CRITICAL FACTORS FOR LEVERAGING TECHNOLOGY TRANSFER FROM A TECHNOLOGY INTERFACE CENTER TO THE INDUSTRIAL ECOSYSTEM: THE CASE STUDY OF A METALLOGRAPHY LABORATORY

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Abstract

This paper aims at identifying and empirically evaluating the critical success factors for technology transfer practices (TTP) from the Technology Interface Center (TecIC) dedicated to the metalworking industry into the industrial and manufacturing ecosystem in the Portuguese context based on a case study from a metallography laboratory.

The authors will explore the rationale and practical implications for TTP in four vectors: i) technology adoption and technological outputs adoption by the industrial ecosystem; ii) networks, standardization, and knowledge creation; iii) lifelong learning/training and team capacitation; iv) industrial, academic and TecIC ecosystems interaction and knowledge and outputs transfer.

This work calls attention for the central role of support and development that infrastructures such has technology interface centers play in accelerating technology transfer practices to the industrial ecosystem, especially in small and medium sized enterprises or highly differentiated organizations. The adoption by the industrial ecosystem of new or renewed processes and practices are also mediated and potentiated by the differentiated access to knowledge networks, access to technology, and technology mediated outputs such as the one promoted by TecIC.

Keywords: *technology transfer, technology interface center, standardization, research, and innovation*

1. INTRODUCTION

The Innovation Scoreboard (EURAXES, 2022) results show that countries that are innovation leaders perform better than countries with economies with low levels of innovation investment and institutions that do not favour knowledge and technology transfer activities. This result confirms that to achieve a high level of performance, countries need a balanced innovation system performing well across eight dimensions - human resources, open, excellent research systems, finance and support, firm investments, linkages and entrepreneurship, intellectual assets, innovators and economic effects (Calcagnini & Favaretto, 2016; EURAXES, 2022). However, although universities and technological interface centers play important functions in the innovation systems of most industrial and industrializing economies, the importance of their role varies considerably across economies, and is influenced, among the others, by the structure of the domestic industry, the firm size, the size and composition of human and social capital, and the way domestic institutions make doing business easier (Calcagnini & Favaretto, 2016; World Bank, 2013).

Technology transfer practices (TTP) can be defined as the transfer of physical devices, processes, technical skills, proprietary information (Bozeman, et al., 2015; Bozeman, 2000) or technical information transposition from one entity to another. This transfer can lead to several outputs such as dissemination, acquisition of knowledge, experience and/or correlated artefacts (Silva, et al., 2021; Hameri, 1996), development of new products or services and access to differentiated markets and/or value networks based on technical knowledge (Fernandes & Rocha, 2006) or technological outputs exchange and access to shared innovation resources. TTP implies exchanges of these assets between different sources, organizations or interested parties, and the process can be catalysed by organizations or the environment in which it occurs (e.g., cluster dynamics).

TTP are complex and multidetermined, implying diverse interactions and a combination of emitters (Bessant & Rush, 1995; Silva, et al., 2021). According to the literature, the process of technology transfer is dependent of several variables, such has the transfer agents, characteristics of the transfer object, transfer channels, ecosystem characteristics, market demands, market needs, management practices, expertise from the actors (Bozeman, et al., 2015; Silva, et al., 2021), information access and the type of organization. But it's well documented that there are environments that potentiate transfer, for example, joint clusters or creative areas, giving light to the importance of policy definition and structured investment (Danquah, 2018). If policy can help the TTP by facilitating and promoting the transfer of key enabling technologies (KET) to the industrial ecosystem, strengthening bounds and networks (Agarwal, et al., 2015; Danquah, 2018; Silva, et al., 2021), and policies can also delay or stop these TTP, e.g. promoting institutional or legal frameworks (Castillo, et al., 2018). Research shows that there are organizations that can act as catalysts in the ecosystem for fostering or delaying these exchanges.

