focusing only on certain cases and examine them through a comprehensive and realistic perspective (Yin, 2014).

3.2 Definition of the cases and sampling selection strategy

When a phenomenon has no solid theoretical background, the case study methodology suggests selecting a "case in point" or unique case of the phenomenon as being most revelatory (Miles et al., 1994). In addition, the study of multiple cases is pointed out as a preferable approach that provides a deeper understanding of the processes and outcomes that the cases illustrate. Examining more than one case offers the possibility to test research hypotheses and yields a fair representation of field-based (grounded) causation. Conducting two- or more cases is encouraged as the findings are likely to be more robust than having one single case. Yet the cases should not necessarily be homogeneous among them (Yin, 2014) and they might include sub-cases embedded within them.

Selecting the cases to be studied is an essential step in the implementation of the case study methodology. Our starting ground was the expenditures dataset of the University of Strasbourg for the period 2011-2014. The final data include 47.373 transactions between 91 research unities[3] and 1.908 suppliers. We needed to restrict our scope to a handful of representative cases among the whole data. For this reason, we followed two approaches. First, we established a shortlist of research unities, by retaining only those which had purchased equipment and rank them from the highest to the lowest amount in order to obtain some idea about how each laboratory accounts in the total data in terms of value. However, such ranking of research unities was not so operational because we did not dispose of any contact at the laboratory level. Thus, we contacted the director or the responsible person of the equipment platform within each research unity in order to present them our study and ask

[3] The total number of research units equals 91 unities. In 2012 many transformations took place in the structure of the University of Strasbourg, i.e. fusions of laboratories. Some of them existed under a different label or as part of a larger lab. See the Appendix for extensive list of all the research unities.

them to relate us to the most appropriate researcher(s) that had purchased a piece of equipment.

Meanwhile, in order to restrict the scope of the data and obtain reliable contacts at the research side, we contacted the personnel of the public procurement office of the University of Strasbourg. Besides interviewing them for the purpose of this study, they provided us with a detailed list of purchases made by research unities during the period 2011-2017. The sample consisted of 40 scientific instruments and for each transaction, it enclosed information about the purchased item, name of the researcher who commissioned the technical specification, and supplier who delivered the equipment. We contacted randomly researchers from this sample belonging to research unities within our initially established ranking. Following this procedure, we could obtain the first two contacts that agreed to participate in the study. We then applied reputational case selection also called "snowball sampling" (LeCompte and Goetz, 1982; Patton 2002, 2008) to add a third participant to the study. We asked our two participants for a recommendation of further contacts that could possibly accept to be involved to the study. From a methodological perspective, combining these two sampling strategies - random and reputational - is considered as a good practice as it increases confidence in the analytic finding of the study as a consequence of cases representativeness.

3.3 Data collection

The main goal of our field study is to collect a rich dataset of information for each research-supplier case. To achieve this goal, we relied on multiple sources of evidence. For each case, we collected extensive documentation information: personal documents provided by researchers and engineers (e.g., slides describing instrumentation, presented by researchers in an event with suppliers); written reports of events; reports of laboratories assessment; newspapers articles; administrative documents that describe the general procedures of public procurement; reports of laboratory activity among others. Besides documentation, the real-life setting of cases that characterizes our field study allowed us to get direct observations as part of our data collection methods. These observations concern the immediate environment of the research unity where we were meeting our contacts; their (spontaneous) reaction towards our questions and other subjects; their relations to other people in the cases in which we could interview two people at the time; their access to certain data as for example when we were asking about suppliers' contacts - some researchers had the suppliers' personal phone number directly accessible on their cell phones. In addition, we could visit at least part of the equipment platform of each research unity and could see various pieces of equipment while researchers were working on them. This allowed us to obtain an authentic impression about the laboratory environment and have an informal exchange with researchers about their equipment. Direct observations thus consist of noticing all types of details that could allow us to confirm or question evidence received by other more formal ways.

Finally, we conducted face-to-face interviews based on a semi-structured questionnaire. The main goal of the questionnaire was to collect information about the general background of researchers and suppliers' relations; how they start and what are the initial conditions with the ultimate aim to trace their evolution. Second, we were interested in the different modes of communication between researchers and suppliers and on their specific outcomes. We wanted to know what the benefits for both sides were. Finally, we wanted to understand how these processes are related to formal public procurement procedures. The answers to these questions helped us to characterise to what extent researcher-supplier interactions are affected indirectly by the creation of relational embeddedness with each other (Macneil, 1982; Uzzi, 1997). The latter can further be decomposed into cognitive embeddedness (i.e. common vision and language); structural embeddedness (i.e. network reach) and social embeddedness (i.e. trustworthiness) (Autio *et al.*, 2004). In addition, we were able to identify more direct ways by which university laboratories serve as a learning ground for their suppliers. These key direct and indirect dimensions are discussed at length in Section 6. The information gathered during the interviews may be summed up in the following points:

1. *The genesis of the relation*: we were interested in the way the researchers and suppliers enter for the first time in contact and chose each other, as well as in the general features of the process: criteria of selection; what the research unity searched as equipment; initial characteristics of each party.

