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Technology transfer 4.0 in Latin American innovation ecosystems

Transferencia de tecnología 4.0 en ecosistemas latinoamericanos de innovación

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Resumen: Este artículo analiza los procesos de transferencia de tecnología 4.0, las condiciones implicadas en ésta y las principales tendencias tecnológicas transferibles en América Latina. El enfoque de complejidad en el ecosistema permite explicar cómo los actores o subsistemas se (re)adaptan o (re)aprenden con base en su interacción sin ser gestionados por alguna entidad o componente específico. El proceso metodológico se basa en un análisis cienciométrico, uno temático con base en los proyectos financiados con recurso público de 2002 a 2018, y otro del ecosistema de innovación en la región emergente del Bajío mejicano. Los hallazgos muestran la relevancia de los organismos intermedios en el liderazgo social para la transferencia tecnológica. Big data, IoT y cloud computing son las principales tecnologías 4.0 potencialmente transferibles para responder a condiciones territoriales heterogéneas.

Palabras clave: transferencia de tecnología; ecosistema de innovación; tecnología 4.0; reestructuración productiva de sectores locales.

Abstract: This paper analysed the processes of technology transfer 4.0, its conditions and the main transferable technological trends in Latin America. The complexity approach in the ecosystem allowed to explain how the actors or subsystems are (re)adapted or (re)learned based on their interaction without being managed by any specific entity or component. The methodological process consisted of a scientometric analysis, a thematic analysis based on the projects financed with public resources from 2002 to 2018, and an analysis of the innovation ecosystem in the emerging region of the Mexican Bajío. The findings showed the relevance of intermediate organisms in social leadership for technology transfer; big data, IoT and cloud computing are the main technologies 4.0 that are potentially transferable to respond to territorial heterogeneous conditions.

Keywords: technology transfer; innovation ecosystem; technology 4.0; productive restructuring of local sectors.

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Transferência de tecnologia 4.0 nos ecossistemas de inovação da América Latina

Resumo: Este artigo analisou os processos de transferência de tecnologia 4.0, suas condições e as principais tendências tecnológicas transferíveis da América Latina. A abordagem de complexidade no ecossistema permitiu explicar como os atores ou subsistemas são (re)adaptados ou (re)aprendidos com base em sua interação sem serem gerenciados por nenhuma entidade ou componente específico. O processo metodológico consistiu em uma análise cientométrica, uma análise temática com base nos projetos financiados com recursos públicos de 2002 a 2018 e uma análise do ecossistema de inovação na região emergente do Bajío mexicano. Os resultados mostraram a relevância de organismos intermediários na liderança social para transferência de tecnologia; big data, IoT y cloud computing são as principais tecnologias 4.0 que são potencialmente transferíveis para responder a condições territoriais heterogêneas.

Palavras-chave: Transferência de tecnología; ecossistema de inovação; tecnologia 4.0; reestruturação produtiva dos setores locais.

Introduction

Science, technology and innovation (STI) are crucial axes to guarantee the development of the territories and to influence society; their structure and knowledge capital are enabled to modify the performance of the sectors or actors with whom these interact (Fukuda, 2020; Hou, Hong, Wang & Zhou, 2018; Villani, Rasmussen & Grimaldi, 2017). In Latin America, the operationalisation of the STI has been insignificant and with weakly systematised results to influence socioeconomic welfare (Casas, 2020; Giraldo, 2019). An extensive body of literature around this question shows that this operationalisation is not only explained by public investment in STI, but also by other factors such as the prioritisation of areas of knowledge (Yao, Huan & Su, 2020; Hasanefendic, Heitor & Horta, 2016) or the connection between educational and STI policies, and politics (González & Álvarez, 2019; Álvarez & Palacios, 2018; Ankrah & Al-Tabbaa, 2015). Furthermore, it is explained between one region and another by different factors as institutional, cultural, productive vocation or technological capabilities (Kim, Rheeb & Kotha, 2019; Shi, Wu & Fu, 2019; Chang, Yang & Chen, 2009).

One of the most frequent mechanisms with which the STI affects the territory is the transfer of technology, which occurs in organisations with the capacity and willingness to innovate, such as universities, or public and private research centres (Etzkowitz, 2018; 2003; Soares, Torkomian & Seido, 2020). Technology is one of the most relevant enablers in the dynamism of the regions and in their socioeconomic welfare, which is constantly evolving, and has become a field of reflection and practice (Fayomi, Akande, Esse & Fayomi, 2019) to generate social mobilisation (Leahey & Barringer, 2020). Technology has a significant sociotechnical influence and a high impact on the territory when social, cultural and organisational aspects are considered in its transfer due to their high degree of interdisciplinary integration (Beier et al., 2020; Coscieme et al., 2020). In current global conditions with a post-pandemic world in crisis, dynamism in technology transfer is essential. This research was focused on the transfer of technologies 4.0.