Over the past decades emerged the need, not only on the academic field but also among managers, entrepreneurs and policy makers, to systematize TTP practices into models (Agarwal, et al., 2015; Bozeman, 2000; Bozeman, et al., 2015; Calcagnini & Favaretto, 2016; Castillo, et al., 2018; Silva, et al., 2021; Rauch, et al., 2018) that could highlight, provide insight on these phenomena hoping for usable knowledge (Bozeman, et al., 2015) that could help to understand the functioning of knowledge transfer.

One of the most accepted, used and applied model is the contingent effectiveness model of technology transfer or its successor the revisited contingent effectiveness model of technology transfer (Bozeman, 2000; Bozeman, et al., 2015) it has been used in applications or as a conceptual framework in a wide variety of approaches in diverse fields, from industrial ecology to educational innovations and the pharmaceutical vaccines industry (Mohammadi, et al., 2021; Hendriks, 2012; Kitagawa & Lightower, 2013).

The revisited contingent effectiveness model of technology transfer (Bozeman, et al., 2015) it is based on the original contingent effectiveness model of technology transfer (Bozeman, 2000) and almost identical, but adds the public value creation (see Figure 1).

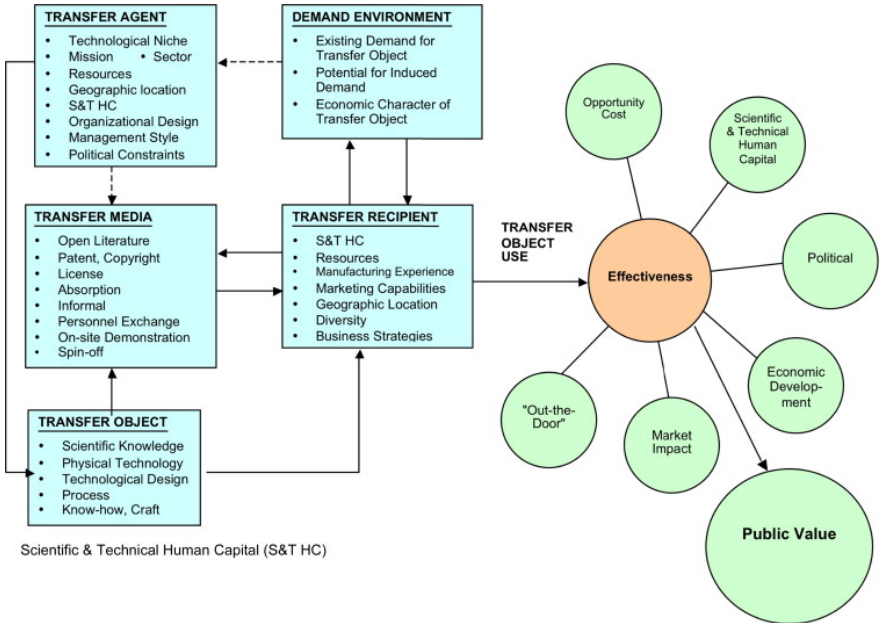


Fig. 1. Revised contingent effectiveness model of technology transfer

Source: Bozeman, B., Rimes, H. & Youtie, J., 2015. The evolving stat-of-the-art in technology transfer research: Revisiting the contingent effectiveness model. *Research Policy,* 44, pp. 36.

The model identifies five categories of technology transfer effectiveness determinants or contingencies: (1) characteristics of the transfer agent, (2) characteristics of the transfer media, (3) characteristics of the transfer object, (4) demand environment, (5) characteristics of the transfer recipient. These five dimensions are not entirely exhaustive but are broad enough to include most variables examined in most studies (Bozeman, et al., 2015). The technology transfer agent is effective once technology has been converted into a transfer mechanism either formal or informal, and another party has acquired the technology (Bozeman, et al., 2015), that may or may not put it to use.