2. *The emergence of new technology/new equipment*: we collected evidence about a particular equipment and technology that emerged in each case. We intended to grasp the contributions of each party (in terms of knowledge, people, financial means, equipment etc.).

3. *Legal framework:* we studied the legal dimension of their accounts/co-development. What kind of exchanges does it include for both parties?

4. *Communication style*: We were interested in the modes of communication and exchange between partners (formal and/or informal), in their frequency and duration, but also in the division of tasks.

5. *Outcomes*: We wanted to identify the main benefits for the suppliers and the impact for their subsequent relations with the university.

We conducted 10 (prolonged) recorded and 5 (shorter) informal interviews between May and December 2018 (one exploratory interview took place in November 2017) and collected the perspectives of 11 individuals: researchers, engineers, heads of equipment platforms, directors of research unities, managers of public procurement procedures and one of the supplier companies' ex-director. All of our interviewees have been directly involved in the process of equipment purchase or development.

The 10 recorded meetings were 15 hours of a total duration with 90 minutes of average duration per interview. They were transcribed, which gave place to 140 pages of verbatim data. Following our case study protocol, we stored formally the entire range of data collected and made it available for potential inspection by an outside observer. The insights and observation obtained in the interviews were matched, for validation purposes, with documentation and direct observation data (Yin, 2014).

We conduct a pattern matching analysis of the verbatim. The analysis consists into confronting two patterns of research-suppliers' relations: theoretically based predicted pattern, developed before the actual data collection with an empirically based one emerging from the evidence of our cases (Trochim, 1989; Sinkovics, 2018). Showing that the theoretical and empirical pattern exhibit similar characteristics is strong evidence for case study internal validity. Patterns can be related to both dependent variables, when a given process can have a variety of relevant outcomes to consider, and independent variables, when several cases have the same outcome and the study focuses on the reasons why this outcome emerges in each case. When in each case, a set of possible outcomes emerges, the matching pattern is performed by considering the initially predicted values for each outcome; if those haven't been challenged by alternative patterns revealed by empirical observations, this could allow for a causal inference to be made. In essence, we will compare the suppliers' performance outcomes across the three cases and the patterns of their realisation with the theoretical propositions, exposed throughout and at the end of the theoretical background.

In the following Section 4, we provide brief summaries of our cases and then in Section 5 we discuss the main evidence arising from our case studies and whether it validates or not the main theoretical conjectures formulated above in Section 2 of the paper.

4. Brief overview of the three cases

Case 1. The first case study revealed how in 2015 a University of Strasbourg laboratory in chemistry has collaborated with one of its essential long-term suppliers to develop a new Nuclear magnetic resonance (NMR) equipment. The case describes the processes associated with the development of the new equipment. It all started with the supplier that had developed an in-house prototype of the device. The university laboratory then was contacted and asked to be the first user and beta-tester of the prototype. The supplier put the device at the laboratory disposal for a year. During this period the researchers ran daily experiments, which were documented and addressed to the supplier. Two years later, the supplier was able to introduce a commercial product resulting from the tested prototype. The supplier-company was the first on the market to introduce this kind of device and at the moment of the interview (2018) is still the sole manufacturer in the world.

Case 2. The second case illustrates the emergence of three different devices developed in collaboration among researchers and engineers at Strasbourg research unity in Molecular and Cellular Biology on the one hand and two of the institute's suppliers of optical systems. At the beginning of the 90's, the Institute had a unique need to perform observation on a broad scale of micro and macro samples, which drove researchers to come up with the idea of the macroscope fluorescence. They produced the first prototype and shared it with their supplier of microscopes who then introduced the macroscope as a commercial product. The introduction of the macroscope opened a new market for the supplier and the collaboration led to a whole series of new developments and to microscopy instruments such as the confocal scanner that we describe as well as other specialized accessories. Furthermore, researchers also use various part of existing products as building blocks for new systems. Adapting them to a new environment of functioning results often into an introduction of new valuable extensions of the initial device. We examine this case in point in-depth by considering the microtome integrated microscope put together by the researchers.

Case 3. The third case describes the emergence of a hybrid equipment among researchers of an Institute in Supramolecular Science and one of their laboratory equipment suppliers together with a spin-off company. The new device allowed combination of two already existing techniques performed by two different instruments. Since the manufacturer of these devices was reluctant to the new development because it could deteriorate its existing market, the university approached a spin-off company of the supplier in order to develop the first prototype of the hybrid device. Progressively the supplier became aware of the potential of the new equipment and purchased the prototype from the spin-off company to pursue the development until the final product was developed. The third case thus reveals a complex pattern of interactions among the research unity and the two companies involved through the whole process of development of the new device.

