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Technological learning: an analysis of the contribution of knowledge qcquisition and conversion to technological capability accumulation

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Abstract

This article aims to analyze the learning processes and identify the knowledge acquisition and conversion mechanisms that contribute to technological capability accumulation. To this end, an exploratory study was conducted with 44 companies from the mechanical capital-goods sector. The contribution of knowledge acquisition and conversion mechanisms was analyzed by means of the Technological Capability Index (TCI) and multiple linear regression with stepwise variable selection. The econometric analysis results indicate the participating companies' adherence to few learning mechanisms for external knowledge acquisition, internal knowledge acquisition, and knowledge codification. The separate use of any single mechanism, however efficient it may be, does not suffice to explain the TCI. Therefore, multiple mechanisms should be employed and continuously improved in all learning processes in order to routinize conversion of individual learning into organizational learning.

Keywords: Technological learning. Technological capability. Knowledge Acquisition. Knowledge Conversion.

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Aprendizagem tecnológica: uma análise da contribuição dos Mmecanismos de aquisição e conversão do conhecimento para o acúmulo da capacidade tecnológica

Resumo

Este artigo tem por objetivo analisar os processos de aprendizagem e identificar os mecanismos de aquisição e conversão de conhecimento que contribuem significativamente para o processo de acúmulo de capacidade tecnológica. A fim de alcançar tais objetivos, realizou-se um estudo exploratório junto a 44 empresas do setor de bens de capital mecânico no Brasil. Para analisar a contribuição dos mecanismos de aquisição e conversão de conhecimento, foram utilizados o Índice de Capacidade Tecnológica (ICT) e a regressão linear múltipla com seleção de variáveis *stepwise*. Os resultados da análise econométrica revelaram a aderência de poucos mecanismos de aprendizagem para a aquisição externa de conhecimento, aquisição interna de conhecimento e codificação de conhecimento. O uso de apenas um ou outro mecanismo, por mais eficiente que se apresente, não é suficiente para contribuir e explicar o ICT. É necessário ampliar e aprimorar continuamente uma variedade de mecanismos em todos os tipos de processos de aprendizagem, para rotinizar a conversão de aprendizagem individual em organizacional.

Palavras-chave: Aprendizagem Tecnológica. Capacidade Tecnológica. Aquisição de Conhecimento. Conversão de Conhecimento.

Aprendizaje tecnológico: un análisis de la contribución de los mecanismos de adquisición y conversión del conocimiento para la acumulación de capacidad tecnológica

Resumen

Este artículo tiene como objetivo analizar los procesos de aprendizaje e identificar los mecanismos de adquisición y conversión de conocimiento que contribuyen significativamente al proceso de acumulación de capacidad tecnológica. Para lograr estos objetivos, se realizó un estudio exploratorio con 44 empresas del sector de bienes de capital mecánicos en Brasil. Para analizar la contribución de los mecanismos de adquisición y conversión de conocimiento, se utilizó un Índice de Capacidad Tecnológica (ICT) y regresión lineal múltiple con selección de variables por *stepwise*. Los resultados del análisis econométrico revelaron la adhesión de pocos mecanismos de aprendizaje para la adquisición externa de conocimiento, la adquisición interna de conocimiento y la codificación de conocimiento. El uso de solo un u otro mecanismo, por eficiente que sea, no es suficiente para contribuir y explicar el ICT. Es necesario ampliar y refinar continuamente una variedad de mecanismos en todos los tipos de procesos de aprendizaje para hacer de la conversión del aprendizaje individual en organizacional una rutina.

Palabras clave: Aprendizaje tecnológico. Capacidad tecnológica. Adquisición de conocimiento. Conversión de conocimiento.

INTRODUCTION

Acquiring technological capability has been considered, over the last decades, a key factor to promoting the industrialization of developing countries. However, cultivating the skills, experience, and efforts needed for acquiring this capability is not an easy undertaking. In other words, building the technology capabilities that enable organizations to effectively acquire, use, adapt, and create technologies is not a passive, mechanistic or automatic process; on the contrary, it is a deliberate process of learning and accumulating knowledge and skills (ROMIJN, 1997; LALL, 1992).

Another important aspect that sets developed countries apart from developing ones is the speed of their technological capability accumulation processes. According to Figueiredo (2001 and 2003), while companies from developed countries dealing in cutting-edge technologies already have innovative technological competencies, this is not the case with companies operating in latecomer economies as the latter employ mostly imported technologies. For this reason, their competitiveness requires the creation or acquisition of knowledge for technological capability accumulation.

Knowledge acquisition and conversion processes comprise different learning mechanisms that affect the way companies accumulate technological capability. Accordingly, Figueiredo (2001) claims that understanding how the learning system works — by analyzing the characteristics of the knowledge acquisition and conversion processes conducted by companies — helps to identify effective and ineffective learning systems, which, in turn, can indicate the best way for accumulating technological capability and improving their technical and economic performance over time.

