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Technological capabilities accumulation and internationalization strategies of Mexican biotech firms: a multi case study from agro-food & pharma industries

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ABSTRACT

In this paper our aim is to analyze the relationship between technological capabilities accumulation of Mexican biotech firms and their different types of internationalization strategies. Because of the determining effect of firms' capital investment level, we analyzed three groups of firms: start-ups, small and medium-sized firms (SMEs) and multinational firms (MNEs). We made use of a wide range of information: *The First Survey of Biotechnology Development Firms in Mexico*, the systematization of 20 case studies, interviews with key persons in the industry and public sources. We confirmed the two hypotheses outlined: (i) TCA process does not follow a linear path in Mexican biotech firms and (ii) firms with lower capital investment levels exhibit a lower level of TCA and less complex internationalization strategies; while firms with higher capital investment levels are associated with higher TCA levels and more complex internationalization strategies. Biotechnology requires high levels of capital investment and these to a large extent determine the development and technological capabilities accumulation. Therefore, we suggest that a capitalization program is much needed to foster Mexican biotech firms' TCA processes and develop internationalization strategies.

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Biotechnology; technological capabilities; internationalization strategies

Introduction

Biotechnology is a multidisciplinary activity focused on making use of living systems and organisms to generate applications for specific uses (CDB 1992, 3; OECD 1989). Because of its complexity there are many challenges related to the promotion of modern biotechnology at the industrial level: it requires high levels of research and development (R&D), is capital intensive and demands long periods for innovation. Capital investment levels are decisive for firms' growth and development. A variety of funding mechanisms have been established for financing and risk sharing R&D, product development and manufacturing activities (North Carolina Biotechnology Center 2009–2015): public funds, private funds (contract research organizations, venture capital) and stock market capitalization. Financial constraints have led to two types of concentration in industrial biotechnology: (i) in R&D performing and financing, where United States holds 70% and 86% correspondingly (ICEX 2016) and (ii) marketing and sales activities in large multinational companies, while there is a large number of start-ups and small and medium-sized firms performing R&D and manufacturing tasks, using external or shared financing sources (ICEX 2016).

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This brief outlook is enough to surmise a relationship exists between firms' possibilities of achieving higher levels of technological capabilities and their interactions with international markets. Furthermore, in developing countries, where access to financial resources are limited and systemic problems are common, the impact of these interactions could be critical to the development of firms' technological capabilities accumulation. Biotechnology is both relevant as it is immersed in global dynamics and demanding in terms of the required specialized knowledge, advanced capabilities and financial resources.

To understand this problem, we need to make use of two traditions in the literature on innovation studies. On one hand, the literature of technological capabilities and their cumulative process is useful in analyzing the characteristics of biotech firms: how are these capabilities distributed? Are they balanced or not? and why? On the other hand, the literature of firms' internationalization strategies is relevant to understanding the diverse mechanisms and determinants that condition firms' interactions with foreign markets; particularly in those firms based in developing countries, where great attention has recently been paid to this literature. We will use the case of Mexican biotech firms to illustrate this phenomenon.

In this paper, we aim to analyze the relationship between the technological capabilities accumulation of Mexican biotech firms and their different types of internationalization strategies. There are few studies that approach it in a similar way (Gonsen 1998; Rodríguez, Gómez, and Ramírez 2015; Morales and Díaz 2019), so we want to contribute by investigating the conditions faced by biotechnology firms in developing countries and their possible opportunities in a subsystem dominated by international market dynamics, with a strong tendency towards market concentration.

The paper is structured as follows: in Section 2, we present a review of literature on the accumulation of technological capability, internationalization strategies and a characterization of Mexican biotech firms. Section 3 contains the analytical framework. In Section 4, we present the data and the methodological approach used to apply our analytical framework to the Mexican case. In Section 5, we discuss the results obtained and finally, in Section 6 we outline some conclusions and policy recommendations.

2. Literature review

In the following lines, we will present the set of literature traditions that we will use to analyze the internationalization process of Mexican biotech firms in agro-food and pharma industries. In order to do so, we will review the Technological Capabilities Accumulation (TCA) proposal and previous research on Latin American firms' internationalization strategies to understand how we could find interactions between them. Finally, we will characterize the biotech sector in Mexico. Acting like this, we will have all the components to present an analytical framework that will be applied to study the determinants of Mexican biotech firms' internationalization strategies. It is necessary to mention that in Mexico the issue of technological capabilities in biotechnology firms has been little analyzed (Gonsen 1998; Rodríguez, Gómez, and Ramírez 2015; Morales and Díaz 2019) given the complexity of having to build information. So in many ca,ses the use of surveys or case studies is used.

2.1 Technological capabilities accumulation (TCA)

Technological capabilities (TC) are the technical, managerial, and organizational skills that firms need in order to efficiently utilize the hardware (equipment) and software (information) of technology and to accomplish processes of technological change (Morrison, Pietrobelli, and Rabelloti 2008).

