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A Micro–Macro Approach in Latin America

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Abstract

Enhancing the technological capability accumulation process (TCAP) in firms is essential for Latin America's economic development. Yet, the dynamics between firms' characteristics and contextual factors that can help improve TCAP remain underexplored in the region. This study assesses the effects on TCAP of firm-level factors and national innovation systems (NISs)—the network of institutions, policies, and relationships governing innovation within a country. Using data from the harmonized Latin American Innovation Surveys Database (LAIS) and a dataset to measure capabilities at the country level, we undertake a multilevel analysis for 2006–2016 to estimate the effects of NISs and firms' structural characteristics on TCAP. Our results reveal that firm size, R&D capabilities, qualified personnel, and macro factors like national R&D investment and scientific output significantly drive TCAP. Conversely, factors such as corruption perception emerge as significant obstacles. These findings underline the complex interplay between innovation policies and firm capabilities, offering nuanced insights for policymakers to foster innovation in Latin America.

1. Introduction

This paper analyzes the impact of national innovation systems (NISs) on firms' accumulation of technological capabilities. It combines innovation literature about how NISs affect the innovation process (Edquist and Hommen, 1999; Freeman, 2004; Lundvall, 1992; Nelson, 1993) and literature on firms' technological capability accumulation process (TCAP), as proposed by Bell and Pavitt (1995). Contributions from Latin America have long proved that when studying the region a broad definition of NISs is more relevant, given the recurrent instability of the macroeconomic environment, the productive structure, and all social and political arrangements that determine the incentives faced by firms when seeking innovations (Dutrénit and Sutz, 2014; Dutrénit and Katz, 2005; Erbes, Katz, and Suárez, 2016). This has led to NISs characterized by low levels of investment in knowledge creation and application, mainly concentrated in the public sector; isolated successful firms that are not enough to trigger structural change; and deep intra- and international heterogeneity in productive and technological capabilities (Álvarez, Natera, and Suárez, 2020).

Literature on technological capabilities defines them as "the resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages" (Bell and Pavitt, 1993). Innovation studies, under an evolutionary framework (Nelson, 1991; Nelson and Winter, 1982), show that the accumulation of capabilities determines firms' ability to survive market selection based on a Schumpeterian competitive process. These capabilities result from path dependence processes of knowledge creation and application within the firm and between the firm and its environment (the NIS) (Lundvall, 1992, 2007). From an empirical standpoint, this suggests that the technological capabilities of firms are closely linked to their strategic decisions regarding the allocation of resources to the innovation process as well as their structural attributes and unique innovative behaviors. All in all, technological capabilities determine the type and complexity of technical functions that firms may develop (Erbes and Suárez, 2016).

This paper argues that TCAP is the result of the interaction between micro (firm level) and macro (NIS) factors. Then, firms' structure and the NIS's different dimensions condition firms' possibilities to develop innovation activities. Given the development paths among Latin American countries, we expect the impact of NISs' dimensions on firms' TCAP to be a combination of driving forces and stoppers that determine its rhythm and intensity. A unique dataset is used derived from combining the Latin American Innovation Surveys Database (LAIS) (Crespi et al., 2021) with an updated version of the CANA dataset (Castellacci and Natera, 2011). The former contains harmonized information from Latin American innovation surveys; the latter is a collection of indicators for measuring NISs' evolution for the period 1970–2015. A multilevel analysis is used to observe how the characteristics of NISs and firms' structural characteristics and innovation infrastructure affect firms' TCAP and economic performance. One specific question guides the research: What are the micro and macro driving forces and stoppers of firms' TCAP in different countries in Latin America?

The paper is organized as follows. After this introduction, Section 2 reflects on the NIS literature and on the TCAP at the firm level. Methodology and a general description of the dataset is presented in Section 3. Section 4 contains the estimation results and discussions. Some conclusions and policy recommendations are provided in Section 5.

2. Theoretical Framework

Technological capabilities encompass the essential skills and knowledge that firms require to effectively utilize technology and engage in technological change, including the ability to acquire, use, adapt, and innovate technologies (Morrison, Pietrobelli, and Rabellotti, 2008; Kim, 1997; Bell and Pavitt, 1995; Lall, 1992). Following Dutrénit, Vera-Cruz, and Arias (2003), technological capabilities are the firm's skills that allow it to use knowledge for innovative and productive activities. Technological capabilities are accumulated via different paths related to the development of different technological functions, which include the design and implementation of innovative projects, the development of new products and processes, and new linkages with agents from the NIS, among others (see Annex 1 for a more detailed discussion). TCAP is complex and non-linear, with firms progressing through different evolutionary paths that are not necessarily sequential. This accumulation involves both primary activities (like investment and production) and supporting activities across four levels of TCAP ranging from routine production to advanced innovation. TCAP is influenced by a firm's internal and external interactions and the broader institutional and economic context, indicating a blend of micro- and macroeconomic factors, including the NIS (Dutrénit, Vera-Cruz, and Arias, 2003; Katz, 1987; Dahlman, Ross-Larson, and Westphal, 1987; Lall, 1987, 1992). This framework underscores the importance of both firm-specific factors and the external environment in developing technological capabilities; therefore, there is a strong link between TCAP (closely connected to the firm, at the micro level) and the NIS (linked to the country level, the macro interactions).

NISs are broadly conceptualized as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies (Lundvall, 2007). From a wide-ranging perspective, NISs encompass a plethora of factors affecting innovation processes, including macroeconomic conditions, societal norms, and institutional frameworks, far beyond the narrow focus on elements that directly influence technological or scientific progress. This comprehensive view recognizes that innovation is not solely the outcome of scientific research and technological development but is also significantly shaped by economic policies, cultural practices, and the regulatory environment. In contrast, the restricted perspective of NISs concentrates on the core components of science and technology systems, such as research and development (R&D) activities, patent outputs, and the role of higher education in generating skilled labor for technological advancement. There are diverse interpretations of NISs; some approaches focus on the actors involved in innovation, exemplified by the triple helix model of university-industry-government relations (Etzkowitz and Leydesdorff, 2000), while others emphasize the capabilities and competencies within a country that facilitate innovation, as discussed by Fagerberg and Srholec (2008). These varying lenses underscore the multifaceted nature of innovation ecosystems and the importance of considering both the actors engaged in innovation activities and the capabilities they possess.

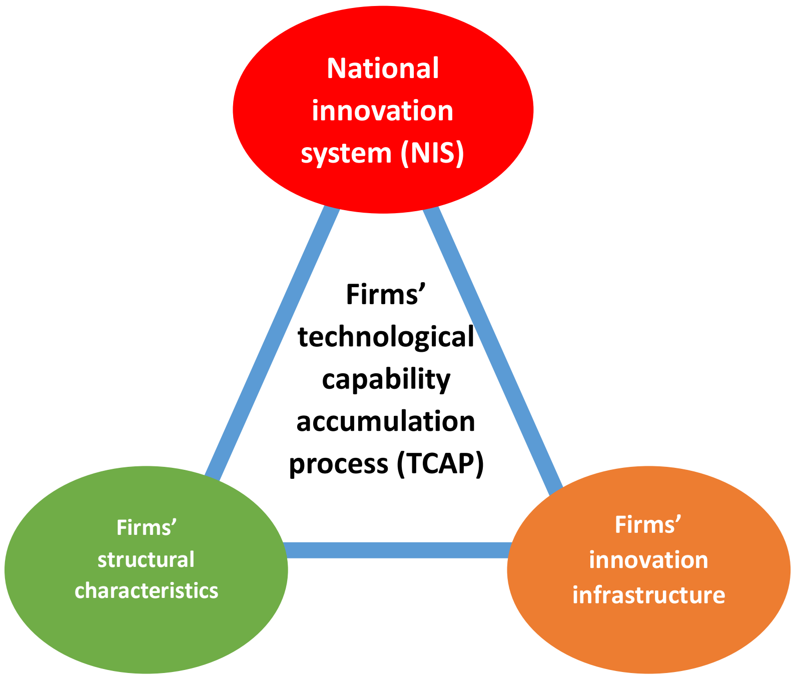
Despite the vast branch of literature on the impact of micro–macro interactions on the innovation process, particularly in Latin America, quantitative cross-country evidence is still scarce. Katz (1987, 1998, 2001) has intensively proposed that decisions on the execution of innovation activities and the related outcomes of these processes are heavily determined by the macro conditions. There is also a set of analysis of science, technology, and innovation (STI) policy evaluation, linking the innovation process to productivity and economic gains (Albis, Álvarez, and García, 2021; Benavente, Crespi, and Maffioli, 2007; Crespi and Zuniga, 2012; Fiorentin, Pereira, and Suárez, 2019; Fiorentin, Suárez, and Yoguel, 2021). In the context of 32 developing countries, Srholec (2011) proposed a multilevel analysis that shows macro conditions affect firms' propensity to undertake innovation activities, finding a strong link between them. Nevertheless, advances in these fields in terms of the quality and quantity of available data call for new research. We would expect the micro–macro interactions to vary according to the development paths and enabling factors that countries have followed:

there will be different combinations of driving forces (which promote the development of innovation activities) and stoppers (which highlight the necessity of policy intervention). Along this line, there is a recent proposal to include systemic characteristics that go beyond firms' boundaries at the micro level to study the innovative processes, considering that countries' development paths are determined by their position in terms of techno-economic and socio-institutional levels and their firms' TCAP (Dutrénit, Natera, Puchet Anyul, and Vera-Cruz, 2019). We argue that TCAP and NISs are a micro-macro interaction by nature: considering the institutional framework and its linkages is a recognition of the important impact of context on firms' possibilities to develop innovation activities.

3. Conceptual Model and Hypotheses

Our conceptual model departs from the idea that TCAP emerges from the relationship between NIS characterization and firms' micro configuration (structural and in terms of their innovation infrastructure), as presented in Figure 1.

Figure 1. Conceptual Model



Source: Authors' elaboration.

Below are the definitions of each of the elements of the conceptual model:

- National innovation systems (NISs): Following Fagerberg and Srholec (2008) and Castellacci and Natera (2013), we characterize NISs from a capability-based approach. In order to do so, we will include a compendium of different dimensions (and their related national-level indicators) to express the multifaceted nature of countries' systemic interactions that support the innovation process. NISs are defined as a set of elements that encompasses the techno-economic dimensions (innovative capabilities, economic competitiveness, industrial structure, infrastructure, human capital, environmental conditions) and socio-institutional factors (social cohesion, political conditions). Furthermore, following the important contributions made by Katz (1987, 1998, 2001), we are also including the macroeconomic conditions as part of the conceptualization of the broad definition of NISs because of its relevance for Latin America.

- Firms' structural characteristics: This part of the conceptual model aims to succinctly outline the most fundamental characteristics that can describe firms in Latin America. To this end, we have selected two typical attributes commonly identified in the TCAP literature: the size of the firm and its export capability. In terms of firms' export, we argue that those that orient part of their production to international markets gain important learnings in export processes that affect their technological capabilities through the so-called learning-by-exporting process (Anderson and Lööf, 2012; Freixanet and Federo, 2023). In fact, the connection with global markets allows companies greater access to hard and soft technologies developed abroad, which, when introduced into the productive activity of the firms, increases their ability to assimilate and accumulate new knowledge. As a result, it is expected that firms that export will show superior technological capabilities. On the other hand, the relationship between firm size and technological capabilities is often debated. Larger firms generally have enhanced technological and innovation capacities due to economies of scale in R&D, scope economies from the complementarity between R&D and other corporate functions, a major availability of both internal and external resources for financing innovation, and a superior ability to capture the returns from innovation (Cohen, 2010; Varis and Littunen, 2010). Conversely, smaller firms might be more innovative because their size enables greater flexibility in responding to changes in the competitive and technological landscape (Koberg, Detienne, and Heppard, 2003).
- Firm's innovation infrastructure: This section of the conceptual model seeks to account for the structural characteristics of firms that condition their ability to undertake innovation activities. It is structured around three axes. The first axis is the existence of an R&D department. R&D organized within large organizational departments or in small units or research groups is an essential organizational mechanism for innovation (Mejía, 2007; Orozco, Chavarro, and Ruiz, 2010; Lewkowicz and Lewczuk, 2021). Within these units, organized behaviors towards innovation give meaning to research as a fundamental mechanism for resource utilization, in a combination that generates capabilities and routines such as organizational habits with degrees of autonomy to investigate, generate, and apply new knowledge (Sørensen and Stuart, 2000; Orozco, Chavarro, and Ruiz, 2010). The development of research infrastructure and the strategic organization of personnel within R&D

departments, guided by targeted and shared objectives, support the establishment of independent organizational units and reduction of cost due to scale economies in R&D investments (Lewkowicz and Lewczuk, 2021). These units function autonomously yet cohesively within the broader organizational framework. (Sørensen and Stuart, 2000; Mejía, 2007). The second axis of firms' innovation structure is related to R&D continuity: the accumulation of technological capabilities is inherently a dynamic process, influenced by previous decisions and in a path-dependent way. Also, the development of these capabilities is time consuming, with significant opportunity costs and uncertainties associated with the innovation process (Majd and Pindyck, 1987). Therefore, consistently engaging in R&D activities can positively impact the likelihood of future success and enhance technological capabilities (Raymond et al., 2015). Finally, the third axis of firms' innovation structure is having qualified personnel, since the accumulation of technology within firms is greatly influenced by the expertise and knowledge they possess in their efforts to innovate (Klette and Kortum, 2004). The presence of skilled labor plays a crucial role in a company's capacity to absorb, assimilate, and advance new knowledge and technologies (Cohen and Klepper, 1996). Employees with specialized skills are more capable of tracking and evaluating the significance of new technological and knowledge advancements for the firm's production processes.

Based on this conceptual model, we seek to answer the following question:

How do national innovation systems (NISs) and firms' structural characteristics and innovation infrastructure determine their technological capability accumulation process (TCAP)?

To answer that question we outline two hypotheses, one at each level of analysis:

- H1: Micro-level conditions, encompassing structural characteristics and innovation infrastructure within Latin American firms, significantly influence their technological capability accumulation process (TCAP), acting either as facilitators (drivers) that enhance or as barriers (stoppers) that impede their ability to innovate and grow.
- H2: Macro-level conditions, defined by the systemic attributes and policies of the national innovation systems (NISs) in Latin American countries, play a critical role in

shaping the technological capability accumulation process (TCAP) of firms, with certain elements serving as catalysts (drivers) for growth and innovation while others may function as impediments (stoppers) to their development.

To test H1, we will relate firms' structural characteristics and firms' innovation infrastructure to firms' TCAP. Accordingly, we will relate the NIS characterization and firms' TCAP to test H2. The availability of comparable information across countries used to be an obstacle to analyze the micro–macro interactions at a greater level of detail, particularly looking at the heterogeneity of intra- and inter-regional specificities and its evolution over time. The availability of continuous and complete data enables the conduct of time series analyses, and the CANA dataset (Castellacci and Natera, 2011) was specifically developed to address this issue. It employs a multiple imputation method (Honaker and King, 2010) to produce statistically significant data points for missing observations, facilitating more robust and comprehensive analyses. The recent contribution made by Crespi et al. (2021) is the other fundamental part because it allows firm-level innovation data to be used in a comparable way across the region. The possibility of combining different datasets for micro–macro analysis is key to this paper.

4. Data Description and Methodological Approach

4.1. Micro Data

The construction of micro-level variables is based on firm-level data of manufacturing and service sectors from the harmonized Latin American Innovation Surveys Database (LAIS), compiled by the Inter-American Development Bank (IDB). The dataset includes 28 innovation surveys (ISs) conducted between 2007 and 2017 for nine countries: Argentina, Chile, Colombia, Ecuador, El Salvador, Panama, Peru, Paraguay, and Uruguay (Table 1). The microdata of Argentina, Ecuador, El Salvador, Panama, Peru, Paraguay, and Uruguay have a period of observation of three years, while the other two countries (Chile and Colombia) collect biennial information of innovation activities. The dataset includes 89,234 observations. A pool subsample from the LAIS was used of innovative firms, defined as those that declare innovation investment in the reference period of each wave of innovation surveys.