In this context, this study, centered on companies in emerging economies, aims to analyze the learning systems related to technological capability accumulation with emphasis on knowledge acquisition processes and mechanisms (individual-level learning) as well as on knowledge conversion processes (company-level learning).

In the next section, this article presents the main technological learning concepts with emphasis on processes and mechanisms for technological capability accumulation. Then, it presents the indicators used in this study to measure technological capability, the Technological Capability Index (TCI). The following section presents the analytical framework on which this study is based and the method employed to investigate the types of learning processes. Lastly, there follow the results obtained in the analysis and the conclusion.

ANALYTICAL FRAMEWORK AND RESEARCH HYPOTHESES

Technological Learning

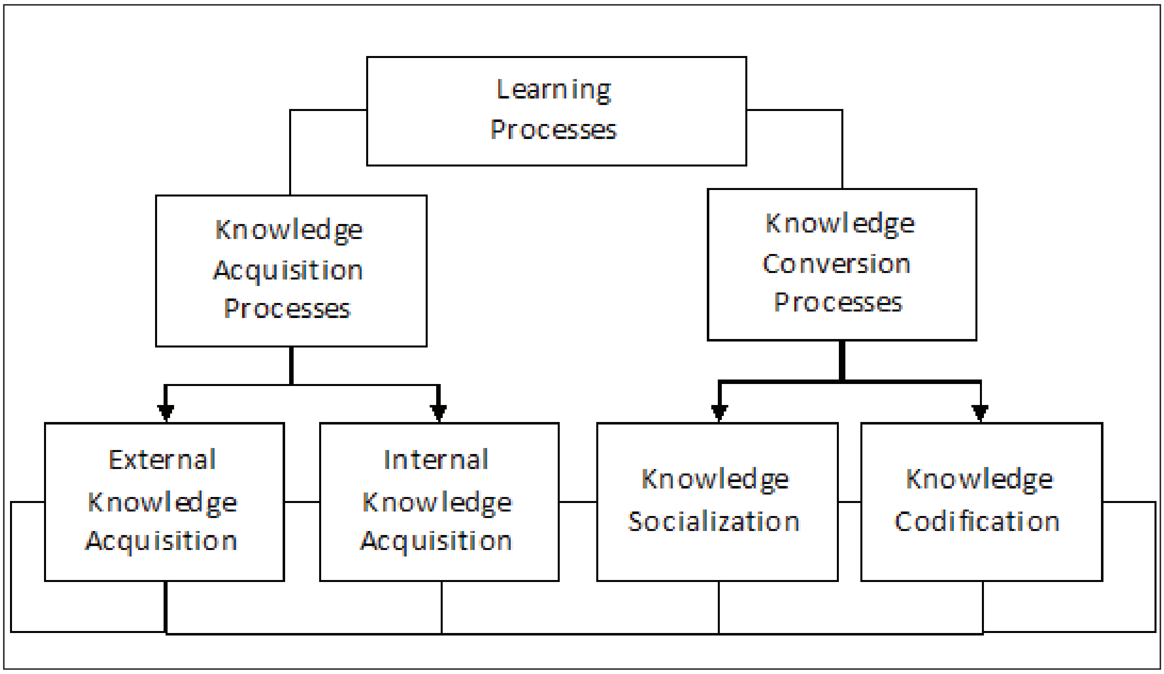
As stated by Kim (2001), technological learning is the process of building and accumulating technological competencies. It comprises, according to Bell (1984), several processes by which individual learning becomes organizational learning. Organizational learning, in turn, consists of internal elements, e.g., intra-company efforts, and external elements, i.e., elements related to networks and interactions with other organizations (KARAOZ and ALBENI, 2005; HANSEN and OCKWELL, 2014).

An important feature of technological learning refers to the dimensions of knowledge, defined as tacit and explicit. In particular, tacit knowledge is the main building element of the learning process (GERTLER, 2003). However, accumulating either tacit knowledge or explicit knowledge, separately, does not favor the creation of an organization's knowledge base, i.e., it is essential that the two types of knowledge interact.

According to Nonaka and Takeuchi (1995), individual tacit knowledge converts into organizational learning via several modes of interaction between the two types of knowledge. Through this conversion process, knowledge is shared, structured, and incorporated by the company's employees. Hence the importance of analyzing learning processes in late-industrialization economies: it promotes not only the understanding of how this conversion takes place in companies, but also the improvement of their existing processes.

In short, according to Figueiredo (2001), the learning processes that enable technological capability accumulation can be divided into two different types: a learning process at the individual level (acquisition of external and internal knowledge), converted into another learning process at the organizational level (conversion through socialization and codification). Figure 1 shows a detailed representation of the learning processes adopted by this study.

FIGURE 1
Technological Learning Processes



Source: Figueiredo (2001).