Technologies 4.0 are characterised by the intensive use of sophisticated digital technologies that interconnected have the potential to transform the society, the environment and the economy; its three main axes are connectivity, intelligence and flexible automation (Schwab, 2017). Furthermore, these are distinguished by their capability to personalise and virtualise (Thuemmler & Bai, 2017). According to Hermann, Pentek & Otto (2016), the strategic components of technologies 4.0 are cyber-physical systems, the internet of things (IoT), the internet of services (IoS) and smart organisations. Based on the revised literature, the favourable conditions in the territory with a transformative and collaborative approach stimulate the transfer of these technologies with greater possibilities of social impact, and inclusive and sustainable economic growth (Janse, Telukdarie & Dhamija, 2019). However, the complexity of this phenomenon and its multidimensionality in emerging territories demand analytical frameworks that go beyond studying a company, a productive sector, a value chain, an institution or a knowledge network.

In this sense, the innovation ecosystem construct is used to provide a holistic view of the phenomenon under study. Phillips & Ritala (2019) argue that the adoption of the ecosystem as a construct to explain this social phenomenon generates very relevant methodological challenges; these are related to its limits, structure, timing and interactions to explain its dynamism and coevolution. This construct is called an innovation ecosystem when the studied phenomenon is related to the categories of technology, innovation, knowledge or digital transformation (Arenal et al., 2020; Jacobides, Cennamo & Gawer, 2018; Järvi, Almpanopoulou & Ritala, 2018; Russell & Smorodinskaya, 2018). Based on the literature review, the innovation ecosystem was conceptualized as the behavioural pattern of interactions between actors and subsystems in an innovation network, in which the connections have a high degree of complexity since these execute activities related to science, technology and innovation in regard to social environment (Arenal et al., 2020; Fukuda, 2020; Phillips & Ritala, 2019; Jacobides, Cennamo & Gawer, 2018; Järvi, Almpanopoulou & Ritala, 2018; Russell & Smorodinskaya, 2018).

The studied ecosystem in this research is located in the Mexican *Bajío*. This region located in the centre of the country has registered a high level of industrialisation and a strong dynamism in the service sector. In addition, it is host to some traditional productive sectors -agroindustry, textile, leather and footwear- and to the most dynamic automotive concentration in Latin America (Álvarez, Estrada & Palacios, 2018; Pérez, 2015). This automotive cluster is assembled by leading automobile manufacturing companies, a large number of supplier companies (tier 1) and several hundred SME supplier-companies that provide services to the automotive industry, and to auto-parts manufacturers in other regions, which are installed in a polycentric path in the region (Álvarez, Estrada & Palacios, 2018). The territorial scientific capability is significant, and its institutional system seems to have created the conditions for an innovative environment (Pérez, 2015). In this territory, industrial and technological parks, incubators and business accelerators have been installed; these call themselves a cohesion resource of the ecosystem (NOVAERA, 2019). Besides, a smart port is located in the region, which trigger internationally the ecosystem (GPI, 2019).

The environmental, economic and social complexities of the region, its productive restructuring and reindustrialisation processes experienced in the last decade, its aggressive economic policy of attracting foreign investment, its institutional discourse that has put science and technology as the natural path to achieve social welfare, among other details of its profile, have motivated its study. Therefore, the main aim of this paper is to analyse the conditions in innovation ecosystems to transfer technologies 4.0; these ecosystems are complex adaptive systems whose economic, social and environmental challenges are marked by strong inequality and heterogeneity.

Design and methodological process

The methodological design is focused on the analysis of the complex and contextual interactions of the ecosystem (Jenson et al., 2016; Phillips & Ritala, 2019). Data triangulation was used for internal validation and analytical generalisation for external validation (Yin, 2003). The methodological process was integrated by two phases. The first phase of the research began with a search of the Web of Science database; the publication date was not a restriction and keywords were delimited to Smart technology, Internet of things + technology transfer, Internet of things + technology 4.0, future Internet + technology transfer, future Internet + technology 4.0, IoT+ technology transfer, IoT + technology 4.0. The related documents were 986. Based on the indicators of relevance, 21 documents were selected; one was published in 2013, three in 2014, two in 2015, four in 2016, nine in 2018 and two in 2019; the thematic trend reported an annual geometric average growth of 140.03% in this period. In addition, a data bank was built with the STI projects, which were financed with public resources in the *Bajío* region between 2002 and 2018.