Identifying the TC through the taxonomy of Lall (1992) and Bell and Pavitt (1995) does not allow us to analyze the accumulation process of these capabilities. According to Dutrénit, Vera-Cruz, and Arias (2003), firms can follow different and sometimes uneven evolutionary paths of Technological Capabilities Accumulation (TCA). To analyze the TCA, Dutrénit, Vera-Cruz, and Arias (2003) propose a matrix

that distinguishes TCs based on primary activities (investment and production) and supporting activities. There are also four levels of TCA: one of technological capabilities of routine production and three (basic, intermediate, and advanced) of innovative technologies. The matrix classifies six technical functions, two for each type of activity: decision-making and control and preparation and execution of large projects for *Investment*; processes and organization of production and products for *Production*; and external relations and supply of capital goods for *Supporting Activities*.

TCA are the result of the complex interaction of micro- and macroeconomic elements to obtain new combinations of processes and products, influenced by the characteristics of the national system of innovation (Dutrénit, Vera-Cruz, and Arias 2003; Dutrénit et al. 2019).

The relationship between TCA and the internationalization process for developing countries has been studied in depth. The more critical (and useful) studies have pointed out that exposing these firms to international arenas is a double-edged sword: it could be an opportunity to learn and move forward in the TCA process, putting firms in contact with knowledge generated or applied in different contexts (Kuramoto Gonzalez and Kindl da Cunha 2012; Alvarez and Marin 2013); but it could also be a risk when facing strong competition that comes with advantages obtained abroad and uneven power relationships that could threaten domestic firms (Rodrik 2018; Narula 2015).

2.2. Internationalization strategies of Latin American firms

Cuervo-Cazurra (2007, 2008, 2016) has focused on the internationalization strategies of Latin American firms. He proposes an integrative model of internationalization (Cuervo-Cazurra 2007) that combines two of the main research traditions on this topic: the incremental internationalization model (Johanson and Vahlne 1977, 2017) and the eclectic paradigm (Narula and Dunning 2000). In this section, we will follow his lead in approaching internationalization strategies, adding two additional dimensions that are not fully considered in his research: exports as the first step of firms' internationalization process and the different possible ways of participating in Global Value Chains.

2.2.1 Exports

Not surprisingly, trade has been typically considered as the very first step to internationalization (Johanson and Vahlne 1977; Vahlne and Johanson 2017). It is associated with the requirement of low levels of capital and a sufficient TC level that allow firms to reach foreign markets, offering an initial beginning to achieving international learning processes. Even when the so-called *global born firms* have challenged this vision of trade as a starting point of internationalization strategies, the relevance of this activity for firms in developing countries cannot be neglected (Harrison and Rodríguez-Clare 2010).

In firms' internationalization continuum, exporting is normally considered at the lowest TCA level. In fact, through this strategy, learning process and TCA are recommended for firms from less developed countries (Harrison and Rodríguez-Clare 2010). Export activities are associated with lower commitment of resources (Agarwal and Ramaswami 1992; Slangen and Hennart 2007) and normally leveraged by (Cuervo-Cazurra 2008; Álvarez and Marín 2010): (i) the size of the domestic market, (ii) access to natural resources or low-cost labor and (iii) level of openness of foreign markets.

2.2.2 Latin American firms' multinationalization process

Cuervo-Cazzura's integrative model proposes a three steps sequence of value-added activities for Latin American firms' multinationalization processes (Cuervo-Cazurra 2007): (i) *start multinationalizing with marketing subsidiaries in all countries*, firms in this group leverage using the location advantage of producing in their home countries (which they would lose if producing abroad) to set up sales and distribution facilities in foreign countries; (ii) *start multinationalizing with production subsidiaries in all countries*, because of location advantages of the host country, accessing its assets or the difficulties of moving their products across borders, firms decide to establish production facilities abroad; and (iii)

start multinationalizing with marketing subsidiaries in some countries and production subsidiaries in others. The group that follows a combined strategy (mixing marketing and production activities) might act for different reasons: they could start with one activity (marketing or production) and then carry out the other accordingly (production or marketing) or evaluate host countries and determine what the best alternative is.

The formulation of this integrative model is based on the analysis of 20 cases of multinational firms in Latin America (the so-called *Multilatinas*). In the model, there is no explicit relationship between the stage of the multinationalization process and TCA, which is an open-end to further research. However, under proper institutional conditions, there is evidence of a direct effect of TCA on achieving more complex internationalization strategies (Álvarez, Fischer, and Natera 2013).

2.2.3 Participation in Global Value Chains (GVC)

GVC highlight the role of global producers and buyers in supporting learning and innovation for producers or service providers in developing countries through *upgrading*, and exploring their implications for development (Morrison, Pietrobelli, and Rabelloti 2008).

The concept of *upgrading* is closely related to innovation and has been defined as a process for value-added increase (Giuliani, Pietrobelli, and Rabellotti 2005). Firms achieve this in different ways, that is: process (Schmitz 2006), product (Gereffi 1999), functional (Bair and Gereffi 2001), or intersectoral upgrading (Humphrey and Schmitz 2002). Firms embedded in a GVC are supposed to have advantages in the learning and innovation process: they can learn from leaders and *upgrade* by creating or accumulating technological capabilities.