Table 1. Sample of Countries and Innovation Survey Waves (Reference Periods)

Country	Reference period	Sector	Innovative firms
Argentina (ARG)	2010–2012 2014–2016	Manufacturing	15,300
Chile (CHL)	2008–2016	Manufacturing and services	8,592
Colombia (COL)	2009–2016	Manufacturing and services	36,502
Ecuador (ECU)	2009–2014	Manufacturing and services	11,730
El Salvador (SLV)	2010–2012	Manufacturing	840
Panama (PAN)	2006–2008 2011–2013	Manufacturing and services	1,128
Paraguay (PRY)	2010–2015	Manufacturing and services	1,578
Peru (PER)	2009–2014	Manufacturing	5,493
Uruguay (URY)	2007–2015	Manufacturing and services	8,071
	Total		89,234

Source: Authors' elaboration based on LAIS (Crespi, Guillard, Salazar, and Vargas, 2021).

Table 2 provides detailed definitions of all micro-level variables used in the analysis. To measure firms' technological capabilities, we adapted the classification proposed by Dutrénit, Vera-Cruz, and Arias (2003) for Latin American countries (see Annex 1). Then, this classification allows us to analyze innovation capabilities of firms in two ways: (i) the generation and management of technical change and (ii) the use and operation of existing technologies. Therefore, we propose a classification of technological capabilities of firms derived from the combination of the two main types of measures: (i) the type of innovation activities and (ii) the results achieved by the firms (see Aeron and Jain [2015] for the case of India, Dutrénit, Vera-Cruz, and Arias [2003] for Mexico, Karabag [2019] for Turkey, and Molina-Domene and Pietrobelli [2012] for Argentina, Brazil, and Chile). Given the different characteristics of technological functions, the technological capability classification considers different levels when executing innovation activities and obtaining innovation results: basic capabilities, low intermediate capabilities, high intermediate capabilities, and advanced technological capabilities (see Table 2). Classification is based on four main assumptions:

1. R&D activities reflect the highest technological capabilities, while machinery purchases reflect lower levels of capability. Other activities such as training, external knowledge acquisition, marketing, or engineering and design are related to intermediate technological capabilities.
2. Product innovation is linked to a higher level of capabilities than business process innovation (marketing, organizational, or process).
3. The greater the scope of product innovations (new to the firm, new to the domestic market, or new to the world), the higher the firm's level of capabilities.
4. If the firm does not obtain innovation results, even being innovative, it is classified as having basic capabilities.

Firm's level of capabilities was constructed as a variable whose score depends on the level of technological capabilities index according to innovation activities and results. This index was constructed considering a minimum score of 1 for basic capabilities and a maximum of 3 for advanced capabilities. A low intermediate score is assigned a value closer to the basic capabilities and a high one a value closer to the advanced capabilities.

Table 2. Definitions of Micro-Level Variables

Dimension	Variables	Description
Technological capabilities according to innovation activities and results	Technological capabilities index	Variable that takes the following values according to IAR classifications of firms: Basic capabilities: 1 Low intermediate capabilities: 1.75 High intermediate capabilities: 2.5 Advanced capabilities: 3
Firms' structural characteristics	Export	Dummy variable that takes the value 1 if the firm has exported to international markets and is equal to 0 otherwise.
	Size L(emp)	Number of firm's employees (in log).
Firms' innovation infrastructure	R&D continuity	Dummy variable that takes the value 1 if the firm reports continuous investments in R&D activities during the period of each survey wave and is equal to 0 otherwise.
	Qualified personnel	Percentage of employees with technical or professional education.
	R&D department	Dummy variable that takes the value 1 if the firm has an internal R&D department and is equal to 0 otherwise.

Source: Authors' elaboration.

Firms' structural characteristics define a firm's basic competitive and resource endowment characteristics, approximated by the firm's propensity to export and its size. Firms' innovation structure is measured through variables such as the presence of an R&D department, the qualification of employees, and the continuity of innovation activities in the firm. We use two-digit classification based on the International Standard Industrial Classification (ISIC) to control for sectoral conditions.[1]

Table 3 provides a descriptive overview of the TCAP variables used in the analysis. Firms with advanced capabilities—the highest ranking—followed by those enterprises with high intermediate capabilities are more common in Latin American countries. In contrast, about a third of the innovative firms in LAC have basic or low intermediate technology capabilities. However, the distribution of firms according to our main classification seems to be different across countries: in Argentina, firms frequently exhibit low intermediate capabilities, while in Chile, Colombia, El Salvador, and Uruguay firms with basic capabilities have a higher share.

Table 3. Descriptive Overview of the Dependent Variables at the Micro Level (Averages)

Dimension	Variables	ARG	CHL	COL	ECU	SLV	PAN	PRY	PER	URU	Total LAC
Technological capabilities according to innovation activities and results	Basic capabilities	0.09	0.21	0.20	0.12	0.26	0.14	0.18	0.13	0.17	0.16
	Low intermediate capabilities	0.24	0.11	0.15	0.15	0.13	0.13	0.20	0.16	0.10	0.16
	High intermediate capabilities	0.21	0.30	0.30	0.28	0.08	0.23	0.25	0.23	0.34	0.28
	Advanced capabilities	0.46	0.39	0.35	0.45	0.54	0.51	0.37	0.48	0.38	0.40
Firms' structural characteristics	Exports	0.44	0.23	0.31	0.16	0.72	0.25	0.25	0.55	0.35	0.33
	Size (log)	3.82	4.42	4.44	3.86	4.58	4.19	3.86	4.38	4.17	4.22
Firms' innovation infrastructure	R&D continuity*	0.59	0.43	0.57	0.58	0.36	0.43	0.46	0.61	0.45	0.55
	Qualified personnel*	0.18	0.12	0.53	0,13	0.27	0.24	0.15	0.15	0.86	0.34
	R&D department*	0.15	0.25	0.27	0.14	0.28	0.19	0.16	0.28	0.18	0.22

Source: Authors' elaboration based on LAIS (Crespi, Guillard, Salazar, and Vargas, 2021).

[1] Most of the firms in LAC belong to the personal goods and services sectors, followed by mass production goods.

4.2 Macro Data

The macro-level data was obtained from an update of the CANA dataset (up to 2018) for cross-country analyses of national systems, growth, and development. Following Castellacci and Natera (2011) we have selected the most-used available indicators for international comparisons in the literature. This selection is based on a systematic empirical analysis about innovation systems from both developed and developing countries, which identifies the most suitable proxies to express countries' evolution. Additionally, the dataset is available with complete information (including observed and estimated data) that makes the most out of the existing data for time series and panel analyses. In selecting indicators, those dimensions listed in the CANA dataset (education systems, development level, infrastructure, industrial structure, institutions, science and technology, internationalization) were considered and two additional dimensions were included (macroeconomic stability and environmental conditions [see Table 4]). On one hand, the aim is to provide a closer description of a region that is constantly suffering from macroeconomics changes; on the other, it was desirable to include an environmental discussion that could position the region in terms of its possibilities for sustainable development.