In the second phase of the research, data was collected through semi-structured interviews with 12 productive, institutional and academic actors in the ecosystem with experience in technology transfer. Table 1 shows the academic profile of the interviewees, who are part of three interest groups for the study: entrepreneurs and technology-based managers 4.0; STI managers and managers of intermediate organisations; researchers. The data collection instrument was made up of 14 questions that were classified into four dimensions: interaction in the environment; research with social impact; innovation as a binding mechanism; technology transfer 4.0. The interviews lasted between 32 and 53 minutes, which were recorded and later transcribed. This dense description (Clifford, 2003) was analysed semantically with Atlas.TI 8.3.1®; it was categorized through the analysis of the word cloud, the calculation of co-occurrence frequencies and the construction of the semantic network.

Table 1. Profile of the interviewers

Role	Academic degree	Role	Academic degree
Innovation Park Director	PhD. in Engineering	Technology-based Entrepreneur	Master of Business Administration and Master of Digital Marketing
Technology Park Director	Bachelor of International Trade and Master of Finance	Entrepreneur of technological services	Engineering in Product Design
Research promotion Coordinator	Industrial and Systems Engineering	Software Factory Manager (previously entrepreneur)	Mechanical Engineering and PhD. in Technology Management
Researcher	PhD. in Electrical engineering	Researcher and entrepreneur	PhD. in Computation and industrial mathematic
	PhD. in Regional development and sustainability		PhD. in Physics
	PhD. in Science (optical)		PhD. in Engineering

Source: Author's own construction, 2020.

Analysis and discussion of results

Technologies 4.0 are characterised by interconnection and sophisticated digitisation; their scope and the complexity with which they have invaded daily life exceeds any previous technological revolution; these technologies involve a cyberspace where the physical, the digital and the biological merge (Show, Kim & Hua, 2020; Thuemmler & Bai, 2017; Schwab, 2017). Some authors have called them digital transformation to explain how analytics, robotics, cognitive technologies, artificial intelligence, nanotechnology, IoT, IoS, additive manufacturing, digital twins, among others are incorporated into daily life and transform it, from the individual aspect to the social, organisational, productive, public and cultural aspects (Ivanov, 2020; Show, Kim & Hua, 2020; Thuemmler & Bai, 2017; Schwab, 2017; IBD & WEF, 2019; WEF, 2020). Based on the co-occurrence analysis, table 2 shows the technological trends 4.0.

Table 2. Co-occurrence analysis (technologies 4.0)

Technology 4.0	Frequency	Technology 4.0	Frequency
Big data (advanced analytical)	0.161	Cloud computing	0.145
IoT (digital track and trace; Smart labs, Industrial IoT)	0.097	Robotic (human-machine interaction)	0.065
Sensors and actuators	0.065	Technologies 3D	0.065
Mobile devices	0.048	Green Chemical and Chemical engineering	0.048
Chips with genomic sequence	0.032	Drones	0.032
GPS (5G)	0.032	Artificial Intelligence	0.032
Machine learning (deep learning)	0.032	Machine vision	0.032
Nanomaterials (nanotechnology)	0.032	Simulation	0.032
Biohybrids systems (bioengineered)	0.032	Smart sort bands	0.016

Source: Author's own construction, 2020.

It has been debated that building capabilities to transfer of technologies 4.0 and to act immediately on data will be the key to achieve serve social welfare and territorial development (Ivanov, 2020; Fukuda, 2020). This in some Latin American political discourses has been called *"ciencia para el pueblo"* (Casas, 2020, p. 24). In Latin America, the countries that lead the technology transfer 4.0 are Brazil, Argentina and Mexico; mainly with big data technologies (advanced analytics), IoT, robotics, 3D technologies, artificial intelligence and machine learning (deep learning); first and foremost, these technologies have been transferred to three sectors -financial, mobility and education- (IBD & WEF, 2019; OECD, 2019; WEF, 2018).