The word contingency is central to understanding the global model since it encompasses the concept of multiple goals and multiple effectiveness criteria. These effectiveness criteria include and can be better understood by answering some questions: (1) "out-the-door", we are responding to the question was technology/knowledge transferred to the ecosystem? When analysing the contingency, it might be possible to focus on the activity itself rather than the outcome; (2) Market impact - Did the practice reverted on the organizational profitability and/or sales? The focus is clearly in one key feature of technology and knowledge transfer, although we must have in mind that there are non-for-profit transfer activities and other classes of valuable market value rather that money; (3) Economic development – Did the technology and knowledge transfer lead to regional economic development? (4) Political advantage – Was there a political gain for any of the interested parties? (5) Development of scientific and technical human capital – Did the technology transfer activity lead to an increment in capacity to perform and use research? (6) Opportunity cost considerations – What was the impact of technology transfer on alternative users of the resources? and (7) Public value – Did the technology transfer enhance collective good and broad societally shared values? The answer to these questions allows transfer practices beneficiaries to systematize and map the impact of transfer practices within its own practice and in the ecosystems in which they function. It's not always easy and direct to measure each one of the assets identified. The research suggests using diverse approaches from qualitative methodologies to quantitative methodologies or combined methodologies.

2. MATERIALS AND METHODS

The study is based on a case study approach. Case study research typically includes multiple data collection techniques and data are collected from multiple sources. Data collection techniques include interviews, observations (direct and participant), questionnaires, and other relevant documents (Yin, 2014), training records, auditing reports, test reports. The case study is a research strategy in which a contemporary phenomenon is to be examined within its real-life context, especially where the boundary between phenomenon and context is difficult to define (Yin, et al., 1983; Yin, 2014).

The data collection was done in a metallographic laboratory within the TecIC that supports industry and other relevant interested parties of the industrial ecosystem. The study was based on multiple data collection techniques (Yin, 2014) and data were collected from multiple sources. Data collection included national, European, and international standardization participation mapping, general standardization documents, standards, semi-structured interviews with interested parties, focus-groups with stakeholders, observations (direct and participant) accreditation documents, technical reports, project outputs and deliverables, and other relevant documents.

Semi-structured interviews according to the revised contingent effectiveness model of technology transfer (Bozeman, et al., 2015) were conducted to pre-identified interested parties in the transfer process. The preliminary results were discussed within focus-groups. A content analyses was performed to the data.

Data was systematized accordingly to the revised contingency effectiveness model of technology transfer (Bozeman, et al., 2015) and the main success factors and barriers to transfer identified and categorized. In this research 25 critical factors were extracted from the data and were adjusted using experts´ and other relevant interested parties' opinions.

3. RESULTS

TTP are multidetermined and complex alongside with the multiplicity of technological transferable critical factors identified. It was identified, extracted and classified 25 critical factors from the experts 'and other relevant interested parties' opinions. The critical factors were classified and analysed according to:

i) Rationale and practical implications for TTP in four vectors - technology adoption and technological outputs adoption by the industrial ecosystem; networks, standardization, and knowledge creation; lifelong learning/training and team capacitation; and industrial, academic and TecIC ecosystems interaction and knowledge and outputs transfer.

ii) Possible effectiveness criterium according to the revised contingency effectiveness model of technology transfer (Bozeman, et al., 2015) and its perceived potential impact in practices.

iii) Perceived relative impact of these critical factors according to the effectiveness criterium.

The result of the critical factors classification is shown in Table 1.

Critical factors	**Effectiveness criterion and relative impact**						
	"Out the door"	**Market impact**	**Economic development**	**Political**	**Opportunity cost**	**Scientific and technical human capital**	**Public value**
National standardization participation (2)	++	+++	+++	+	++	+++	+
International and European standardization participation (2)	++	+++	+++	+	++	+++	+
Standards creation and revision (3)	+	+++	+++	++	++	+++	+
Standards transposition to practice (e.g., technical reports, test methods) (1)	+++	+++	+++	++	+++	+++	++
New (or renewed) test methods (1)	+++	+++	+++	+	+++	+++	++
Knowledge creation has support to peer recognition (1)	+++	+++	++	+	+	+++	++
R&D processes and knowledge creation to support audits (first- and second-part audits) (4)	+	+++	+++	+	++	++	+
New technologies available for market use (1)	+++	+++	+++	++	+++	+++	++
New knowledge available for market use (1)	+++	+++	+++	++	+++	+++	++
Knowledge transposition for training and lifelong learning (3)	+++	+++	+++	++	++	++	++
Peer-training and knowledge internalization (3)	+++	+++	+++	++	++	++	++
Technical documents writing (2)	+++	+++	+++	++	++	+++	+