Table 4. Indicators for the Macro Level

Indicator	Source	Definition
Macroeconomic Conditions		
Exchange rate	World Bank	"Official exchange rate" refers to the exchange rate to U.S. dollars determined by national authorities or to the rate determined in the legally sanctioned exchange market.
Inflation rate	World Bank	Inflation as measured by the annual growth rate of the GDP implicit deflator shows the rate of price change in the economy.
Education System		
Government expenditure on education (% of GDP)	World Bank	General government expenditure on education (current, capital, and transfers) is expressed as a percentage of GDP.
School enrollment, tertiary (% of gross)	World Bank	Gross enrollment ratio is the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the university level of education.
Growth and Development		

GDP per capita (PPP) constant international $	World Bank	GDP per capita based on purchasing power parity (PPP). Data is in 2011 international dollars (constant).
Population living below income poverty line, PPP $1.90 per day	UNDP	Percentage of the population living below the international poverty line of $1.90 (in purchasing power parity terms) a day.
Infrastructure		
Internet users (per 100 people)	World Bank	Internet users are individuals who have used the internet (from any location) in the last three months.
Electric power consumption (kWh per capita)	World Bank	Electric power consumption measures the production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants.
Industrial Structure		
Total natural resources rents (% of GDP)	World Bank	Total natural resources rents are the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents.
Manufacturing, value added (% of GDP)	World Bank	Manufacturing refers to industries belonging to ISIC divisions 15–37.
Institutions		
Corruption Perceptions Index	Transparency International	Each year countries are scored on how corrupt their public sectors are seen to be.
Gini index	WIID, World Bank, OECD	The Gini index measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution.
Science and Technology		
Gross Expenditure on Research and Development (GERD) (% of GDP)	UNESCO, OECD, RICYT	Expenditures for R&D are current and capital expenditures (both public and private).
GERD performed by business enterprise (%)	UNESCO, OECD, RICYT	GERD performance by firms considers the total intramural expenditure on R&D during a specific reference period.
GERD financed by business enterprise (%)	UNESCO, OECD, RICYT	GERD financed by firms considers the total intramural expenditure on R&D during a specific reference period.
Scientific and technical journal articles (per million people)	World Bank	Scientific and technical journal articles refer to the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

Patent applications (per capita)	World Bank	Patent applications (per capita) are worldwide patent applications made by residents and filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years.
Internationalization		
ICT goods imports (% of total goods imports)	World Bank, UNCTAD	Information and communication technology (ICT) goods imports include computers and peripheral equipment, communication equipment, consumer electronic equipment, electronic components, and other information and technology goods (miscellaneous).
High-tech exports (% of manufactured exports)	World Bank	High-tech exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery.
FDI flow inward (% of GDP)	UNCTAD	Foreign direct investment (FDI) is an investment made by a resident enterprise in one economy (direct investor or parent enterprise) with the objective of establishing a lasting interest in an enterprise that is resident in another economy (direct investment enterprise or foreign affiliate).
Environment		
CO_2 intensity (kg of CO_2 per kg of oil equivalent energy use)	World Bank	Carbon dioxide emissions from solid fuel consumption refer mainly to emissions from use of coal as an energy source.

Source: Authors' elaboration.

To explore the macro effect in a more stable way, we used a five-year average of the indicators considering the period before the year of reference of each micro data. In addition, given the focus on TCAP, we included the percentage of R&D expenditure that is performed and financed by firms, in addition to the whole aggregate of R&D expenditure (percent of GDP). This approach led to the problem of data heterogeneity across countries. For example, Peru exhibits insufficient datapoints to assess R&D expenditure financed by firms for the period of analysis, while El Salvador exhibits few datapoints regarding R&D expenditure performed by firms in the corresponding period. Given that we do not have enough simultaneous information for El Salvador and Peru, we split the sample into two groups: one that includes Peru and excludes El Salvador and another that includes El Salvador but not Peru. Finally, we decided to include the already-defined indicators directly in the regression—instead of using principal component analysis or any other technique of dimensionality reduction—to provide a more direct analysis of the results by keeping the multidimensional characteristics of the innovation nature.

4.3 Method

We propose using a multilevel model to analyze how micro–macro interactions explain firms' TCAP in Latin America. In our case, we will use firms' technological capabilities level as a dependent variable, while the first level (micro) will contain firms' structural characteristics and innovation infrastructure and the second level (macro) will be used to include the NISs' proxies. To test our model, we decided to explore the TCAP using as a dependent variable an ordinal variable that expresses the TCAP as a cumulative process.

For this ordinal variable, we used an ordered probit model as follows:

$$Pr\ [TCA_{it,\,l-1} < y *< TCA_{it,\,l}|\ X_{it}] = \Phi(X_{it}\beta_k + \varepsilon_i) \qquad \text{(Equation 1)}$$

In which:

$TCA_{it,\,l}$: technological capability cumulative level (basic, low or high intermediate, or advanced) of firm *i* in period t

Φ: ordered probit function with a standard and cumulative normal distribution

X_{it}: vector of explanatory variables (micro, macro, and control variables)

β : parameters of interest

ε_i: error term

We incorporated a set of country-dummy and time-dummy variables in the set of control variables to deal with the estimations following a pooled strategy. A typical multilevel (two-step) method was discarded because the number of countries is small and the time span of the sample is short. In fact, Chandar et al. (2019) note that this method leads to biases on the estimated coefficients when the numbers of individuals and time periods included are reduced.[2]

Equation 1 was estimated considering TCAP as a mix of activities and results.[3] Furthermore, to present the best characterization at hand of the micro–macro interactions, we investigated the heterogeneity by taking two complementary approaches: (i) following

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[2] Therefore, a pooled treatment for our panel data is considered a reliable estimation strategy. Of course, it would be more desirable to undertake a causality analysis, making use of long time series to explore causal relationships between our micro and macro dimensions in a dynamic approach; however, data limitations prevent us from pursuing such alternatives.

[3] The empirical models were also evaluated with two distinct definitions of TCAP: one rooted solely in activities and the other exclusively in outcomes. To conserve space, these results are not included in this document but are available upon request. This dual approach to defining TCAP serves as a sensitivity analysis, reinforcing the validity of the findings reported in this paper.

the classification proposed by Dutrénit et al. (2019), using the NIS dimensions to generate two country groups—one more oriented to techno-economic development and the other more oriented towards socio-political dimensions—and (ii) using different time frames to assess how the TCAP unfolds over time (2008–2016, 2010–2016). In all cases, we always split the sample in two configurations (considering R&D performance and R&D funding).

Unfortunately, the compromises made for data homogenization, the small number of countries, and the short time span represent major limitations in building a solid characterization of the heterogeneity in the TCAP. For instance, when assessing the heterogeneity of country groups, data limitations made it possible only to estimate results for a reduced set of variables of the techno-economically advanced group (Dutrénit, Natera, Puchet Anyul, and Vera-Cruz, 2019). Because of this, results should be taken with caution and only as preliminary references of the heterogeneity that we still want to observe. Similar considerations apply to the analysis based on time frames (2006–2014, 2006–2012).

5. Results and Analysis

5.1 Understanding TCAP across the Region

Table 5 summarizes the results for the ordinal characterization of the TCAP (see Annex 1 for the complete estimation results), where bold letters refer to drivers (positive and significant coefficients) and italics to stoppers (negative and significant coefficients). We observe that the first hypothesis (H1) is partly confirmed, since we only find drivers at the micro level (and no evidence of stoppers): firms' structural characteristics and innovation infrastructure have a positive and significant relationship with the TCAP; the capacity to export, the presence of an R&D department, the hiring of qualified personnel, and the continuity of innovation activities support the TCAP cumulative process. These results are fully consistent for both cases of R&D (that performed by firms and financed by firms—see Table 5, columns 1 and 2) and when considering only countries within the techno-economic advanced group (see Table 5, column 3). Firm size has a mixed result, being positive and only significant when considering the whole sample, but it is not a driver among the techno-economic advanced group. At the micro level, results agree with the literature discussed in Section 3: innovation efforts and active participation in international markets are drivers for the accumulation of technological capabilities.

At the macro level we confirm the second associated hypothesis (H2): we found drivers and stoppers from the NIS characterization. We observe mixed signs of significant coefficients depending on the dimension being focused on. In Macroeconomic Conditions, exchange rate depreciation is positively related to the TCAP in all cases (both estimations for the whole panel and the techno-economic advanced group). Conversely, the inflation rate appears with a negative effect in the whole panel but is not significant among the techno-economic advanced group. As discussed in Katz (1987), these macroeconomic variables have an impact on firms' innovation processes: when the local currency appreciates, incentives for buying technology from abroad are more relevant; similarly, high inflation rates generate uncertainty that hampers firms' learning processes.