In this regard, the dense description exposed some solutions to socioeconomic issues that could be mitigated by transferring these technologies 4.0, such as the smart use and provision of water, the energy efficiency, the early responses to natural disasters, the efficient public services, the urban mobility, the open communication between citizens and government, the cybersecurity, the social and technological challenges in the healthcare sector, among others. In this sense, extant literature proposes that the four productive sectors with a high level of receptivity for the transfer of technologies 4.0 are automotive, textile, electronics, and food and beverages (WEF, 2020; IBD & WEF, 2019; OECD, 2019). Based on the co-occurrence analysis, table 3 shows the challenges of technology transfer 4.0 to a Latin American innovation ecosystem.

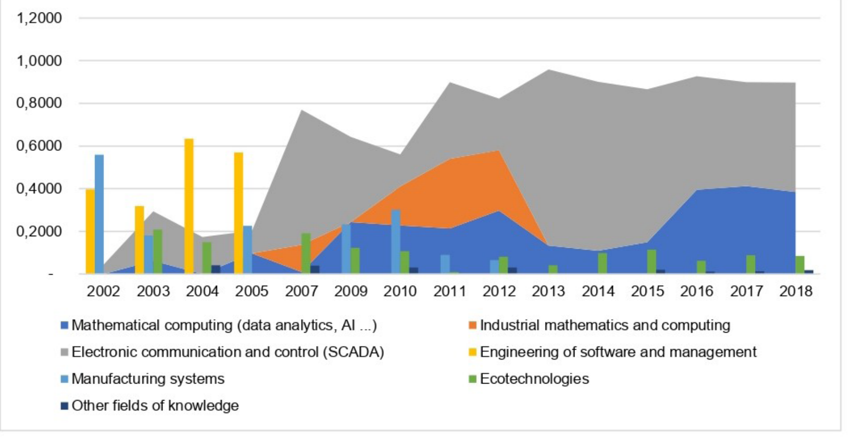
Table 3. Co-occurrence analysis, categories in technology transfer 4.0

Category	Frequency
Scientists (interdisciplinary, horizontal knowledge networks)	0.258
Social Adoption of technology	0.194
Mix of knowledge (scientific, technological and vernacular knowledge)	0.032
Processes (scalability and massiveness)	0.161
Intellectual property (licence agreement to general-use or industrial property)	0.123
Impacts on the sustainability (social, environmental and economic)	0.113
Funding (public, private, public-private, private-public)	0.065
Others	0.054

Source: Author's own construction, 2020.

Based on the defined methodological process, three strategic programs of the National Council for Science and Technology (CONACYT for Spanish initials) that promote technology transfer were analysed. The programs analysed were the Incentive for Innovation, the Technological Innovation Fund of the Ministry of Economy and the Mixed Funds of the region under study. Reached from the information published on the results of the calls for these programs, a data bank was integrated with the coded thematic information of these projects, which had been financed with public resources during the period from 2002 to 2018. The result of this thematic analysis is shown in figure 1, where it is exhibited the behaviour pattern of the STI priorities detected in the ecosystem. The identification of knowledge areas in STI projects is relevant since it allows associating the knowledge area with the technology transferred to the ecosystem, which could generate social processes of response.

Figure 1. STI thematic priorities



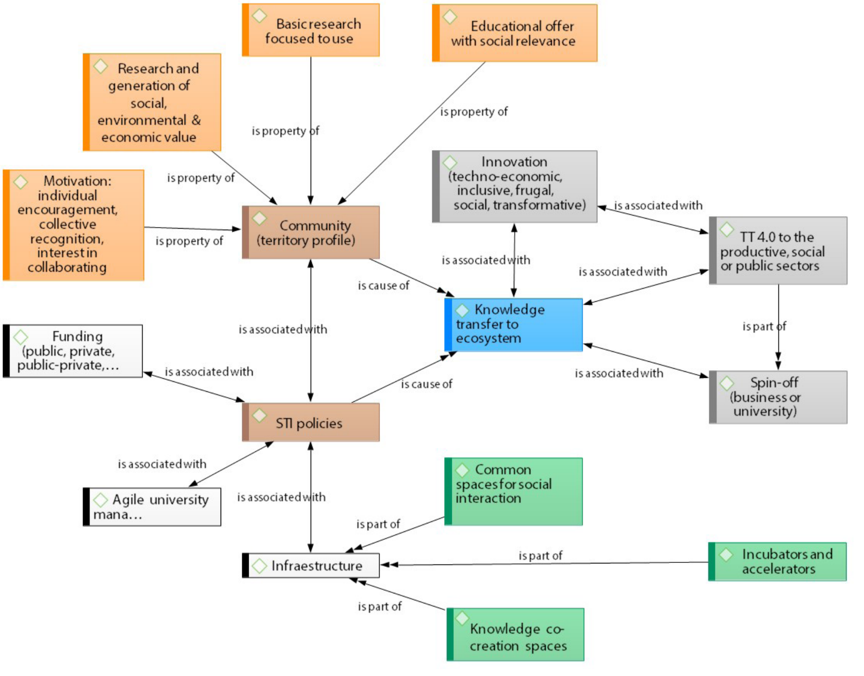
Source: Author's own construction based on CONACYT (2018a; 2018b; 2018c).