Critical factors	**Effectiveness criterion and relative impact**						
	"Out the door"	**Market impact**	**Economic development**	**Political**	**Opportunity cost**	**Scientific and technical human capital**	**Public value**
Participation in networks promoted by TeiIC (2)	+++	+++	++	+	+	++	+++
Use of project outputs in day-to-day business (4)	+++	+++	+++	+	+	+	+
I&D KPI to Business (4)	+	+	+++	+	++	+++	+
Technology transfer case studies (2)	+++	++	++	++	++	+++	++
Collaborative R&D development/projects (4)	+++	+++	++	++	+++	+++	+++
Membership in research groups (2)	+++	++	+++	++	++	+++	+
Scientific publications (2)	+++	++	+	++	++	+++	++
International and national conferences (2)	+++	+	++	+	++	+++	+
Training and consulting (3)	+++	+++	++	+	+++	+	+++
Technology surveillance and business intelligence (4)	+++	+++	+++	++	++	+++	+++
Undergraduate and graduate scholarships (3)	+	+	+++	+++	+++	+	++
Strategic networks (2)	+++	+++	+++	+++	++	++	++
Brand registrations (1)	+++	+++	++	+	++	+	++

(1) Technology adoption and technological outputs adoption by the industrial ecosystem, (2) Networks, standardization, and knowledge creation, (3) Lifelong learning/training and team capacitation, (4) Industrial, academic and TecIC ecosystems interaction and knowledge outputs transfer

Expert's level of perceived relative impact in the ecosystem + low impact; ++ median impact; +++ high impact

Table. 1. Critical factors according to vector analyses and classified according to the effectiveness criterion ant its relative impact

From the semi-structured interviews to experts and interested parties the main finding concerning barriers and enablers to the transfer process were identified in Table 2.

Asset	**Barriers**	**Enablers**
Cultural	Communication difficulties	Clear communication
	Communication failures	Clear communication
	Misconceptions (e.g., stereotypes)	Correct reality read
Political	Excessive regulations	Favourable regulations
	Incentives	Inflexible rewards

Asset	**Barriers**	**Enablers**
	Difficult access to transfer agents (e.g., TecIC)	Access to transfer agents (e.g., TecIC)
Geographic	Geographic distance	Cluster regions
Organizational	Organizational policy that facilitates transfer and new knowledge adoption	Organizational policy that difficult transfer and new knowledge adoption
	Excessive bureaucracy	Correct information and process design
	Lack of infrastructure	Shared/adjusted infrastructure (e.g., knowledge, technology)
	Inadequate technology	Adequate technology and/or critical shared technological resources
	Lack of economic resources	Availability of economic resources, shared resources
	Proprietary resources	Shared resources (e.g., technology)
	Complexity of the transfer object (e.g., technology, knowledge, knowledge application)	Shared resources (e.g., technical experts, shared technology, networks)
	Lack of interest/knowledge	Interest/knowledge
Personal, individual, or collective	Lack of management skills	Adequate management skills
	Lack of skilled technicians	Technically skilled technicians Shared skilled technicians
	Difficulties in obtaining support from experts in the transfer area	Shared experts in key-transfer areas
	Lack of trust	Trust
	Commitment	Lack of commitment

Table 2. Critical factors (barriers and enablers) to the technology transfer process

From the semi-structured interviews and focus groups with experts and stakeholders it was identified a variety of factors that can influence the TTP. These factors can act as positive success factors or negative influence factors according to the way they're managed and put into practice within organizational practices and procedures. As shown in Table 2, the same asset can be a barrier to the process of technology/knowledge transfer or an enabler to that same process. It's a very dynamic and contextual process, closely linked to the industrial ecosystem and the individual resources and capabilities of the ecosystems itself.