External Knowledge Acquisition Processes

External knowledge acquisition processes refer to the knowledge acquired outside the company, be it tacit or explicit (codified). Since most companies from developing countries lack resources, they must either acquire external knowledge to operate existing technologies or develop new ones in order to build and accumulate competencies (FIGUEIREDO, 2009). However, acquiring external knowledge is neither trivial nor automatic; it requires deliberate and effective knowledge selection and acquisition strategies.

The main learning modes related to external knowledge sources are imitation learning and interaction learning. For Filippini and Molini (2003), strategies for imitation and reverse engineering have been long encouraged with the aim of reducing and bridging the wide technological gap between developing countries and developed ones. Imitation learning takes place when innovations introduced by other companies are reproduced in an autonomous and non-cooperative fashion. To accomplish it, according to Cassiolato (2004), the company needs to be able to perform reverse engineering of the product in question.

According to Rosenberg (2013), reverse engineering has proven to be an effective strategy for creating new-to-the-company knowledge, although not new to the world. For Kiamehr (2017), building technology capabilities in emerging economies implies performing some learning steps for product and process technologies, from simple tasks, e.g., assembly (production capability), to more complex ones, e.g., process enhancement, product technology learning (reverse engineering), and process and product R&D (process and product design).

On the other hand, interaction learning refers to a systematic flow of information. Deepening learning through interaction presupposes selectivity regarding relationships among companies, time to strengthen the trust between actors and a system of incentives that induce the process (LUNDVALL, 1992). In this sense, this article raises the following hypothesis:

H1. Variables that make up external knowledge acquisition processes are positively correlated with technological capability accumulation at established companies.

Internal Knowledge Acquisition Processes

Through these processes, individuals acquire tacit knowledge by performing activities at the company. Learning takes place by means of routine tasks related to processes, products, production, and equipment. Figueiredo (2003 and 2009) and Mathews (2002) point to the centrality of these processes as they enable the company to integrate externally acquired knowledge and perform different innovative activities. According to Cassiolato (2004), a company's internal capability is fundamental to acquiring new external knowledge, i.e., the company must be internally capable of receiving, elaborating, and assimilating new knowledge.

The main modes of learning from internal sources are: (i) learning by use, related to the company's adaptation to new technologies; (ii) learning by experience, considered a key factor to the accumulation of knowledge conducive to innovation, as pointed out by Beneito et al. (2014);

the company learns through its own production, i.e., in this case, the technology is related to the company's experience in producing its own goods (DE NEGRI, 2005); (iii) learning by research, through formal R&D activities aimed at creating new knowledge. In this sense, this study raises the following hypothesis:

H2. Variables that make up internal knowledge acquisition processes are positively correlated with technological capability accumulation at established companies.

Knowledge Socialization Processes

Knowledge socialization occurs when tacit knowledge is shared from one individual to another, by means of observation, meetings, joint work to solve problems, and task switching (FIGUEIREDO, 2001).

According to Kogut and Zander (1992), it is through interaction between individuals in a group that knowledge and information are shared. Knowledge generated by individuals in a group goes beyond the domain of information, extending to how activities should be organized. Knowledge sharing among individuals is facilitated by a common knowledge base of a technical and organizational nature.

For Cyr and Choo (2010), knowledge sharing in organizations is the process by which individuals voluntarily grant other members of the organization access to their knowledge and experience. Knowledge sharing is shaped by many factors, including the organization's culture, the nature of the technology, and the individuals' values and attitudes toward sharing. In this sense, this article raises the hypothesis:

H3. Variables that make up knowledge socialization processes are positively correlated with technological capacity accumulation at established companies.

Knowledge Codification Processes

Knowledge codification refers to processes through which tacit knowledge becomes codified concepts. In other words, processes through which tacit knowledge is systematized into easy-to-understand formats and procedures. These processes are vital to knowledge dissemination within the organization (FIGUEIREDO, 2009).

For Prencipe and Tell (2001), codification mechanisms are responsible for converting knowledge into information in the form of easily identifiable messages that can be communicated to the organization's decision makers. Codification, according to Teece (2007), facilitates new combinations of accumulated codified knowledge. There are several knowledge-codification mechanisms, such as standardization of production methods, documentation, and seminars.

Figueiredo (2003 and 2009) maintains that internal training is fundamental to promoting both knowledge socialization and codification processes, i.e., it is through these processes that individual learning converts into organizational learning. In this sense, this study raises the following hypothesis:

H4. Variables that make up knowledge codification processes are positively correlated with technological capability accumulation at established companies.

Technological Capability: Indicators for Measurement

Yam et al. (2011) define technological innovation capability as a set of features that facilitate and support the technological innovation strategies of a company. More broadly, technological capability refers to resources needed for promoting and managing technical changes. It comprises, in particular, institutional structure, knowledge, experience, and skills (BELL and PAVITT, 1995). At least three components store and accumulate these resources, namely, human capital, organization system, and technical-physical systems (FIGUEIREDO, 2014).