The conception of innovation ecosystem proposes a holistic vision based on the institutional, organisational and technological categories, among others. According to Phillips & Ritala (2019), the limits and interactions are established beyond the traditional ones of the company, the value chain or the network. The dynamism in the interactions of the innovation ecosystem is caused by the intensity in the technology transfer and by the collaboration of the academy with the ecosystem (Milesi, Verre & Petelski, 2017); besides, this is characterised by multifaceted motivations and plasticity in the structural transformations (Russell & Smorodinskaya, 2018). The results of the interactions affect the ability to absorb knowledge and to diffuse (transfer) technology, and the interests agreed or not during the process (Arenal et al., 2020; Jacobides, Cennamo & Gawer, 2018; Álvarez & Palacios, 2018; Perkmann et al., 2013).

The word cloud reported 275 codes that were categorized to analyse their frequency. The codes that showed the highest frequency were those related to the environment, institutional policies, research design with social impact and possibility of use, and horizontal knowledge networks. The codes with less frequency were commercialization, technological markets, business spin-offs, territorial welfare, and the intervention of the State in the definition of research. It should be noted that the technology referred to in the dense description as transferable, is diverse in characteristics and scope; one of the highest frequencies was recorded in technology services, followed by marketable patents and experience in troubleshooting (engineering). Furthermore, the relevance of a robust basic research system focused on being used in a short time period by other actors in the ecosystem was highlighted.

Next, the hermeneutic unit code network was analysed semantically to show the relationship between these codes based on property, causality, association and participation. The figure 2 shows the complex context of technology transfer, which is pressured by high uncertainty, and the possibility of interaction between multi-networks or groupings, and other innovation ecosystems. According to Russell & Smorodinskaya (2018), the innovation ecosystem is related to management flows and matrix networks that co-evolve based on its regional/territorial profile and its innovation-driven design.

Figure 2. The complexity in the conditions of the innovation ecosystem



Source: Author's own construction, 2020.

The basis of the semantic network was the profile of the ecosystem and the institutional policies of innovation and research to achieve the technology transfer with the productive, public and social environment. In semantic analysis it was frequently recorded that the university must be more active in the ecosystem; however, motivation and resilience are required to be the core of the academic community's profile; this could facilitate the transfer of technologies 4.0. The systematisation of the codes allowed to stratify these mentions into three categories: socially pertinent educational offer, robust research system and systematic generator of applicable knowledge, and stimulator of the ecosystem to strengthen social welfare and balanced development.

The analysis of the citations showed that technology is viewed as a linking mechanism capable of transforming the innovation ecosystem through the processes of transfer with the productive, public and social environment. Evidence was collected that technology is considered a route to reduce inequality and to achieve social equity. This coincides with Fukuda (2020) who proposes the social transformation of the STI ecosystem, and with Casas (2020) who raises the urgency of redefining STI policies. STI managers emphasized that technology transfer is a process that mixes knowledge, and it allows mainstreaming and interdisciplinarity; this coincides with Chesbrough (2017), who proposes open models to explain the mix of internal knowledge with knowledge external to the organisation (micro-ecosystem) that facilitate the generation of technology, the increase in its transfer and the strength of inter-organisational collaboration.

Entrepreneurs highlighted the relevance of reconverting accumulated technological capabilities to applied technologies 4.0 towards other uses in shorter time cycles. Institutional policies were related to the need for public-private or private-public funding schemes to streamline technology transfer, to the urgent disruption of the university management to streamline its responses to the ecosystem, to the integration of interdisciplinary teams, and to the multiple use of institutional infrastructure; this infrastructure is integrated with intermediate organisations (parks, incubators, business accelerators), laboratories and coworking spaces. The researchers insisted on the need for institutional policies that facilitate technology transfer, on openness to prioritise the use of technological equipment and infrastructure to strengthen the transfer of knowledge to the ecosystem, and on training and systematic advice to negotiate intellectual property.