4. DISCUSSION

With the fast advances on technology there is a need from the industrial ecosystem to use new technologies, technological outputs and differentiated knowledge to have a competitive advantage

transferred into everyday practices in a systematic, sustainable, and competitive way. Technology and knowledge transfer are also seen has a useful approach to gain competitive leverage over other organizations and/or supply chains (Kumar, et al., 2015). As most companies alone cannot research and develop their own technologies, they should use knowledge sources outside the organization, hence, organizations need technology transfer practices in order to survive (Mohammadi, et al., 2021; World Bank, 2013; Kumar, et al., 2015) and maintain sustainability. This capability becomes critical in Small and Medium Size enterprises (SME) where resources are scarce and innovation practices and technology transfer are many times dependable on network participation (Mancini & González, 2021; Miranda & Kusrini, 2021) and shared expertise/technology. The absorptive capacities of TTP in the ecosystems are not only dependent on the organization by itself, but the more networks, groups, teams, and communities are receptive to "new" ideas the more enhanced is the chance for an efficient absorption of technologies from other sources (Amesse & Cohendet, 2001). The effectiveness criterium and que corresponding key performance indicators (KPI) are many times difficult to quantify and dependable of the ecosystems and the environments. It was clearly noticed the impact of the world pandemic we are facing in organizational practices, and the urgent need of resilient systems and access to the needed resources just-in-time. It was highlighted by the experts and interested parties, the central role of accessing transfer agents – TeiIC - for making available shared technology, knowledge and resources, shared experts' competencies, and shared differentiated information. These assets make a difference in anticipating market needs or aligning strategic routes of development, or even on offering new or differentiated services and/or products. The access to transfer agents is perceived has an asset for prospering.

From the focus group and interviews approaches it were identified 25 critical factors for leveraging knowledge and technology transfer (see Table 1). There are four critical areas identified by the experts:

1) Technology adoption and technological outputs adoption by the industrial ecosystem – The existing FabLab and other shared infrastructures, technologies and knowledge allows TeiIC users or beneficiaries to experience and share new technologies ant its outputs, without having excessive costs when comparing to the acquisition of dedicated and proprietary technology. The TecIC also allies the access to shared technology, shared qualified experts in knowledge development areas (e.g., materials, materials processes and proprieties, corrosion, materials' tests, and analyses). New technologies imply new knowledge, allied to trained and/or qualified technicians in strategic development areas, the real cost is not only the technology cost, but also the training and development of new (or renewed) skills in technicians and the ability to transfer data into applicable knowledge and wisdom. The production of specialized and dedicated technical reports (e.g., tests from the standardization system) with sample materials or sample products from clients allows access to qualified technicians in differentiated areas. It can be enunciated the case for the development, translation to the national language, test design, and knowledge transfer to the ecosystem in the form of technical reports/ individualized research studies, derived from the standards EN ISO 6509-1 Corrosion of metals and alloys — Determination of dezincification resistance of copper alloys with zinc — Part 1: Test method, and ISO 6509-2 Corrosion of metals and alloys — Determination of dezincification resistance of copper alloys with zinc — Part 2: Assessment criteria (many other examples could be enunciated). TeiIC participates, makes available and promotes transference to the ecosystem of outputs resulting from the several phases upper enunciated. Granting access to differentiated valuable and contextual knowledge with real and perceived value for the ecosystem. It allows, for example, unlocking access to other regions fostering the entrance in new markets with specific requisites (either for product or for service), or promoting the development of excellence knowledge centers in specific technical areas (e.g., stainless stell). The case of the stainless stell material is also very interesting since the material and related methods and techniques have evolved gradually over the past 20 years, either for material applications, or for new alloys in the market, evidencing the constant need for up-to-date knowledge and expertise.