One of the most comprehensive taxonomies for company-level technological capability is that proposed by Lall (1992). According to Molina-Domene and Pietrobelli (2012), Lall's taxonomy of technological capabilities has been successfully used in many case studies to assess company-level technology development in developing countries (LALL, 1987; ROMIJN, 1997). At the company level, Lall's (1992) taxonomy encompasses several aspects of technological capability. This study employed two of them: production capabilities and external link capabilities.

Production Capabilities

Production capabilities refer to the skills and knowledge needed for operating production facilities. They range from basic technological skills (e.g., quality control and inventory, operation and maintenance) to more complex ones (e.g., improvement or adaptation to research, design, and innovation) (EGBETOKUN, 2009; EGBETOKUN et al., 2012). These processes are closely related to process engineering, product engineering, and industrial engineering (LALL, 1992; BIGGS, SHAH and SRIVASTAVA, 1995), which implies the mastery of process and product technologies, innovation skills, and competence to monitor and control activities inherent to industrial engineering. These skills determine not only how technologies are implemented or improved, but also how internal efforts are employed to integrate technologies imitated or purchased from other companies.

External Link Capabilities

External link capabilities refer to the skills needed for disseminating information, competencies, and technology in order to acquire new knowledge from components or suppliers, service providers, consulting experts, and technology institutes, especially those actors that promote interactions, market or non-market in nature, aimed at developing, adopting, and using new or existing technologies. They include the analysis of customers, suppliers, manufacturers, universities, financial institutions, government, etc. (LALL, 1992; OLAMADE, 2001). These links affect not only a company's production efficiency (thus facilitating its specialization) but also the dissemination of technologies. The importance of non-market links in promoting increased productivity is well documented in the literature from developed countries.

METHODOLOGICAL PROCEDURES

Sample Profile

This study aims to analyze the learning processes for technological capability accumulation; to this end, it sampled 44 companies in the capital goods sector, with at least 50 employees, in the market for over 20 years, and grouped them into four subsectors, according to Brazil's National Classification of Economic Activities (CNAE 2.0). The sample encompassed national-capital companies and transnational companies. The main activities performed by the companies include the manufacture of machines, general-purpose equipment, machine tools, engines, pumps, and compressors. The study comprised companies located in Brazil's southeast region, especially in the State of São Paulo, as it represents an important percentage of companies in this sector.

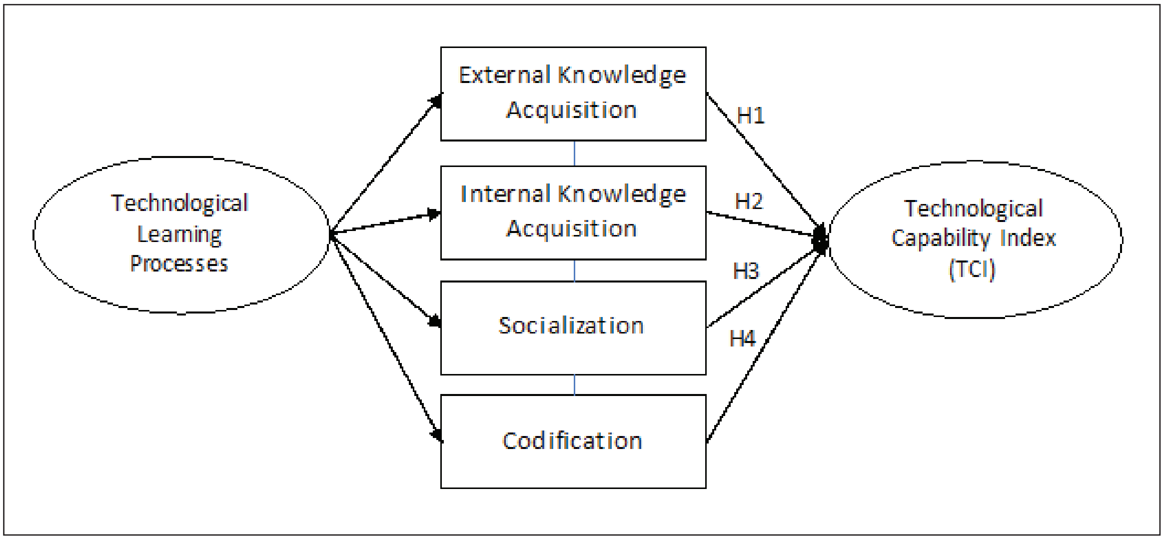
Data Collection

This study collected several types of data by way of interviews and analysis of documents. The interviews were divided into two parts: the first part focused on the participating companies' TCI and the second part focused on their technological learning processes. The interviews were conducted in person with 52 professionals, including directors, managers, and technicians. The documents analyzed comprised reports and database records.