The Education System dimension normally shows a complicated relationship with the innovation process in most of the empirical analyses (Castellacci and Natera, 2013). Government expenditure on education has a negative and significant relationship in the two estimations for the whole panel but is not significant among the techno-economic advanced group. Other relevant variables—such as enrollment in tertiary education—are not significant in either of the models. It is worth mentioning that the negative coefficient for the whole panel seems to be associated with high increases in governmental expenditure in recent years, especially among the techno-economic low group, after historically low levels of investment. The impact of these investments on the innovative dynamic of firms and the economic structure may not be immediate. In fact, literature about Latin American countries points to the existence of thresholds of investments that have to be overcome and sustained to build solid systems of education, both basic and advanced (Erbes, Katz, and Suárez, 2016). Also, a country's development level could determine whether benefits from this type of investment are observed (Suárez, Fiorentin, and Erbes, 2021) as well as a possible mismatch between the supply and demand of skills in terms of the relevance of tertiary education to respond to the needs and demands of the business sector (Smith and Waters, 2011).

The Growth and Development dimension supports the idea of the importance of welfare: On the one hand, we observe that GDP per capita levels have a negative and significant effect on the TCAP variable, while the level of structural development and diversification reached among the techno-economic group leads this variable to lose significance. On the other hand, the percentage of the population living below the poverty line behaves similarly in all estimations. This indicates that the technological capabilities of firms are higher in countries with lower levels of poverty. It may also indicate that poverty measures work better than per capita GDP to capture the living conditions of countries. In terms of Infrastructure, we find a negative relationship between electric power consumption and TCAP, which implies that firms developing the higher level of technological capabilities are not part of energy-intensive sectors and may have more efficient consumption (we also verified this postulation by looking at sector variables included in the model). Internet access also show a negative association, although only in the case of the sample based on R&D financed by firms. Similar to the Education dimension, a significant increase in connectivity among low-income countries departs from significant low levels and still does not impact the economic structures. For the rest of the estimations, results show that there is an opportunity to increase the digital transformation of the region. Based on the literature (Natera and Castellacci, 2021), the lack of significance is not a sign of lack of importance but an indication of the need to overcome the minimum thresholds to this infrastructure to have an impact on economic activity.

In terms of Productive Structure, we observe mixed signs from the rents from natural resources. This is coherent with Latin American recent history, in which the last cycle of commodity upswing experienced during the first years of the 2020s generated mixed effects on the economies and, therefore, on the domestic firms as well as the long-term effect of the deindustrialization process suffered in the region since the 1990s (Kim and Lee, 2014). Regarding the manufacturing sector, we find a negative and significant coefficient, which suggests that the services sector is more able to trigger TCAP in the region at higher levels than the rest of the sectors.

With the Socio-Political Factors we observe a positive and significant effect of improvement in the corruption perception in Latin American countries, implying that institutional stability and quality is highly appreciated when undertaking learning processes. Moreover, we observe a negative and significant coefficient of the Gini index because inequality is one of the major historical challenges in the region. Along the same lines, even though the discussion between inequality and innovation is far from being closed, there is some consensus regarding the non-linear relationship between these two processes (Hatipoglu, 2012). In particular, because Latin American income levels are involved in development traps (Lee, 2013) and the size of the market is not the most favorable to develop the TCAP, the sector of the population that could afford the cost innovations tends to be those in the higher income quantiles (Cozzens and Sutz, 2014).

The Science and Technology dimension exhibits a positive relationship between R&D investment and the TCAP. Even when expected, it calls to our attention that R&D expenditure performed by firms is negatively associated, even among countries within the techno-economic advanced group. This is consistent with previous evidence that shows a tendency of firms located in developing countries towards the adaptation of external innovations and technologies in production processes (Huang, Arundel, and Hollanders, 2010) and also with studies conducted for Latin America that indicate that a significant part of innovation processes respond to the need to solve production, profitability, or market problems, rather than to taking offensive action to gain greater market share based on R&D activities (Dutrénit and Sutz, 2014). We think that this implies two important points: (i) R&D investments should be foster and sustained in the region and (ii) we need to improve the quality of firms' participation in R&D processes, not only focusing on the level but also on the way that these resources are being executed. Scientific production (represented by the number of scientific and technical journal articles produced) shows a positive and significant sign, which suggests that increasing interaction between the academic community and the productive sector is an important way to improve learning processes in the region. Finally, we observe that patent applications are negatively associated with TCAP in the whole panel, which accounts for the negative impact of barriers to innovate based on imitation, which is the most common characteristic of middle-income countries (Hall, 2022). Additionally, considering the low level of patenting activity in the region, we think that this outcome is based on the fact that patenting activity in the region is mostly derived from innovation processes that take place outside the country and an increased propensity of firms in developing countries to use strategic mechanisms to promote innovation (Hurmelinna-Laukkanen, 2009; James, Leiblein, and Lu, 2013).

The Internationalization dimension shows a negative and significant coefficient for ICT goods imports and a positive and significant coefficient for high-tech exports (percent of GDP), in all models. The former might confirm that models based on strategies like those used during the import substitution process should be revisited. Of course, we are facing a very different and much more interconnected world nowadays; however, the development of local capabilities is still of utmost importance (particularly during crises such as that created by the COVID-19 pandemic).

Finally, the Environment dimension shows that increases in the emissions of CO_2 gases is negatively and significantly related to the TCAP in all models. Once again, this is linked to the type of activities that more advanced firms perform, but also shows how energy inefficiencies do not contribute to firms' learning processes in the region.

The results from this study offer nuanced insights into the interplay between NISs and firms' TCAP in Latin America, underscoring the complex dynamics of micro–macro interactions. The theoretical framework, underpinned by contributions from Katz, Srholec, and others, situates the innovation process within the broader socioeconomic and institutional context, highlighting the importance of both firm-level characteristics and national innovation policies.

At the macro level, the mixed signs of significant coefficients illustrate the dual nature of economic variables. For instance, as we previously discussed, exchange rate depreciation's positive association with TCAP underscores the advantage firms gain in importing technology when the local currency is weaker. However, high inflation rates, reflective of economic instability, obstruct firms' learning processes. This aligns with Katz's observation that macroeconomic conditions exert substantial influence on innovation processes (Katz, 1988, 1998, 2001). Finally, while higher education expenditures show a negative effect on TCAP, this does not necessarily signify that education is detrimental to technological capability. Instead, it may point to a lagged impact of education investments or a mismatch between the educational output and the skills demanded by the innovation-driven sectors.

Table 5. TCAP as a Cumulative Process

	GERD performed by business enterprise	GERD financed by business enterprise	Techno-economic advanced group
Micro			
Firms' structural characteristics	**Exports** **Size**	**Exports** **Size**	**Exports**
Firms' innovation infrastructure	**R&D continuity** **Qualified personnel** **R&D department**	**R&D continuity** **Qualified personnel** **R&D department**	**R&D continuity** **Qualified personnel** **R&D department**
Macro			
Macroeconomic conditions	**Exchange rate** *Inflation growth rate*	**Exchange rate** *Inflation growth rate*	**Exchange rate**
Education system	*Government expenditure on education*	*Government expenditure on education*	
Growth and development	*GDP per capita* *Population living below income poverty line*	*GDP per capita* *Population living below income poverty line*	
Infrastructure	*Electric power consumption*	*Internet users* *Electric power consumption*	
Productive structure	*Total natural resources rents* *Manufacturing, value added*	**Total natural resources rents**	**Total natural resources rents**
Institutions	**Corruption Perceptions Index** *Gini index*	**Corruption Perceptions Index** *Gini index*	
Science and technology	**Gross Expenditure on Research and Development (GERD)** *GERD performed by business enterprise* **Scientific and technical journal articles** *Patent applications*	**Gross Expenditure on Research and Development (GERD)** **Scientific and technical journal articles** *Patent applications*	**Gross Expenditure on Research and Development (GERD)** *GERD performed by business enterprise* **Patent applications**
Internationalization	*ICT goods imports* **High-tech exports**	*ICT goods imports* **High-tech exports**	*ICT goods imports*
Environment	*CO_2 intensity*	*CO_2 intensity*	

Source: Authors' elaboration based on LAIS (Crespi, Guillard, Salazar, and Vargas, 2021) and CANA (Castellacci and Natera, 2011) datasets.
Notes: Bold text indicates drivers (positive and significant coefficient); italics indicate stoppers (negative and significant coefficients).