5. Putting the threads together: technology co-invention versus technology transfer

In the present section, we put together the conceptual framework laid down in section 2 with the empirical evidence gathered in the three field-case studies presented. More precisely, we analyse whether the field-study evidence corroborates or not the main theoretical conjectures that we outlined in Section 2 and whether exchanges occurring between researchers and their suppliers go beyond simple contractual relationships and they embed instead learning and trust, which in turn favour the emergence of new technologies.

We begin by examining the direct mechanisms of knowledge exchange among researchers and suppliers that are illustrated by our field-study. We stress how researchers are a source of specific and advanced feedbacks on existing equipment; they provide alpha, beta and field-testing for the manufacturers and also use existing devices as components in the building of new systems at the university labs.

Second, we highlight how the researchers-suppliers interactions that we observed in our field study produced also indirect effects. More precisely we discuss how these interactions were characterized by the types of embeddedness discussed in Section 2: 1) "cognitive embeddedness", that is the capacity of developing common language, shared vision and goals between the partners involved in the interactions, 2) "relational embeddedness", which captures the quality of the relationships in terms of good-will, trust and reciprocity among partners and, finally, 3) "structural embeddedness" which refers to the generation of new and useful connections in the partners' networks.

Third, we review how the above direct and indirect effects of researchers-suppliers interactions were produced during the formal public procurement procedures for the selection of suppliers.

Finally, we discuss the conduits of knowledge we find in the light of previous research on the economic value-added generated by public science infrastructure.

5.1 Universities as catalysts of suppliers' technological capabilities

Overall our field study indicates that university laboratories represent a unique source of technological knowledge for suppliers because of their specific requirements about instrumentation. In particular, researchers confirmed our main hypothesis that they turn to suppliers to ask them for something specific when they do not find what they need on the market. So, the starting point of the process is that researchers' scientific agenda includes, by its very nature, very specific scientific questions and it often requires new approaches to observation and measurement which then call for different devices from what is available on the shelf, on the market and/or in suppliers' catalogues. This phenomenon emerged at various instances throughout the three cases and its presence is neatly confirmed by one of our interviewees:

"We make developments on the basis of a scientific question and this is a bit different than a company because the company is going to have a set of demand - see a homogeneous market and produce a product that will respond somehow to the requests but which necessarily must be general enough so that it can be useful to a greater number of customers and suddenly will not suit perfectly nobody. And in science, as researchers are advancing in a theme - the more specific and specialized applications become. Then we inevitably fall into cases where the systems driven by the companies respond almost but not enough so we have to do from time to time checks and sometimes find a completely new solution with pieces of systems of different suppliers that we are going to put together." (interviewee 1, case 1)

When researchers contact the suppliers in order to discuss a precise need for a device, the communication takes place in a very meticulous way, which already enables suppliers to receive a real and practical feedback about their existing products. The feedbacks received on a precise device by researchers differ substantially from the abstract feedbacks that are often received from customers by sales representatives and which are then transferred to the R&D service of the company. The case of macroscopy (Case 2) illustrates well how significant the consequences of these feedbacks can be for suppliers. In the 90s the majority of public research was striving to observe infinitely small objects and it was oriented towards super-resolution. Meanwhile, researchers at Institute 2 (case 2) were interested also on larger objects, i.e. at a dimension from half a millimetre to 10cm such as zebrafish, drosophila and mice. This resulted in a huge demand for devices able to make observations at different levels, i.e. not just limited to infinitely small scales. However, manufacturers of optical systems were not interested in devices that could allow such a variety in observational levels. Moreover, companies did not work in this area, because they couldn't see the interest in macroscopy, they could not understand and master it. The lack of any available solution on the market forced researchers to build their own macroscope by combining existing pieces of supplier's devices. When they showed their first prototype to the suppliers' engineers, their only reaction was: « *We didn't see this coming* » (Interviewee 1, Case 2). As a result, interacting with university laboratories keeps suppliers aware of the real needs of laboratories and helps them to see new technological opportunities. Feedbacks from researchers have let suppliers to redirect and re-orient their activities to an emerging field of interest for the scientific community, which then resulted in the opening of a new promising market for these companies.

Another way through which researchers' feedback serve as a source of learning and valuable information is when suppliers reach out to academics for their opinion on products before launching them on the market. These processes are illustrated by the confocal optical system developed with researchers' help, and also discussed in the second case study. Typically, confocal microscopes were closed systems that required the purchase of everything - an integrated system at one time. Constrained by the shrinking university budget and by the desire of making their equipment evolve, researchers addressed to their suppliers requests to deliver a confocal system that was modular and buildable. Such requests shifted the way companies sold confocal systems. Thus, under the pressure of budget constraints researchers identified the desired devices characteristics and they communicated them to the supplier to influence the evolution of the equipment (to become more modular). Our second case study also confirm that the modifications that suppliers introduced based on researchers' suggestions made the devices more flexible and effective.