Analytical Structure

As proposed by Figueiredo (2001), the four types of learning processes, presented in Figure 1, comprise diverse mechanisms that affect the companies' technological capability accumulation path. Thus, this study proposes a research structure in which these four types of learning processes play an important role in promoting the technological capability of established companies. Figure 2 presents the analytical structure of this study.

FIGURE 2
Analytical Structure



Source: Elaborated by the authors.

The independent and dependent variables are described below.

Dependent Variable: TCI

The Technological Capability Index (TCI) was employed to analyze the contribution of learning processes to technological capability accumulation of, based on Lall's (1992) taxonomy variants. This index has been widely adopted to operationalize technological capability in companies, e.g., the studies carried out by Molina-Domene and Pietrobelli (2012), Romijn (1997) and Wignaraja (2002 and 2008).

In order to compound this index, the measured variables were grouped under process engineering, product engineering, quality engineering, and external link development. Categorical variables — 0 (none), 1 (ad hoc), and 2 (systematic) — were used, representing low, medium and high capability levels, as shown in Appendix A.

A score was attributed to each company, based on its capability level. The top score for capability is 38 points, considering a total of 19 variables. It can be obtained by summing the highest capability level value presented for each variable. In order to get the TCI value, the results were then normalized between 0 and 1. The table in Appendix B shows the distribution of TCI score frequencies for the 44 companies sampled.

Independent Variables: Technological Learning Processes

To evaluate the contribution of learning processes to the technological capability accumulation process, the intensity at which the processes occur in the companies under investigation was adopted as a measurement value. Intensity is defined as the frequency with which learning processes are created, updated, used, and improved over time.

According to Figueiredo (2001 and 2009), sporadic learning processes do not result in effective knowledge acquisition and organizational internalization. In the course of time, some practices can be routinized and become part of the company's daily routine. In this sense, intensity matters because it guarantees the constant flow of external knowledge to the company and ensures continuous conversion of individual learning into organizational learning.

The intensity measures adopted in this study were adapted from Figueiredo (2001 and 2009) and comprise four indicators: (0) lack of mechanism; (1) rare; (2) intermittent; and (3) continuous.

RESULTS AND DISCUSSION

Reliability and Validity of Scales

Multiple linear regressions with stepwise variable selection were employed to analyze the contribution of variables to technological capability accumulation. The assumptions of the models, namely, normal distribution, linearity, and multicollinearity, were analyzed. In order to identify multicollinearity problems, Tolerance Index and Variance Inflation Factors (VIF) were used for each variable. The collected data were submitted to a reliability test, Cronbach's Alpha coefficient, according to Table 1.

TABLE 1
Internal Consistency of Scales

Learning Processes	Tolerance	VIF	Cronbach's Alpha
External knowledge acquisition	From 0.604 to 0.898	From 1.14 to 1.656	0.717
Internal knowledge acquisition	From 0.369 to 0.790	From 1.266 to 2.709	0.711
Socialization	From 0.732 to 0.846	From 1.182 to 1.366	0.763
Codification	From 0.709 to 0.874	From 1.144 to 1.409	0.669

Source: Elaborated by the authors.

Tolerance and VIF values are considered appropriate, according to Hair et al. (2009), indicating that there are no multicollinearity problems. According to Field (2013), the values obtained for Cronbach's Alpha are also considered acceptable, as they are above 0.60.

External Knowledge Acquisition Processes

For the external knowledge acquisition process, the following learning mechanisms were assessed: specialists (e.g., technical experts); external training to keep employees updated; training abroad; access to/use of regional educational infrastructure; interaction with customers, suppliers, and researchers/scientists.

From the collected data (Figure 3), multiple linear regression with stepwise selection yielded three significant models ($p<0.001$), as shown in Table 2. Based on the largest Adjusted R^2 criterion, we opted for Model 3 as explaining 56.5% of the variation observed in the TCI variable.

TABLE 2

Multiple Regression Analysis: External Knowledge Acquisition

Variables	Model 1		Model 2		Model 3	
	Beta	t	Beta	t	Beta	t
EK3-Training abroad	0.679	5.999	0.525	4.413	0.391	3.030
EK4-Access to regional educational infrastructure			0.331	2.786	0.297	2.582
EK7-Interaction with researchers/scientists					0.267	2.183
Adjusted R-squared		0.449		0.525		0.565
F-Statistics		35.986		24.769		19.617

Source: Elaborated by the authors.
Note: N=44 companies; p<0,001.

The adjusted Model 3 enabled testing H1 by analyzing the variables that make up knowledge acquisition processes. Only three out of seven variables analyzed were identified as TCI predictors, as shown in Figure 3.

FIGURE 3

Characterization of Learning Mechanisms Supporting H1

Training abroad	• Present in half of companies. • Variable with largest contribution to explaining the TCI. • 85.7% are transnational companies with training at headquarters. • 30.7% of companies conduct some kind of training abroad. · Explored by 75% of companies investigated.
Access to regional educational infrastructure	• Modest interaction, despite the presence of several institutions. • Most important learning source for small- and medium-sized companies. • Second variable that contributed significantly (t=2.582) to explaining the TCI.