2) Ownership/belongingness to networks, standardization, and knowledge creation. Standardization is a key-area for anticipating tendencies, designing roadmaps and align the ecosystems strategy. TeiIC manages 16 national technical commissions that mirror the work of more than 130 standardization technical groups (European and International) (CATIM & IPQ, 2022) in strategic areas for the industrial ecosystem. Belonging to these networks allows experts to access not only knowledge, but also to participate on the co-creation of knowledge that supports new or revised standards and other

standardization documents. These standards are mainly based on ecosystems' needs and/or gaps. Belonging to these networks gives direct access to a structured international network of highly differentiated experts and highly valuable and with high potential for transference knowledge. Strategically this is a big asset since it can lead and anticipate market tendencies (e.g., regulatory or market access) and support the development or renewal of industrial processes from manufacturing to management and certification. The belonging to these networks is pointed as critical for users since its seen has a mean to access privileged information, social capital, socio-economic goods, and attachment values (Fernandes & Rocha, 2007). The social capital paradigm can help us to better understand this trend, since it joins assumptions from the economic field (e.g., capital theory) and psychology (e.g., motivation theories). Social capital can be defined as a person or group sympathy towards another person or group, that may produce a potential benefit, advantage or preferential treatment that go beyond that expected exchange in relationships (Robinson & Flora, 2003). Its basic premise is that a network provides value to its members by allowing them access to the social resources that are embedded within the network (Bourdieu, 1985; Fernandes & Rocha, 2006; Florin, et al., 2003). Standardization technical groups participation unlocks knowledge and knowledge application to key industrial areas, see for example the case for EN ISO 6509-1 and ISO 6509-2 where TecIC experts participate in all life cycle of the documents and its transposition to practice. The deep understanding and expertise and its communicating and sharing with the ecosystem is only possible because of the TecIC investment in strategic areas for the country industrial development and the qualification of experts.

3) Lifelong learning (LLL)/training and team capacitation. TeiIC develops specialized training and consulting in key-strategic areas according to market needs and gap analyses, new areas of development, standardization updates and developments, and new trends in standardization and strategical approaches to the market. These areas are result of business intelligence research, network participation, standardization developments, KETs availability, I&D project findings and outputs allied with internal expertise. The investment in qualified technicians allow the multiplier effect of results through the TecIC users, clients, and beneficiaries. Transfer areas are mainly: quality, environment, energy, machinery and equipment, safety at work, industrial metrology. The big asset for the access to shared expertise of the TecIC allows the ecosystem to have access to state-of-the-art knowledge and to embed it into daily practices. Being a shared resource makes it more affordable and easier to access and to adopt. The pedagogical approach of the TeiIC to LLL has been from several years based on technology and hybrid models underlying an integrated theoretical approach when designing learning scenarios, the need was potentiated by the pandemic context (Norgard, 2021) and allowed generalized access to training while in lookdown to TeiIC users. LLL is a key competency either for individuals or for organizations that has gained importance with the actual context (Cermakova, et al., 2021). The importance is highlighted by being one of the categories pointed has prominent and critical for success by the experts.

4) Industrial, academic and TecIC ecosystems interaction and outputs transfer. TecIC increases the degree of connectivity between the actors within the ecosystem (government, organizations, industry, entities from the national and international scientific and technological system) and it's shown by the importance of the critical factors identified and its perceived impact on organizational practices. When answering to gaps in knowledge from industry, TecIC potentiates the access to collaborative work among a diversity of interested parties. For example, when performing a failure analyses TeiIC has the internal expertise and technology that is combined with the expertise from the academia, industry and laboratory fields and the need from the client. The outputs that are made available for the ecosystem, let's take the example a technical report (see Figure 2), are one of the possible results of TTP to practice resulting from the access to expertise, technology and networks belonging.