5.2 Exploring the TCAP Heterogeneity

As a final characterization of the TCAP, we wanted to explore temporal characteristics of the process. Once again, the data constraints in terms of the time span and the number of countries made these exercises limited. We could construct different windows to observe how the process unfolds over time: 2008–2016, 2010–2016, 2012–2016, and 2014–2016. Based on the results, we see that the shortest time span to observe the characteristics of the whole TCAP is between 2008–2010 and 2010–2016, indicating that the approximate average time lag needed to observe the micro and macro interaction is between eight and six years. However, even when this confirms previous results (Crespi, Maffioli, and Meléndez Arjona, 2011) we do not rely on this outcome to make any firm statement and acknowledge that it is simply the best information we can provide with the available data; much more research is needed to provide a better answer. Future research should also consider that macro dimensions could have different time lags to impact on micro dimensions. For instance, the education system might take longer to influence the TCAP than internationalization activities do.

Table 6 summarizes results, this time in terms of significant coefficients from each dimension grouped in terms of drivers and stoppers. At the micro level, exports, size, and innovation investments remain positive and significant in both periods, meaning they could be seen as drivers for the accumulation of technological capabilities. At the macro level, drivers and stoppers from all dimensions remain with the same sign and significance except for five variables. The impact of scientific and technical journal articles is only significant during the first period, which might be due to changes in academic agendas connected to the internationalization of these activities. This calls attention to the type of research that is being published, which to some extent is more connected to the problems of developed countries than to the issues affecting Latin America (Arocena and Sutz, 2012). GDP per capita is no longer a stopper in the 2010–2016 period; this is most probably connected to the positive evolution of economic conditions once the 2008 financial crisis was overcome in the region. The introduction of technologies closer to the technological frontier, also derived from better economic conditions and the expansion of connectivity during the last period, might also explain the loss of significance of variables such as manufacturing value added, internet users, and CO_2 intensity, which are no longer stoppers in 2010–2016.

Table 6. TCAP over Time

	2008–2010		2010–2016	
	Drivers	Stoppers	Drivers	Stoppers
Micro	Exports Size R&D continuity Qualified personnel R&D department		Exports Size R&D continuity Qualified personnel R&D department	
Macro	Exchange rate Total natural resources rents Corruption Perceptions Index R&D expenditure Scientific and technical journal articles High-tech exports	Inflation growth rate Government expenditure on education GDP per capita Population living below income poverty line Internet users Electric power consumption Total natural resources rents Manufacturing, value added Gini index GERD performed by business enterprise Patent applications ICT goods imports CO_2 intensity	Exchange rate Total natural resources rents Corruption Perceptions Index Gross Expenditure on Research and Development (GERD) GERD performed by business enterprise High-tech exports	Inflation growth rate Government expenditure on education Population living below income poverty line Electric power consumption Total natural resources rents Gini index Patent applications ICT goods imports

Source: Authors' elaboration based on LAIS (Crespi, Guillard, Salazar, and Vargas, 2021) and CANA (Castellacci and Natera, 2011) datasets.

6. Final Remarks: Drivers, Stoppers, and Opportunities for More Integrated NISs

The objective of this paper was to analyze the impact of NISs and firms' micro characteristics on their TCAP. Based on the broad definition of NISs, we investigated how NISs' dimensions and firms' innovation profiles determine enabling factors for TCAP among Latin American firms during the period 2006–2016. Based on the integration of the LAIS (Crespi et al., 2021) and CANA (Castellacci and Natera, 2011) datasets, the methodology consisted of a multilevel analysis to observe how the characteristics of NISs and firms' structural characteristics and innovation infrastructure affect their TCAP and economic performance.

We constructed an indicator to assess the TCAP in the region based on innovation activities and results, the two main axes of the technological capabilities matrix (see Table A1 in Annex 1). Based on our conceptual model, we aimed to explain the TCAP by considering a micro level (structural characteristics and innovation infrastructure of the firms) and a macro level (macroeconomic stability, education system, growth and development, infrastructure, socio-political factors, science and technology, productive structure, internationalization, and environment). We used an ordered probit model to test the relations between micro and macro variables and the TCAP level. We confirmed both of our hypotheses.

- At the micro level, we found only drivers (a positive relationship) between the micro variables and innovative firms' TCAP; this result is consistent across all the empirical testing executed in this research. It implies that innovative firms in Latin America are orienting their efforts to sustain their learning processes. Of course, the possibilities to improve innovation management and innovation effort are always open and part of the TCAP as adaptation to constant change, but results suggest that firms are on the right track.
- At the macro level, the identified TCAP drivers include having a stable and competitive monetary regime, improvements in institutional quality, R&D investments, linkages with scientific production, and fostering high-tech exports. In terms of the stoppers, we found evidence of negative effects from high inflation rates, the percentage of population living below the poverty line, the leverage on population's high-income sectors to sustain the TCAP and the imports of ICT products, and inefficiencies in energy use. We also observe that activities occurring outside the manufacturing sector tend to be more linked to higher levels of TCAP. Furthermore, we observe some disconnections between crucial dimensions, in which we could expect new opportunities to emerge for the TCAP: the need to reassess the education system's participation, the quality of the use of R&D resources, the possibilities of incorporating digital technologies, and the participation of FDI investments.

This research paper extends existing literature on innovation by providing a detailed, region-specific analysis of factors influencing technological capability accumulation in Latin American firms, particularly focusing on the role of NISs and firm-level characteristics within the broader socioeconomic context. It aligns with previous studies (like those of Lundvall [1992], Nelson [1993], Cohen and Levinthal [1989], and Kleinknecht and Mohnen [2001]) in recognizing the importance of a robust NIS and firm-level factors in fostering innovation. However, it goes further by offering nuanced insights into how specific dimensions of NISs, such as macroeconomic stability, education, and R&D investments, directly affect TCAP. Additionally, the paper uniquely details the impact of firm structural characteristics and innovation infrastructures in Latin America, integrating data from the LAIS and CANA datasets for a more comprehensive analysis.

Moreover, the study contributes fresh perspectives on the influence of macroeconomic and socio-political factors—like high inflation rates and poverty levels—on innovation processes, reinforcing the crucial role of economic stability highlighted in prior research (Aghion et al., 2009). It diverges from earlier works by providing a more granular view of specific "stoppers" and "disconnections," particularly relevant to the Latin American context. The paper also offers new insights into sectoral innovation, suggesting a stronger link between non-manufacturing activities and higher TCAP levels in Latin America, a notable departure from literature that focused on manufacturing sectors (in the tradition of Pavitt [1984]).

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Annex 1. Technological Capabilities Matrix

Following Dutrénit, Vera-Cruz, and Arias's (2003) technological capabilities matrix, the capabilities can be divided based on the technological function that they allow firms to develop. Depending on the type of technological function that the firm executes, the firm needs the previous accumulation of complex technological capabilities, with different levels of maturity. In this regard, capabilities cannot be measured directly because they are a tacit resource that belongs to firms (see Table A1). Nevertheless, they can be approximated based on the type of activity the firm develops to carry out a technological function. This technological function, as was already mentioned, may involve both innovative inputs and results.

Table A1. Technological Capabilities Matrix

	Primary Activities				Supporting Activities	
	Investment		Production			
	Routine production Capabilities: Capabilities to use and operate existing technology					
	Facility users decision-making and control	Project preparation and implementation	Process and organization of production	Product	Developing linkages	Supply of capital goods
Basic production capabilities Capabilities that use existing production techniques	Negotiating primary contract. Securing and disbursing financing. Officiating at opening ceremony.	Preparation of initial project outline. Basic construction. Simple plan implementation.	Routine operation and basic facilities maintenance. Improved efficiency based on experience with earlier tasks.	Replication of fixed specifications and design. Guiding quality control to maintain existing standards and specifications.	Procurement of available supplies from existing suppliers. Sale of existing products to customers.	Replication of durable items of plant and machinery.
Technological Capabilities: Capabilities to generate and manage technical change						
Basic	Active monitoring and control of feasibility studies, technology choice/sourcing, and project scheduling.	Feasibility studies. Organizational planning. Standard equipment procurement. Simple engineering.	Commissioning and debugging. Improved layout, scheduling, and maintenance. Minor adaptation.	Minor adaptation to market needs and incremental improvement in product quality.	Researching and absorbing new information from suppliers, customers, and local institutions.	Replicating new types of plants and machinery. Simple adaptation of existing designs and specifications.