Continue

Interaction with scientists/ researchers	• Third most significant variable contribution (t=2.183) to explaining the TCI. • Although there were limited efforts to accumulate technological capability through this type of learning, companies engaging with this mechanism have the highest technological capability indexes, which indicates its importance.

Source: Elaborated by the authors.

The other variables were not significant to explaining the TCI and, therefore, do not support H1. Albeit important to the external knowledge acquisition process, external training and interaction with experts, customers, and suppliers were not key to explaining the high technological capability levels displayed by some companies.

Internal Knowledge Acquisition Processes

For the internal knowledge acquisition process, the following learning mechanisms were assessed: internal training in process and product techniques; R&D activities; internal training in TQM and quality systems; formation of QCC groups; training in design and process software; studies to increase productive capacity; reverse product engineering.

From the data collected, multiple linear regression with stepwise selection yielded seven significant models ($p<0.001$), as shown in Table 3. Almost all of the analyzed variables made a significant contribution to explaining the TCI, except for one single variable, IK7-reverse engineering, which was excluded for not being significant in any of the seven models. Although Model 6 presents the largest Adjusted R^2 (0.876), we opted for Model 7 as it presents significance $p<0.001$ for all coefficients and explains 87.1% of the variation observed in the TCI variable.

TABLE 3

Multiple Regression Analysis: Internal Knowledge Acquisition

Variable used	Beta Model (1)	Beta Model (2)	Beta Model (3)	Beta Model (4)	Beta Model (5)	Beta Model (6)	Beta Model (7)
IK4-QCC group formation	0.748 (7.304)	0.604 (6.251)	0.390 (4.213)	0.366 (4.371)	0.242 (3.117)	0.141 (1.610)	
IK6-Studies to increase productive capacity		0.369 (3.815)	0.499 (5.905)	0.461 (5.978)	0.389 (5.704)	0.358 (5.374)	0.373 (5.537)
IK5-Training in process and project software			0.390 (4.540)	0.347 (4.420)	0.291 (4.270)	0.299 (4.575)	0.333 (5.290)

Continue

Variable used	Beta Model (1)	Beta Model (2)	Beta Model (3)	Beta Model (4)	Beta Model (5)	Beta Model (6)	Beta Model (7)
IK2-R&D activities				0.222 (3.186)	0.251 (4.209)	0.294 (4.868)	0.321 (5.426)
IK1-Internal training in process and production techniques					0.289 (3.992)	0.232 (3.133)	0.247 (3.292)
IK3-Training in TQM and quality systems						0.190 (2.152)	0.266 (3.488)
Adjusted R-squared	0.549	0.659	0.769	0.812	0.864	0.876	0.871
F-Statistics	53.345	42.557	48.813	47.523	55.763	51.679	59.021

Source: Elaborated by the authors.
Note: N=44 companies; t-statistics in parentheses; p<0,001.

Therefore, the adjusted Model 7 enabled testing H2 by analyzing the variables that make up internal knowledge acquisition processes. Figure 4 shows the five variables identified as significant TCI predictors for this model.

FIGURE 4
Characterization of Learning Mechanisms Supporting H2

Studies to increase productive capacity	• The variable with the greatest effect, with the largest significant contribution (t=5.537) to explaining the Technological Capability Index (TCI). • Carried out continuously by only 33% of companies and absent as a learning mechanism in 25%, all of them being small companies (Table 4). • Most companies that promote productive capability studies are medium-sized, and 70.6% are national.
Training in process and project software	• Third most influential variable (t=5.290) to the Technological Capability Index (TCI). • Just 18% of companies reported not having this learning practice. • 60% of companies provide intermittent or continuous training in design and process software.
R&D activities	• Second most significant contribution (t=5.426) to explaining the TCI. However, only 30% of companies conduct these activities continuously. • 30% do so intermittently. • Only 13% stated that they conducted no R&D activities. These companies have been operating in the market with the same products for a long time and only make minor improvements to them.

Continue

Internal training in process and production techniques	• 35% of companies promote internal training in production and process techniques. • For these companies, this training focuses mostly on improving production and product development. • Lack of this learning mechanism in 18% of companies. Despite this absence, this mechanism represents a variable with significant contribution (t=3.292) to explaining the TCI.
Training in TQM and quality systems	• This variable made a significant contribution (t=3.488) to explaining the TCI. • Frequency of this learning mechanism is continuous for 35% of companies and intermittent for 25%. • In ISO 9000-certified companies in particular, there is greater emphasis on operational training. 25% of companies reported having no formalized quality systems.

Source: Elaborated by the authors.