Furthermore, we find that researchers contribute to the opening of new markets for suppliers also by enlarging the field of applicability and usage of existing devices. Researchers do not always construct new solutions, but they use existing suppliers' pieces in such a way that that adds value to "old" devices and enlarges their domain of possible application. These dynamics are well illustrated by the case of the hypersensitive Japanese camera (Case 2) that researchers integrated within new version of correlative light-electron microscopy system they put together (CLEM 2.0). The integration of the camera in the CLEM prompted two ways of influence. First, researchers obtained an open access to the camera software in order to adapt it for their specific purposes. As a result, they created and enriched the libraries code of the camera software and shared these new libraries with the supplier that could use them afterwards for problem-solving of other customers. Second, in order to manage the whole new system researchers, put in place a modular software that allowed the camera to be combined with rotation system and made is usable to explore more unconventional samples in research fields other than biology (e.g. physics) where more complicated experiments are requested. Therefore, the camera was later purchased by medical physicists and served in their study of the formation of bacteria film. Bacteria form a film to protect themselves and become resistant, increasing the tendency to clog catteries in hospitals, which leads to nosocomial infections and diseases. To study the formation of the film, physicists needed an optical system and a rotation system to move the samples. Thanks to the camera and the optical system, physicists could use the software and make the images they need. This example shows that the software developed by the university facilitated the use of the camera and the CLEM beyond their initial field of application. In this way, researchers made possible a number of possible uses of the camera, opening new markets for the supplier. The software added value to the camera and gave an important solution to a common obstacle that researchers would face every time when they had to use the camera in combination with other devices.

Furthermore, university labs also act as a relevant testing-ground for prototypes and products. Researchers testing suppliers' products was a common practice observed in all the three cases. We identify three types of testing according to the degree of technological maturity of the tested item: alpha-testing of suppliers' prototypes; -beta-testing and field-testing of suppliers' products.

Case 1 illustrates well the role of researchers in alpha-testing: it is when a device is barely developed, and it is a prototype. The aim of this testing procedure is to identify certain flaws of the device and provide a detailed account to the supplier whether the product works or not. Therefore, it means that researchers participate to a certain extent at the design, final development and construction of the device. Testing is related to the scientific production (samples) that researchers use to experiment with suppliers' devices. Therefore, along with the testing, relations with researchers provide to the suppliers also access to their broader scientific parameters. Once alpha-tests are completed, it ensures that the device can be beta-tested.

Researchers also provide beta-tests for the suppliers. This is evidenced by all three cases. The aim of beta-testing is to know whether the device works smoothly and how it could possibly be improved. Beta tests take users on a guided tour of the product to answer the question: do customers like the product? The tests also consist of detailed surveys about the device and of an application letter that suppliers publish on their website to explain how exactly the equipment is to be used. Researchers and lab directors also give interviews for the supplier explaining the advantages of a given device and showing the results that could be obtained with them. Another possible outcome related to equipment testing is a working paper

– i.e. a paper explaining the techniques and how researchers obtained certain results. Such working papers are published on the website of the company. The diffusion of information about researchers using certain equipment comes in various forms – such as articles, videos (e.g. YouTube) and they provide a significant support for suppliers' products. The potential value of such communication channels for suppliers leans on researchers' expertise in a certain field. In return, the university also benefits significantly from it in terms of free worldwide communication.

Testing is thus a significant aspect of researchers-suppliers' interactions in all the three cases. Our empirical evidence also show that it can be implemented via different legal frameworks. For example, in Case 1, the testing of the accessory lasted for one year and it was organized via secret collaboration agreement between the researcher unity and the supplier. In contrast, in the second case alpha and beta testing took place in rather informal context although researchers produced a great deal of formal documentation by way of detailed reports, brochures and working papers. Likewise, in the third case, testing occur in absence of any kind of contractual agreement as a consequence of researcher's choice. Interestingly enough, avoiding a formal agreement with suppliers was a strategic choice. It gave researchers freedom in their decision for the selection of supplier and assured them a better negotiation status during the procurement process.

Lastly, university laboratories can serve as a locus for exchanges among companies and a "social shelter" (Autio et al., 2004 p. 124) for developing new solutions. Our evidence shows how university labs may directly foster their suppliers' learning by putting them in contact with other companies competing in the same markets, thus creating a space for knowledge exchanges among industrials. Such exchanges are prompted by researchers who typically combine technologies from different manufacturers in new ways. This process not only has a positive influence on suppliers, as we discussed above. It also triggers an open dialogue among suppliers of the initial devices. In addition, research unities serve as a "brainstorming place" where companies can pursue the development of something different than their core business. In that respect, laboratories act as incubators for technologies that would be too expensive to develop by a company on its own and/or because the laboratory has a specific expertise in a given field that the company does not have yet. Our three cases represent to a different degree the above described processes of influence. In some instances, the research units allocated dedicated space and personnel for their supplier, allowing the latter to better focus on technology development (Case 1 and Case 2). In other instances, they created intense interactions between the supplier and other companies (Case 3). Finally, researchers generated positive externalities between suppliers by combining their technologies into new systems (Case 2).