The passivity of intermediate organisms was evidenced in some codes; however, other codes recognized their leading role in social technology transfer projects. The dense description evidenced that it is essential to deepen the interaction of intermediate organisms in the ecosystem based on trust and credibility, which would be built by increasing transfer projects, while strengthening their organisational skills. Likewise, it was reiterated that intermediaries can become the element of cohesion or disaggregation in the ecosystem, especially in the inclusion of the actors and the formation of knowledge networks. The literature review reported that if intermediate organisms achieve to unite the ecosystem, interdisciplinary research networks would be mobilized to promote the transfer of knowledge through strategies, smart technologies and digital tools that could empower the sectors with which they interact, and technologically enable them (Janse, Telukdarie & Dhamija, 2019).

The findings showed a high level of supply and demand for technologies 4.0 and digital talent. Evidence was found on the potential contribution of the transfer of these technologies to improve development conditions in the ecosystem. The demand for knowledge insisted on greater links and the involvement of social actors to achieve a transformative impact in the territory.

Conclusions

Based on research results, technologies 4.0 with increased odds to be transferred are the advanced analytics, the cloud computing, and the Internet of Things. The results showed that textile, agro-industrial and automotive productive sectors are those that have potential as receivers and transmitters of technology 4.0 in the innovation ecosystem. Furthermore, it was identified that the demand for knowledge capital 4.0 in the ecosystem is significant to the health and healthcare sectors.

The thematic prioritisation of STI during the last two decades evidenced the construction of capabilities 4.0 accumulated in the ecosystem, which would facilitate the redefinition of the technology transfer strategy to other areas of technology application based on this accumulation of knowledge. Likewise, the discriminated analysis of citations exposed the strong potential of the university and research centres to transfer knowledge to the ecosystem; however, the profile of the community -motivation and resilience- significantly defines its dynamism and the mobilisation of capacities and capabilities.

In conclusion, the technology transfer 4.0 to the innovation ecosystem depends on environmental, institutional and individual conditions; however, this is energized based on the level of interaction of intermediate organisms and the profile of the scientific and productive community that transfers technology in the ecosystem. Technology transfer 4.0 is a complex, multifactorial and multidimensional process, which is not restricted to a question of resource allocation or production, but it depends on the institutional arrangements and STI policies that foster it.

The analysis of the innovation ecosystem in the Bajío region allowed to approach the complex categories that Phillips and Ritala (2019) propose; however, territorial imbalances are latent in this ecosystem because regions with strong social and economic lags coexist with innovative and dynamic territories. This allowed to find additional categories that have to be considered to respond to the heterogeneity of the Latin American reality, which demands a change in the techno-economic view of the STI towards the achievement of social justice in dissimilar conditions in the ecosystem.

Contribution, limitation and lines of continuity of the research

The contribution of the work is theoretical and methodological because it analysed theoretically the transfer of technologies 4.0 in complex environments, which were contrasted with the Latin American reality. The research model was based on the function of knowledge production and technology diffusion (transfer) in the innovation ecosystem of an uneven and heterogeneous emerging economy. Furthermore, the results could have practical implications if inputs are provided to policy makers for the design of STI policies under local and heterogeneous conditions.

This study is not exempt of limitations. Although the qualitative strategy limits the generalisation of the results, the methodological design and the profile of the units of analysis allowed the contrast and identification of additional categories in the conditions of the Latin American ecosystem to transfer technologies 4.0. The continuity of this research will focus on analysing other Latin American ecosystems to explain the phenomenon in non-industrialised or socially disadvantaged regions. In addition, the mediating effects between the categories identified as ecosystem conditions will be analysed quantitatively.

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Tsíká tsaá nuú ñu'ún yo'ó nchaa tsana'á
nuú ntsitsika kue natsanú nda'á tsi chí iso
nuú nikanchí tsi kue yoo savi
ra yo'o ingáyu tisi kue tú in núu ndó o
Tu'un tsá viíñaa ndakani tsi naa ndaku'un ino
Tu'un ñaa tsa a chi I takua ndaki on ichí
Kue tu'un ñña kunu in ora ndakasía nuúgo
Tu'un ñaa sa a yivi.

Con mis pies descalzos he recorrido el camino de los ancestros
donde las abuelas caminaron con pasos firmes y contundentes
bajo el sol de muchas primaveras para no morir
aquí estoy con mi tenate de palabra
con un canto a su historia y su memoria
las palabras son fuerza/valor/camino
y van tejiendo nuestro ser
palabras que construyen mundos.

Celerina Patricia Sánchez
Méjico.