Knowledge Socialization Processes

For the knowledge socialization process, the following learning mechanisms were assessed: dissemination of interactive practices for problem solving; dissemination of outsourced training; forming of teams for anomaly treatment; operational work diagnostic system; hiring and development of trainee engineers; workstation training; improvement suggestion system.

Based on the collected data, multiple linear regression with stepwise selection yielded three significant models ($p<0.001$), as shown in Table 4. Three out of seven variables analyzed were included in the significant models. By the largest Adjusted R^2 criterion, Model 3 was chosen as explaining 82.4% of the variation observed in the TCI variable.

TABLE 4

Multiple Regression Analysis: Knowledge Socialization

Variable used	Beta Model 1	Beta Model 2	Beta Model 3
Dissemination of outsourced training			0.297
			(4.261)
Operational work diagnostic system		0.481	0.429
		(5.582)	(5.846)
Workstation training	0.762	0.539	0.456
	(7.620)	(6.260)	(6.097)
Adjusted R-squared	0.570	0.750	0.824
F-Statistics	58.062	65.452	67.948

Source: Elaborated by the authors.
Note: N=44 firms; t-statistics in parentheses; p<0,001.

The adjusted Model 3 enabled testing H3 by analyzing the variables comprising knowledge socialization processes. Figure 5 shows the variables identified as significant TCI predictors.

FIGURE 5

Characterization of Learning Mechanisms Supporting H3

Dissemination of outsourced training	• Approximately 33% of companies have continuous frequencies of socialization of knowledge acquired internally and externally, a percentage compatible with that presented for knowledge acquisition processes.
Operational work diagnostic system	• Variable with second largest significant contribution (t=5.846) to explaining the TCI. • Transnational companies make up the majority of companies having operational work diagnostic systems while a significant number of companies (32%) — mostly national and small-sized — have none.
Workstation training	• Variable with largest significant contribution (t=6.097) to explaining the TCI as well as the learning mechanism with highest frequency (50%) in knowledge socialization.

Source: Elaborated by the authors.

Knowledge Codification Processes

Among the learning mechanisms and processes analyzed, codification processes are those that present the highest intensity. Most companies have well-organized documentation and give emphasis to employee experience in activities involving product and process improvement.

For the knowledge codification process, the following learning mechanisms were assessed: standardization of activities and processes; technical assistance reports; anomaly analysis reports; technical procedures; standardized operational procedures; industrial regulations; consultation of competitors' products and manuals.

Multiple linear regression with stepwise selection yielded three significant models ($p<0.001$), as shown in Table 5. Practices and procedures for activity and process standardization are continuous. Important efforts were observed in the control of operational activities and production systems.

However, only three out of seven variables analyzed were included in the significant models. The remainders were excluded because they were not significant in any of the models. By the largest Adjusted R^2 criterion, Model 3 was chosen as explaining 63.5% of the variation observed in the TCI variable.

TABLE 5

Multiple Regression Analysis: Knowledge Codification

Variable used	Beta Model 1	Beta Model 2	Beta Model 3
Creation of technical procedures	0.651	0.468	0.341
	-5.558	-3.986	-3.119
Process and activity standardization		0.402	0.406
		(3.427)	-3.929
Industrial regulations			0.352
			-3.578
Adjusted R-squared	0.410	0.530	0.635
F-Statistics	30.894	25.270	25.963

Source: Elaborated by the authors.
Note: N=44 companies; t-statistics in parentheses; p<0,001.

The adjusted Model 3 enabled testing H4 by analyzing the variables comprising the knowledge codification processes. The variables analyzed as significant TCI predictors are shown in Figure 6.

FIGURE 6

Characterization of Learning Mechanisms Supporting H4

Standardization of activities and processes	• Variable with the largest significant contribution (t=3.929) to explaining the TCI. • Practices for standardization of activities and processes are continuously developed in the companies investigated, deemed important to control operational activities and production systems. • Approximately 66% of the sampled companies have continuous activity and process standardization practices, and 23% reported performing them less frequently but not rarely.
Creation of technical procedures	• Significant contribution (t=3.119) to explaining the TCI. • 59% of companies continually develop technical procedures involving new and existing products. • Only 5% do not perform this activity and 27% do so intermittently.
Adherence to industrial regulations	• Variable with second largest significant contribution (t=5.846) to explaining the TCI. • This practice is continuous for only 23% of the sampled companies. However, it is significant as it contributes to differentiation in Technological Capability Indexes. It is worth noting the importance of this practice to dissemination, in particular, of new knowledge acquired by the company.

Source: Elaborated by the authors.

CONCLUSION

This study contributes to the literature by analyzing a set of variables considered important to technological learning processes, the mechanisms that effectively contribute to explaining the TCI of companies.

As aforementioned, the literature suggests that continuous activities lead to conversion of individual learning into organizational learning as they enable creating, updating, and improving learning processes. They also facilitate a lasting flow of external knowledge to the company, which results in better understanding the acquired technology. Effective management of different types of technological learning mechanisms is vital to the way a company conducts its technological capability accumulation process as well as the speed at which this process occur.