Intermediate	Research, evaluation, and selection of technology sources. Offers/negotiation. Overall project management.	Detailed engineering. Plant procurement. Environmental assessment. Project scheduling and management. Commissioning. Recruitment/training.	Process improvement. Licensing new technology. Introducing organizational changes.	Licensing new product technology and/or reverse engineering. Incremental new product design.	Technology transfer to suppliers and customers to increase efficiency, quality, and local sourcing.	Incrementally innovative reverse engineering and original design of plant and machinery.
Advanced	Developing new production systems and components.	Basic process design and related R&D.	Process innovation and related R&D. Radical innovation in organization.	Product innovation and related R&D.	Collaboration in technology development.	R&D for specifications and design of new plant and machinery.

Source: Dutrénit, Vera-Cruz, and Arias (2003).

Then, technological capabilities can be divided among basic capabilities, low intermediate capabilities, high intermediate capabilities, and advanced capabilities. As defined by Dutrénit, Vera-Cruz, and Arias (2003), basic capabilities are those required for the execution of routine operations, based on the use of existing technologies and intermediate and advanced capabilities include at least a little contribution to technical change albeit at different ranges depending on the type of technological capability, as will be explained below.

Basic capabilities refer to those innovative activities that, naturally, require the use of skills and knowledge, but they do not promote or generate new technologies. Thus, basic capabilities involve those skills that firms need to develop innovative and productive activities, using the technologies that the firm already possesses. Following this definition, in terms of inputs, basic capabilities include the less knowledge-intensive innovation activities, such as investing in ICT and machinery, and, in terms of outputs, only business innovation is included (as shown earlier in Table 2).

Low intermediate capabilities include those technological functions that slightly contribute to the administration and generation of technical change. For this reason, the activities included are investments in innovation activities different from R&D, besides the ones in ICT and machinery. Regarding results, at this level new products are generated, either for the firm or the country.

High intermediate capabilities have a higher influence on technical change but still do not contain the direct search for the creation of new and creative knowledge. For that reason, we did not include R&D activities in this level of technological capabilities. Here there are other innovation activities different from R&D and innovation results in either business or product (new to the firm or to the country).

Finally, advanced capabilities involve those activities aimed at the creation and management of new knowledge and technologies. At this highest level of capabilities, both internal and external R&D investments are included as well as the achievement of product innovation, this time new to the market or the world.

Table A2. TCAP as a Cumulative Process

Variables		GERD performed by business enterprise	GERD financed by business enterprise
Micro			
Firms' structural characteristics	Exports	0.324***	0.335***
		(0.00001)	(0.00001)
		0.0409	0.0410
	Size L(emp)	0.0120	0.0104
		(0.466)	(0.548)
		0.0165	0.0173
Firms' innovation infrastructure	R&D continuity	1.759***	1.754***
		(0.00001)	(0.00001)
		0.0442	0.0435
	Qualified personnel	0.00770***	0.00767***
		(8.90e-08)	(1.25e-07)
		0.00144	0.00145
	R&D department	1.311***	1.352***
		(0.00001)	(0.00001)
		0.0602	0.0626

Macro			
Macroeconomic conditions	Exchange rate	0.000664**	0.00161***
		(0.0471)	(0.00121)
		0.000335	0.000497
	Inflation rate	-0.00580	-0.0155
		(0.601)	(0.222)
		0.0111	0.0127
Education system	Government expenditure on education (% of GDP)	-1.071	-0.597
		(0.133)	(0.239)
		0.713	0.507
	School enrollment, tertiary (% of gross)	0.0286	0.0447
		(0.195)	(0.124)
		0.0221	0.0291
Growth and development	GDP per capita (PPP)	-0.000506*	-0.000929***
		(0.0743)	(0.00354)
		0.000283	0.000318
	Population living below income poverty line	-56.71**	-2.895
		(0.0365)	(0.962)
		27.12	60.46
Infrastructure	Internet users (per 100 people)	-0.0230	-0.0703
		(0.485)	(0.126)
		0.0330	0.0459
	Electric power consumption (kWh per capita)	-0.00276**	-0.00314**
		(0.0321)	(0.0484)
		0.00129	0.00159

Industrial structure	Total natural resources rents (% of GDP)	-0.0860	0.0109
		(0.480)	(0.874)
		0.122	0.0687
	Manufacturing, value added (% of GDP)	-0.283*	0.0900
		(0.0978)	(0.605)
		0.171	0.174
Institutions	Corruption Perceptions Index	0.161**	0.126*
		(0.0291)	(0.0508)
		0.0736	0.0644
	Gini index	-0.148***	-0.0700
		(6.19e-08)	(0.143)
		0.0273	0.0478
Science and technology	Gross expenditure on research and development (GERD) (% of GDP)	0.869**	1.226**
		(0.0191)	(0.0153)
		0.371	0.506
	GERD performed by business enterprise (%)	-0.00854	
		(0.715)	
		0.0234	
	GERD financed by business enterprise (%)		-0.0156
			(0.489)
			0.0226
	Scientific and technical journal articles (per million people)	0.0250**	0.0208**
		(0.0115)	(0.0421)
		0.00990	0.0102
	Patent applications (per capita)	-0.0307	-0.0540

		(0.606)	(0.139)
		0.0595	0.0365
Internationalization	ICT goods imports (% of total goods imports)	-0.171***	-0.200***
		(0.000500)	(0.000226)
		0.0492	0.0542
	High-tech exports (% of manufactured exports)	0.186*	0.443***
		(0.0753)	(5.67e-05)
		0.104	0.110
	FDI flow inward (% of GDP)	-0.155	0.0363
		(0.161)	(0.719)
		0.111	0.101
Environment	CO_2 intensity (kg of CO_2 per kg of oil equivalent energy use)	-0.674	-2.001*
		(0.657)	(0.0854)
		1.518	1.163
	Observations	67,909	64,257
	Notes: Robust pval in parentheses; *** p<0.01, ** p<0.05, * p<0.1		

Table A3. TCAP for the Techno-Economic Advanced Group

	Variables	R&D performed by firms	R&D financed by firms
Micro			
Firms' structural characteristics	Export	0.366***	0.366***
		(0)	(0.0001)
		0.0467	0.0467
	Size L(emp)	0.00353	0.00353
		(0.855)	(0.855)
		0.0194	0.0194
Firms' innovation infrastructure	R&D department	1.291***	1.291***
		(0.0001)	(0.0001)
		0.0705	0.0705
	Qualified personnel	0.00779***	0.00779***
		(3.21e-07)	(3.21e-07)
		0.00152	0.00152
	R&D continuity	2.430***	2.430***
		(0.0001)	(0.0001)
		0.0567	0.0567
Macro			
Macroeconomic conditions	Exchange rate	0.00491*	0.0115**
		(0.0605)	(0.0318)
		0.00262	0.00537
	Inflation growth rate	-0.0281	-0.0347
		(0.226)	(0.100)
		0.0232	0.0211

Education system	Government expenditure on education (% of GDP)	-2.922	-3.192
		(0.270)	(0.260)
		2.649	2.833
	School enrollment, tertiary (% of gross)	0.126	0.199
		(0.101)	(0.123)
		0.0769	0.129
Growth and development	GDP per capita (PPP)	-0.000910	-0.000730
		(0.315)	(0.348)
		0.000905	0.000778
	Population living below income poverty line	-107.5	-138.1
		(0.401)	(0.349)
		128.0	147.6
Infrastructure	Internet users (per 100 people)	-0.106	-0.0554
		(0.169)	(0.447)
		0.0771	0.0728
	Electric power consumption (kWh per capita)	-0.00178	-0.00140
		(0.241)	(0.398)
		0.00151	0.00166
Industrial structure	Total natural resources rents (% of GDP)	-0.116	0.0739
		(0.723)	(0.728)
		0.329	0.213
	Manufacturing, value added (% of GDP)	-0.0397	0.0112
		(0.948)	(0.984)
		0.603	0.575