In addition to the above described three conduits of direct influence among researchers and suppliers, our cases indicated the presence of further processes of direct contribution of researchers to firms manufacturing capabilities. Indeed, university laboratories can actively be involved with suppliers also at later stages of a product development process, i.e. the stages that we would normally expect to be part of firms' core business. Our empirical evidence shows indeed that besides the pre-production testing as alpha and beta tests, researchers were also involved in the pre-series production phase. Pre-series production consists of building a limited number of a certain device so the supplier can share them with other companies that are going to perform the large-scale production of the system. These devices will then serve to the supplier to test the future production processes. The limited sample is subject to specific tests for ad hoc realisation. Suppliers need pre-series production as a quick alternative while actual series manufacturing is not yet in place. The pre-series production realized by the research unity enables suppliers to test both the production process and the products in a large-scale setting. Thus, suppliers acquire the experience and knowledge they need to decide whether to step back or move to the next level in their production phase. These pre-series are framed by a formal service agreement. Therefore, researchers and supplier switch roles in this setting: the researchers provide a service to the companies, thus in fact becoming their "suppliers".

5.2 Embeddedness and mutual learning

Beyond the above direct conduits of influence among researchers and suppliers, our three cases revealed that universities labs also favour learning in their industrial supplier companies in various indirect ways. These indirect learning channels are well explained by the notions of cognitive, structural and relational embeddedness (cf. Section 2).

Overall our field studies indicate that at the beginning researchers' and suppliers' match according to complementary technological knowledge in certain domains. Researchers' clearly choose their industrial suppliers of instrumentation let by the desire to find companies able to help them in improving their instrumentation. In this sense researchers with a clear vision about future developments of an instrument get in contact with companies that have capabilities to deliver technically sophisticated and advanced instrumentation and then who could be able to make the desired improvements. At the outset this matching is mainly technology-driven, as researchers have to rely on the most advanced instruments already developed by companies. However, once researchers integrate the instruments in their activities a new learning process is triggered. This process is driven by researchers' scientific agenda which determines the specific way in which the purchased systems is used. The in-depth scientific investigation in a particular field leads researchers to be confronted with unique technical problems whose resolution allows them to develop specific skills and knowledge. This technological knowledge acquired through practice plays then a fundamental role for the development of new instruments or the improvement of existing ones and can then be shared with companies through many channels. Some of them relate to the formation of a certain conduct of communication among researchers and suppliers leading to high level of social a cognitive interaction. This "cognitive embeddedness" generates a common language, symbols as well as common representations and models among the parties. The creation of such a shared vocabulary favours the coordination of researchers and suppliers on how a certain research field is expected to develop in future and about the consequences of these evolutions on equipment. The building-up of such a common language is fairly well illustrated by each of the three cases we analysed. For instance, in Case 1 the company had already a very solid scientific background, as it was created by an academic researcher and had its French branch managed by a University of Strasbourg PhD graduate. Accordingly, in this case, the common language between the company and the university existed because of the suppliers' university roots. Case 2 illustrates instead how common language can be developed through time via repeated interactions. This case also hints at the path-dependent and sometimes accidental nature of these developments. Indeed, common language developed out of initially matching levels of technical and scientific expertise that both parties could put on the table. Practically, in Case 2, the supplier took a very pro-active approach in visiting the research unity even while it was still under construction. At this moment the interest of the supplier has been directed to the laboratory as potential purchaser of tools for the new unity. Once the scientific activity of the imaging platform started the company got conscious about the multitude of other reasons to remain in closer contact with the director of the research unity and its' staff. Furthermore, the third case demonstrates in a slightly different way potential of cognitive relations among researchers and suppliers. In this case, thanks to the common values between the company and the lab, the supplier eventually overcame its initial reluctance to pursue the development of the hybrid device and they engaged in completely informal manner with the institute.

Finally, the three cases altogether illustrate how interactions characterized by shared language trigger suppliers' interest to engage in a certain development and to exchange in informal ways with researchers. This is well summarized by one of our interviewees in Case 2: *"It must also be said that even for the industrialists we are very interesting. Why? Because we try to have a common dialogue. Classically when a scientific researcher has a need, he has his own dictionary which is not necessarily the dictionary of the industrialist. Languages by different actors are not necessarily the same. And the interests of each other are not necessarily the same. When they come here - they feel like we speak the same language and we have the same problems."* (interviewee 2, case 2).

The progress of the relations between researchers and suppliers critically depends on the formation of the above-mentioned shared language. According to the theoretical discussion in Section 2, the researcher's knowledge about scientific instrumentation is codified but latent and its codebook is not manifest for all the members of the community because they have internalized it and it is a common knowledge. Thus, in order to grasp the latent part of their scientific knowledge which is also said to be the most valuable part of it, the suppliers should understand these codes of communications and be able to pass a "closed book" exam to enter in tight communication with researchers.