Most of the learning mechanisms that contributed significantly to explaining the TCI present continuous frequency in a small number of companies, which means that few of the companies investigated have high TCIs. For this reason, they stand apart from the remaining ones. The table in Appendix B shows that just 20.7% of the companies have a TCI above 0.70 while that of 41% is below 0.50.

The results of this study, derived from multiple regression analysis conducted for each of the four learning processes, provide evidence that the use of any single mechanism (interaction with customers and suppliers, creation of technical assistance and standardized operational procedures, etc.), however effective it may be does not suffice to explain the TCI.

By taking several types of learning into account, it was possible to observe that, despite being present, the mechanisms under investigation have different levels of intensity and contribute differently to explaining the TCI. Identifying these particularities is central as they affect the company's accumulation of technological competencies over time.

As regards external knowledge acquisition processes, the contribution of just three learning mechanisms denotes the companies' low interaction with the external environment regarding the acquisition of new knowledge, especially tacit knowledge. Important mechanisms for increasing internal knowledge acquisition (e.g., outsourced training to keep employees updated, interaction with consulting experts and specialists, and interaction with customers and suppliers) did not stand out during the analysis. The low contribution of several external knowledge learning mechanisms indicates that the companies investigated focus primarily on local markets in detriment of the international marketplace in which the demand for more advanced technologies is higher. It should be noted that the mechanisms contributing to explaining the TCI (e.g., outsourced training and scientific research contacts) are present mostly in transnational companies.

The greatest number of mechanisms contributing to the TCI was observed in internal knowledge acquisition processes, which indicates that the companies investigated give emphasis to controlling their process and production routines by means of efforts to increase productive capability, training in process and production techniques, and training in quality systems. However, the frequencies observed for these mechanisms are considered low. Just one-third of the companies have continuous activities.

The presence of several mechanisms points to the companies' efforts to assimilate new technologies, i.e., these learning mechanisms favor the skills and knowledge needed for operating and improving their production facilities as well as the skills required for exploring new technologies, be they imitated or purchased from other companies. However, it should be emphasized the lack of contribution of reverse engineering to the TCI observed in this study. Reverse engineering is a mechanism for internalizing the knowledge needed for creating new-to-the-company knowledge, an important step in learning-by-imitation, which precedes that of setting up R&D activities, crucial to innovations with higher technological intensity. In this sense, the presence of this learning mechanism strengthens the skills needed for creating new technologies.

As to knowledge socialization processes, it is possible to observe a low variety of learning mechanisms. Knowledge is seldom shared through group activities. Group formation for workstation training with has the highest continuous frequency. Despite being important mechanisms for knowledge sharing, anomaly treatment teams and improvement suggestion systems were not significant for the companies in question.

Lastly, a low variety of learning mechanisms was also observed for knowledge codification processes. The learning mechanisms contributing to the TCI indicate focus on maintenance of processes and creation of technical procedures, indispensable to companies from this sector. On the other hand, low adherence to information organization through mechanisms such as reference to competitors' products and manuals, anomaly analysis reports, and technical assistance reports, which have not contributed to the TCI, hinders new combinations of accumulated codified knowledge.

Overall, the econometric analysis results indicate low adherence to learning mechanisms for external knowledge acquisition, knowledge socialization, and knowledge codification. Greater variety was observed only with regard to learning mechanisms for internal knowledge acquisition, even though continuous frequencies were present in less than 50% of the companies investigated. Given that both knowledge socialization and knowledge codification are required for converting individual knowledge into organization knowledge, it is vital that companies continuously develop and improve the aforementioned mechanisms in order to accumulate technological capabilities.

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APPENDIX

APPENDIX A

Questions for Measuring Technological Capability

Production Capability
Process Engineering Functions
i. Acquisition of new equipment
ii. Certifications for production improvement
iii. Internal training in process and production techniques
iv. Standardization of activities and processes
v. Monitoring of productivity
Product Engineering Functions
i. Product development activities
ii. Improvement of existing products
iii. Investment in technology
iv. Introduction of new products to internal market
Quality Engineering Functions
i. Training in quality systems
ii. Training in anomalies
iii. Internal auditing
iv. ISO 9000 status
v. Total preventive maintenance programs
Capability of Links
Link Development Functions
i. Joint actions for product development
ii. Relationship with universities
iii. Relationship with customers re. exploring and developing new concepts

Source: Based on field research.

APPENDIX B

Distribution of Technological Capability Index

CI Classes	% of Companies
0.00-0.10	11.4
0.11-0.20	15.9
0.21-0.30	9.1
0.31-0.40	6.8
0.41-0.50	6.8
0.51-0.60	18.2
0.61-0.70	11.4
0.71-0.80	4.5
0.81-0.90	6.8
0.91-1.00	9.1
Total	100%

Source: Based on field research.