Institutions	Corruption Perceptions Index	0.0752	-0.0450
		(0.453)	(0.682)
		0.100	0.110
	Gini index	-0.0871	-0.0411
		(0.331)	(0.578)
		0.0896	0.0740
Science and technology	Gross expenditure on research and development (GERD) (% of GDP)	3.470**	4.016*
		(0.0477)	(0.0559)
		1.752	2.100
	GERD performed by business enterprise (%)	-0.106	
		(0.189)	
		0.0810	
	GERD financed by business enterprise (%)		-0.0936
			(0.189)
			0.0713
	Scientific and technical journal articles (per million people)	-0.00230	-0.0502
		(0.933)	(0.171)
		0.0275	0.0367
	Patent applications (per capita)	0.110	0.133
		(0.110)	(0.105)
		0.0687	0.0821
Internationalization	ICT goods imports (% of total goods imports)	-0.0354	-0.312
		(0.906)	(0.283)
		0.301	0.291
	Observations	50,813	50,813

Notes; Robust pval in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A4. TCAP (2008–2016)

	Variables	R&D performed by firms	R&D financed by firms
Micro			
Firms' structural characteristics	Export	0.327***	0.339***
		(0.0001)	(0.0001)
		0.0412	0.0412
	Size L(emp)	0.0117	0.0100
		(0.481)	(0.565)
		0.0166	0.0174
Firms' innovation infrastructure	R&D department	1.306***	1.346***
		(0.0001)	(0.0001)
		0.0604	0.0628
	Qualified personnel	0.00780***	0.00777***
		(9.65e-08)	(1.35e-07)
		0.00146	0.00147
	R&D continuity	1.758***	1.753***
		(0.0001)	(0.0001)
		0.0442	0.0435
Macro			
Macroeconomic conditions	Exchange rate	0.000670**	0.00161***
		(0.0451)	(0.00118)
		0.000335	0.000497
	Inflation growth rate	-0.00597	-0.0157
		(0.590)	(0.218)
		0.0111	0.0127

Education system	Government expenditure on education (% of GDP)	-1.067	-0.599
		(0.134)	(0.237)
		0.713	0.507
	School enrollment, tertiary (% of gross)	0.0282	0.0444
		(0.202)	(0.127)
		0.0221	0.0291
Growth and development	GDP per capita (PPP)	-0.000507*	-0.000930***
		(0.0735)	(0.00352)
		0.000283	0.000319
	Population living below income poverty line	-56.29**	-2.890
		(0.0379)	(0.962)
		27.12	60.46
Infrastructure	Internet users (per 100 people)	-0.0236	-0.0707
		(0.475)	(0.124)
		0.0330	0.0460
	Electric power consumption (kWh per capita)	-0.00278**	-0.00316**
		(0.0311)	(0.0468)
		0.00129	0.00159
Industrial structure	Total natural resources rents (% of GDP)	-0.0864	0.00980
		(0.478)	(0.886)
		0.122	0.0687
	Manufacturing, value added (% of GDP)	-0.280	0.0919
		(0.102)	(0.598)
		0.171	0.174

Institutions	Corruption Perceptions Index	0.161**	0.127**
		(0.0284)	(0.0486)
		0.0737	0.0645
	Gini index	-0.148***	-0.0706
		(5.74e-08)	(0.140)
		0.0273	0.0478
Science and technology	Gross expenditure on research and development (GERD) (% of GDP)	0.868**	1.230**
		(0.0191)	(0.0150)
		0.370	0.506
	GERD performed by business enterprise (%)	-0.00833	
		(0.721)	
		0.0234	
	GERD financed by business enterprise (%)		-0.0154
			(0.494)
			0.0226
	Scientific and technical journal articles (per million people)	0.0251**	0.0210**
		(0.0113)	(0.0408)
		0.00990	0.0102
	Patent applications (per capita)	-0.0312	-0.0543
		(0.600)	(0.137)
		0.0595	0.0365
Internationalization	ICT goods imports (% of total goods imports)	-0.171***	-0.200***
		(0.000497)	(0.000220)
		0.0492	0.0542
		0.187*	0.444***

	High-tech exports (% of manufactured exports)	(0.0729)	(5.57e-05)
		0.104	0.110
	FDI flow inward (% of GDP)	-0.156	0.0362
		(0.161)	(0.720)
		0.111	0.101
Environment	CO_2 intensity (kg of CO_2 per kg of oil equivalent energy use)	-0.676	-2.000*
		(0.656)	(0.0855)
		1.518	1.163
	Observations	67,179	63,527
	Notes: Robust pval in parentheses; *** p<0.01, ** p<0.05, * p<0.1		

Table A5. TCAP (2010–2016)

	Variables	R&D performed by firms	R&D financed by firms
Micro			
Firms' structural characteristics	Export	0.338***	0.355***
		(0.0001)	(0.0001)
		0.0395	0.0394
	Size L(emp)	0.00772	0.00427
		(0.669)	(0.821)
		0.0181	0.0188
Firms' innovation infrastructure	R&D department	1.312***	1.351***
		(0.0001)	(0.0001)
		0.0613	0.0628
	Qualified personnel	0.00767***	0.00751***
		(1.58e-06)	(3.01e-06)
		0.00160	0.00161
	R&D continuity	1.804***	1.817***
		(0.0001)	(0.0001)
		0.0464	0.0449
Macro			
Macroeconomic conditions	Exchange rate	-0.000433	0.000579
		(0.650)	(0.580)
		0.000955	0.00105
	Inflation growth rate	-0.0354	-0.0268
		(0.201)	(0.315)
		0.0277	0.0267

Education system	Government expenditure on education (% GDP)	0.366	-0.318
		(0.719)	(0.741)
		1.017	0.962
	School enrollment, tertiary (% of gross)	0.0214	0.0531
		(0.413)	(0.163)
		0.0261	0.0381
Growth and development	GDP per capita (PPP)	-0.000307	-0.000668
		(0.493)	(0.128)
		0.000448	0.000439
	Population living below income poverty li	-67.64**	-26.45
		(0.0296)	(0.505)
		31.09	39.72
Infrastructure	Internet users (per 100 people)	0.00562	-0.0296
		(0.903)	(0.509)
		0.0461	0.0448
	Electric power consumption (kWh per capita)	-0.00662**	-0.00476*
		(0.0192)	(0.0589)
		0.00283	0.00252
Industrial structure	Total natural resources rents (% of GDP)	-0.0821	-0.0538
		(0.450)	(0.628)
		0.109	0.111
	Manufacturing, value added (% of GDP)	0.0735	0.0695
		(0.765)	(0.745)
		0.246	0.214

Institutions	Corruption Perceptions Index	0.263***	0.192**
		(0.00836)	(0.0317)
		0.0997	0.0892
	Gini index	-0.0927**	-0.0642
		(0.0320)	(0.326)
		0.0432	0.0654
Science and technology	Gross Expenditure on Research and Development (GERD) (% of GDP)	-0.423	0.517
		(0.717)	(0.685)
		1.166	1.275
	GERD performed by business enterprise (%	0.0265	
		(0.215)	
		0.0214	
	GERD financed by business enterprise (%)		-0.0162
			(0.535)
			0.0261
	Scientific and technical journal articles (pe million people)	0.00176	0.0116
		(0.935)	(0.654)
		0.0217	0.0259
	Patent applications (per capita)	-0.152**	-0.0863
		(0.0193)	(0.122)
		0.0647	0.0559
Internationalization	ICT goods imports (% of total goods impo	-0.126*	-0.171**
		(0.0836)	(0.0291)
		0.0726	0.0783
		0.365***	0.408***

	High-tech exports (% of manufactured exports)	(0.000198)	(9.81e-05)
		0.0980	0.105
	FDI flow inward (% of GDP)	-0.0548	0.0144
		(0.666)	(0.888)
		0.127	0.102
Environment	CO_2 intensity (kg of CO_2 per kg of oil equivalent energy use)	0.265	-0.708
		(0.899)	(0.746)
		2.088	2.184
	Observations	62,926	60,017
	Notes: Robust pval in parentheses; *** p<0.01, ** p<0.05, * p<0.1.		