Once this initial phase is completed, the shared language and symbols in a dyad represent a fertile ground for more intensive knowledge exchanges among researchers and suppliers and increased common understandings among them. In this process common language translates into the emergence of common vision and goals. In turn, such a common vision and goals trigger off investment by suppliers in the partner-specific assets and create self-reinforcing dynamics among researchers and suppliers. Each of the cases brings out these self-reinforcing dynamics in different ways. In the second case we observe that the co-invention of the macroscope began a longstanding alliance among the research unity and the optics supplier characterized by introduction of series of new microscopy solutions. In November 2017 the two institutions celebrated 20 years of collaborations with a workshop dedicated to presentations and scientific talks highlighting the successful projects stemming from the partnership (The company Press release 2017). Interestingly, the day took place under the heading "From Micro to Macro" which emphasizes the truly transformational nature of the long-term ties among the suppliers and the research unity. At the event, the Vice President of the group stated: *"A long partnership is based on passion for innovation. It is why we are partnering with the Institute 2, an institute always innovating."* Compared to the second case, the first and the third cases appear as part of ongoing continuous relations among labs and supplying companies. Therefore, a common aspect among the three cases is that the exchanges among both parties take place in continuous way.

A second important channel of influence in researcher-supplier interactions is relational embeddedness. Relational embeddedness refers to the ability of interactions to generate trust, norms of reciprocity and credibility among the partners involved. The presence of mutual confidence and trust among researchers and suppliers creates a rich and solid foundation whereupon they build deeply rooted and complex relationships. On this ground, trust triggers off empowering interactions among counterparts and turns the knowledge transfer process smoother. In all the three cases trust between researchers and suppliers originated from previous positive interactions. Such previous experiences, motivated researchers' beliefs in suppliers' good-will, reliability and intentions to fulfil their obligations. For instance, in Case 2, the director of the imaging platform had a good experience working with the supplier at his previous research unity which was one of the reasons he preferred them as the main supplier when he was developing the imaging platform.

He motivated his decision as following: *"I was happy to be able to work with people I knew and trust and people who over time could better meet our needs and be more effective in meeting our needs."* (interviewee 3, case 2). These initial interactions subsequently turned into something more robust, as it is further described by an engineer at the platform: *"The laboratory director created a relationship at that time. This relationship was interesting to such an extent that the director of the factory that made the confocal who was a scientist coming from Heidelberg made it a habit to come once or twice a year to talk to Jean-Luc about biology. So, these exchanges were very interesting, and they lasted for years. When they had a new confocal idea that came out, they came to consult with us to find out what was expected of a confocal in the future."* (interviewee 1, case 2).

This last statement illustrates how trustworthiness among individuals gives rise to rich informal exchanges and routines of communication. These routines are then essential later in the transmission of practical feedbacks, valuable pieces of knowledge and researchers' expectations about techniques and equipment.

Also, in Case 3 researcher's confidence towards the supplier company was based on a former informal collaboration between them that was not even related to equipment, but to a software. However, in contrast to Case 2, our interviewee's experience with the supplier did not took place with the same people he interacted in the past. This did not undermine the course of the relationship. Although our interviewee had never communicated with the same people of the supplier company, he was confident and did not feel like taking any risk or uncertainty by entering in informal exchanges with them: *"It was not with the same people, but we had already had this type of collaboration with the company. So, we knew it was quite functional and we could proceed, and it would work very well."* (interviewee 1, case 3). This evidence suggests that trustworthiness does not concern specific dyad of people; it is not an interpersonal feature of researchers-suppliers relations but rather inter-organisational quality that characterizes interactions in general between the two types of organisations (Geneste and Galvin, 2015; Balboni et al., 2017). Even if trust is inspired by individuals, it can then become a stable trait of relations between organizations and facilitates interactions among their members.

Finally, all the three cases reveal how these relationships of reciprocity and mutual trust occur largely outside contractual agreements. In this context, suppliers actively seek university expertise because they realize that they can benefit significantly from it in this informal way: "*They are lending us new products that have not even come out for testing yet, or the vendor has several ideas and the university says, that is not worth it; on the other hand that's good and they continue. All this is done only by the informal: when the Japanese company lent us the cameras, we did not sign anything. It was based on relationships that existed before.* " (interviewee 3, case 2).