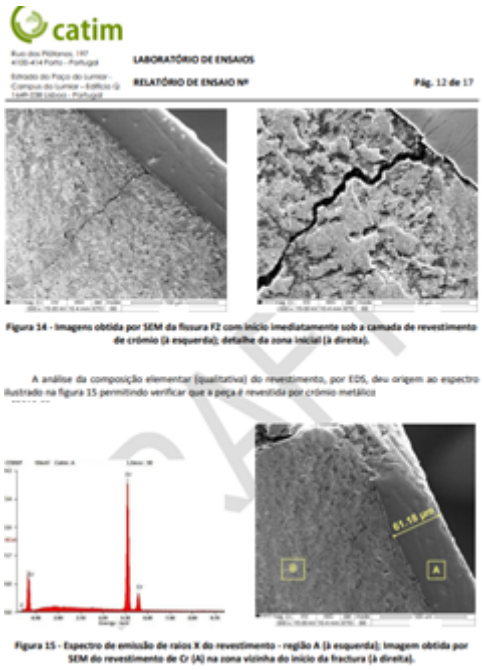


Fig. 2. Output TTP to the ecosystem – Extract from a failure analyses study report performed by qualified experts from the TecIC' Metallographic Laboratory

The capability of participating in standardization groups and create/revise standards with industrial applications, followed by the test design and transferring of knowledge in tangible ways to the ecosystem is perceived has an asset capable of creating wealth and add value to the products (or services) provided to the ecosystem.

It's recognized that TTP need to have more consistent methods to measure its efficiency. Although, generally it is very difficult to define KPI to measure success when analysing technology transfer practices (Mohammadi, et al., 2021; Kumar, et al., 2015; Mancini & González, 2021; Silva, et al., 2021), however metrics for success within each typology of organization must be defined. It's only possible to improve what can be measured. Aligning, for example, certified systems, its outputs and metrics for innovation, development, and transfer practices.

According to the results of the literature review, interviews, and focus groups it was systematized the main drivers and barriers that can promote or hinder the TTP (see Table 2). The same asset, according to the context and/or managerial practices can act as a driver or as a barrier. Giving light to management practices and alignment of organizational practices with strategic planning in key areas and individuals competency and interest. Our study shows that psychological in-process factors such as trust, commitment and belonging to networks, allied with soft skills from management play an important role in facilitating TTP. However, these finding must be interpreted in the context of this specific study due the methodological approach followed. Infrastructures from the scientific and technological system, such has TecIC, have also an important role in the construction of technology transfer narratives to support policies, policy makers and law design that allow to enhance market readiness to adopt new practices and technologies.

This preliminary study intended to be a holist approach to the technology and knowledge transfer practices within a technological infrastructure that supports industry and the industrial ecosystem. It was targeted to promote discussion of practices and its role on resilient practices from the ecosystem. Future studies must ally a more robust analyses, so that causal relations might be drawn among the variables (Kline, 2016) on the design of transfer models and its validation, for example structural equation analyses or cluster mapping (Ketels, 2017). The definition of methodologies to access KPI, advantages and disadvantages for the stakeholders are another important phase of the work for future research.

5. CONCLUSIONS

TTP are strongly dependent on facilitator organizations such as TecIC, alongside with policies and regulator laws for the regions or clusters. The inclusion of narratives of technology transfer success stories and case studies evidence the tacit acceptance by practitioners that public value is an important criterion for the promotion of public values in science, technology, and innovation policy alongside with internalization practices by the ecosystem.

Organizations such as TecIC function has TTP accelerators and mediate the quality of the transfer process. Allowing transfer practices to be systematized, and professionally managed allowing SMEs and other organizations and interested parties to access information and technology that otherwise would be almost inaccessible due to scarce resources. TecIC access allows the market to have competitive advantage by using shared resources (technology, expertise, network access, KET induced outputs) and is perceived has an asset for resilience. These systematized practices allow the ecosystem to be more resilient and competitive adopting and internalizing KET and KET induced outputs into everyday life routines and is faced not only as a technology isolated project but has a consistent practice. TecIC are facilitators for TTP, and foster practices of internalization by the ecosystem as a crucial part of its business strategy. There are also psychosocial success factors underlying the transfer practices, for example trust, commitment, and the feeling of belongingness to the network that fosters TTP and are strongly influenced by personal characteristics.

Our study contributes to better understand the complex process of technology and knowledge transfer within industrial ecosystems alongside with the role of specific transfer agents. By considering cultural, political, geographical, organizational, and personal individual critical factors for enabling or hindering the transfer process the process was mapped in a holistic and integrative perspective.

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