A third and final channel of influence between researchers and suppliers that we could observe in our field study works via the establishment of new and useful interactions. In Section 2, we employed the concept of structural embeddedness to describe the willingness of researchers and suppliers to provide to each other access to their internal and external networks (McEvily and Zaheer, 1999; Uzzi, 1997). When a given researcher-supplier dyad has this structural component, industrial suppliers get access to the whole network of the university of Strasbourg through one particular research unity or team. The internal network represents all the other research unities and their equipment platforms and the external network - other universities and research organizations. Thus, one laboratory provides an access to the science community social network creating boundary-crossing links for the supplier. These researchers thus serve as a “bridging ties” (Granovetter, 1973) that are leveraged by suppliers to access direct and indirect sources of knowledge available within the university’s network. These additional knowledge sources for suppliers then turn into ideas for new products; sources of feedback and assistance in R&D. Such mechanisms of knowledge access can take a multitude forms and ways of influence as shown by all the three cases we analyzed. For instance, in Case 1 suppliers obtained access to the scientific production of the whole research unity. In this way the company could test its device using the newest synthesised samples, that tried to reply to the latest research questions and had completely different significance for the testing of equipment. Similarly, the second case shows how suppliers got access to the internal workshop of the university lab. This allowed suppliers' technicians to repair and adapt a device in a much shorter time than at the manufacturing site in Germany. These results confirm the importance of the access of firms to researchers' network: *"When an industrialist comes in our lab and we take him to the micromechanical workshop - he feels like at home ..."* (interviewee case 2). Lastly, the third case makes an important point by illustrating that the opening of network goes in both ways i.e. also suppliers connect researchers to other firms across their industrial network. In the third case, the supplier company hesitated about engaging in the development of a hybrid device and for this reason put in contact the research unity with a small-scale firm manufacturing interface device for them.

5.3 Researchers-suppliers interactions and public procurement procedures

Finally, our case studies also provided evidence about the ways through which researchers-suppliers interactions take place within the framework of public procurement procedures. Informal interactions with suppliers are illegal during the procurement procedures. Nevertheless, our cases show that, within the boundaries allowed by legal procedures, researchers and suppliers interacted both before and after the end of the procurement bids. We observe a very similar approach followed by researchers and suppliers across the three cases. Researchers were involved in a rich communication, co-development (Case 3) and testing (Case 1) or both (Case 2) with the supplier before the public procurement procedure took place. The pattern that clearly emerges across the three cases is that researchers and suppliers exchange in various ways before the beginning of the procurement procedure in order to discuss possible technicalities concerning the future procurement. Once the procedure is official, they obey the rules of the procedure and researchers examine the offers by all possible providers. Furthermore, all cases indicate how interactions before the procedure allow researchers to obtain important advantages with respect to "ordinary" customers such as discounts and various added options for free. The uniformity and scale of these "gifts" across the three cases represent an additional evidence about the crucial role of researchers for suppliers and the significance of their contributions for the genesis of the final device. Sometimes the discount made by suppliers can be so important that the price of the equipment drops below the lowest bound subject to public procurement. For instance, Case 1 show how researchers purchased an equipment that initial price was 90 000 € and then were involved in the adaption/co-invention with the suppliers obtaining a final discount of 30 000 € which allowed them to avoid the public procurement procedure for this subsequent purchase.

Similarly, in the third case the lab purchased an equipment costing 600 000 € for 240 000 € instead.

These examples illustrate well an important aspect of researcher-suppliers' relations: an equipment purchase is often followed by an whole stream of relations that unfold between researchers and suppliers both before and after moment of acquisition of a new device and that go beyond the initial formal context. [4]

5.4 From conduits of influence to innovation benefits

Altogether our three case studies provided strong empirical evidence with respect to both direct and indirect learning processes that take place among researchers and suppliers. Our results are by and large in line with the prior research that has tried to evaluate the economic impact of public investments into scientific research (Schmied, 1982, 1987) as well as with studies on the economic value generated by public science centres (Autio et al., 2004; Castelnovo et al., 2018; Florio et al., 2018). These studies identify four large mechanisms through which the above value is created.

First, through their interactions with university researchers, suppliers acquire significant innovation benefits in terms of increasing turnover due to the ability to develop new and improved products. As illustrated by the three cases, the conception of these products is impacted by university laboratories in various ways: from feedbacks about which direction to take for the research developments to detailed feedbacks about existing products or, finally, via the conception of new systems by the researchers themselves through the combination of existing devices. Second, keeping close relations with university laboratories yields significant commercial benefits to suppliers, as their turnover increases due to marketing reference value associated with the fact of being a supplier of an internationally recognized research unit. As shown in our field study, suppliers grasp this value in various ways. By diffusing information about their equipment that is used, tested or co-invented with research unities via user manuals; brochures; interviews with researchers published on their site and other communication means as well as by exploiting the researchers' scientific and academic network. A third possible benefit for suppliers stems from the positive financial impact of a

[4] Furthermore, our cases indicate that interactions between researchers and suppliers can also unfold after the end of a formal procurement process. Even companies that do not win the bid, get in touch with researchers with the specific need to understand what the critical flaw of their product was and how it should be addressed.

contract with a university. Contrary to prior studies (Schmied, 1982, 1987; Autio et al., 2004), we do not find support for this channel. In contrast, our interviews show that Strasbourg laboratories are not considered important by companies because they are a big customer i.e., they purchase a lot, but rather because of their scientific distinction and reputation, which creates a significant positive externality for supplying companies.

Finally, it has been argued that public research contributes to suppliers' costs-savings through process improvements (Schmied, 1982, 1987). Our case studies reveal at least two channels through which such a process improvement takes place. First, laboratories build pre-series samples for the suppliers and provide them with precise information about the production process in large-scale environment and possible adjustments that might be required. On these grounds, suppliers take decisions whether to pursue with the large-scale production of the pre-series product or not. Often such pre-series production takes place once the suppliers have loaned the equipment to researchers to perform demonstration on it and test it. In addition, university laboratories carry out alpha, beta and field-testing which also generate relevant information for suppliers' production practices.

6. Conclusions

In this study, we provided field-study evidence about how university research influences the innovative performance of their suppliers. Technological learning among researchers and suppliers is determined by the processes and pace with which knowledge is diffused from its primary locus - the university - to the suppliers for which this knowledge has practical applications. We showed how, by sharing with suppliers' particular pieces of knowledge or technologies, researchers' help companies to develop new capabilities in the production of a certain device. These skills were then applied in the manufacturing of other types of devices, resulting in the expansion and diversifications of suppliers' activities. Thus, technical skills acquired during research activity at the university had direct applications in suppliers' production processes. In a nutshell the university effect on suppliers stems from the new capabilities and technologies that were developed or improved in response to researchers' specific, unprecedented requirements. In addition, once the knowledge acquired by universities was mastered, suppliers used it for other uses and applications.

The above-described process shares several characteristics with the unique historical account of the emergence of the machine-tool industry by Rosenberg (1963), scientific instruments being among the broad spectrum of machine-tool-using industries. According to Rosenberg's analysis (1963) the machine tool industry emerged out of intensive interactions among users (the industries which adopted new techniques of machine production) and producers. Machinery producers acted in response of a specific production requirements of different users and gathered knowledge about their needs with respect to broad range of technical solutions. Tapping into users' local knowledge and skills (accumulated through time with problem-solving of unique technical puzzles) that were essential for the machines' manufacturing process, allowed producers to introduce more efficient solutions.

Furthermore, our field-study shows that, even if the process governing researchers-producers interactions is mainly determined by the state of technology provided by suppliers at the beginning, it is heavily influenced by researchers demand thereafter. Indeed, researchers are in a position to communicate to suppliers' companies requirements that other kinds of organizations would be unable to impose and, in such way, influence them significantly in their evolution within a certain technological paradigm (Dosi, 1982).

Our study thus offers a new perspective about the role of universities than the one advanced by prior university-industry interaction studies. By focusing on the mutual learning processes unfolding through researchers-suppliers exchanges, we have been able to go further than these previous works as well as "input-output" studies that have attempted to quantify the secondary economic impact of universities. While valuable, these studies do not provide in-depth insights into how universities operate as a learning environment in a way different than other entities. The conjecture underlying our study, and that was confirmed by our case studies, is instead that there is something special about the relations among university researchers and suppliers that creates a momentum and allows to the latter to become more innovative (Antonelli and Gehringer, 2015a, 2015b, 2015c, 2019).

Our field-study has implications for researchers, university practitioners and policymakers. Our empirical evidence indeed suggests that interactions among universities and their industrial suppliers are multifaceted, involving a large number of different participants, and shows that universities possess some distinctive potential for acting as a learning environment compared to other types of public research institutions as for example big-science centres. However, the implications of a user-producer approach for industrial and technology policy recommendations are rather laborious. Science and technology policies should target both sides involved in the interactions, i.e. both universities and suppliers, in order to generate dynamic complementarities between them. According to our findings, the emergence of these complementarities is very much linked to the existence of a continuous dialogue between researchers and suppliers, so if one of them is not able to sustain the dialogue with the other the chain of effect will eventually be impaired. Furthermore, our field-study evidence clearly indicates that researchers-suppliers' dialogues are sustained by trust and informal practices of communication. Singular market transactions i.e. purchase of equipment are often embedded in a rich nexus of non-market, informal exchanges. It follows that encouraging knowledge exchanges and collaborations among university researchers and suppliers by settling more informal occasions would create space for non-market relations and enhance the quality and corresponding impact of the relationships among researchers and suppliers.

The present study could be extended in several ways. First, more research is needed for a broader and deeper examination of the effects of universities on second-tier suppliers and other actors of the supply-chain. Second, our current account of the researcher-suppliers' relations represents them as having solely positive effects to both sides. However, during our interviews we collected data that hints also to possible negative externalities for researchers as for example when they are obliged to accept equipment for free in their research unities just by convenience, neglecting their research agenda. Third, as shown by our cases, researchers match their expertise with suppliers that are able to assist them in the further development of instrumentation. Thus, only certain companies would be able to become university suppliers and benefit from the instrumentation knowledge at universities. This could raise questions over the truly public nature of knowledge created by universities through their demand.

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