However, in the case of developing countries, as has been shown in several studies on Latin America, the accumulation of technological capabilities for upgrading in GVC is not necessarily achieved (Bair and Gereffi 2001; Pietrobelli and Rabellotti 2006). The change in the demands of the chains' leaders, which implies having more and better TC, has only allowed local companies, to remain as suppliers (De Marchi, Di Maria, and Gereffi 2017). This may be due to different conditions: the mobility of the technological frontier, the changes in supply requirements or the form of governance of the chain. It should also be noted that insertion in a global value chain has preconditions, for example a minimum absorption capacity and infrastructure and financial resources are needed (Fortwengel 2011; Choksy, Sinkovics, and Sinkovics 2017).

2.3 A characterization of Mexican Biotech firms

Industrial biotechnology requires high levels of R&D, is capital intensive and demands long periods for innovation. It can be divided into four main segments: R&D, product development,[1] manufacturing (pilot and market-level) and marketing and sales[2] (North Carolina Biotechnology Center 2009–2015).

Funding levels vary by sector since the highest requirements are for the development of drugs, especially due to the type of ingredients that are needed. While chemical products require large investments in infrastructure; the sub-segments organic chemicals, polymers and fibers, agrochemicals, food additives, detergents and cosmetics need significant investment in R&D (OECD 2009b). Also, biotechnology is associated with high levels of uncertainty and risk, so the banking systems have more strict requirements when granting loans and demand higher interest rates. This has forced firms to seek various financing mechanisms, such as: mezzanine financing, project financing, public funds, private equity financing, founding angels, business angels and venture capitalists (OECD 2009b; Festel and Boutellier 2008; Festel 2011).

The lack of access to financial resources has caused many firms to develop a scheme for the provision of technological services associated with biotechnology, which allows them to maintain and slowly capitalize certain projects. In the case of public funds, these are mainly granted to R&D, covering approximately 25–50% of the research costs (OECD 2009b). However, despite this, for startups and MNEs public funding is a very important part of their financing strategy. Although it is worth

mentioning that although there are companies capable of accumulating technological capabilities and generating incremental, process and/or organizational innovations, they allow them to compete at local or regional level, which is sometimes more feasible as a technological strategy given the lower levels of technological financing. However, in this work, we focus on the relationship between accumulation of technological capabilities and internationalization, which in principle requires higher levels of investment.

In order to provide a stylized categorization of firms according to their capital investment level, the OECD proposes the following biotech firm types (OECD 2009a):

(1) *Dedicated startups* – dedicated fundamentally to research and development (R&D). These companies act as knowledge providers. In most cases they develop and commercialize special technologies and their applications.
(2) *Dedicated small and medium-sized (SMEs) firms* – dedicated to R&D, as well as the production and commercialization of biotechnological processes and services.
(3) *Diversified SME* – mainly located in established industrial sectors like the chemical or food industry, serving already developed markets with highly specialized products. These companies are introducing step by step biotechnology processes and products into their markets in keeping with opportunities of growth, to reduce costs or to fulfill regulatory aspects.
(4) *Dedicated MNEs – t*his group normally does not use very high-tech but rather well established and over time optimized processes for traditional markets. Industrial biotechnology is one cornerstone in their technology portfolio and increasingly they are moving towards more sophisticated products and processes.
(5) *Diversified MNEs* – are mainly established companies from the chemical industry, agro-industry or food industry. Their strength is the broad and integrated technology portfolio which complements the industrial biotech processes and further technical resources as well as financial resources.

2.3.2 The sectoral composition of the biotech firms in Mexico

Biotech firms in Mexico are mainly in the areas of human and veterinary health, as well as agro-industrial and food (Morales and Chiapa in press) as follows: 28% are related to pharmaceuticals and human and veterinary health, 44% are related to agriculture, crops, services to agroindustry, pesticides, fungicides, aquaculture and forestry, 18% related to food and drinks, 5% chemistry and 5% related to the environment. There are different dynamics among all these sectors, and this has an impact in terms of their TCA and different strategies (Morales and Villavicencio 2015; Morales and Díaz 2019; Stezano 2019; Stezano and Oliver 2019). Firms in the agricultural and food sector include the production of staple foods (seeds, grains, vegetables and fruits), the industrial production of food and beverages, the industries that transform agricultural, livestock or fishing products, applying processes for their conservation or using them to produce consumer or intermediate goods for human or animal consumption, or to be used in other industrial processes (Amaro and Villavicencio 2015). On the other hand, in health sector, we find firms that produce vaccines, drugs and medical treatments for human and veterinary use. In Figure 1, we can see a representation of the sectoral distribution of biotech firms in Mexico.

According to Amaro and Villavicencio (2015), the development of scientific capabilities for biotechnology in Mexico has been very successful but has had limited results when it comes to TCA. Even with the efforts to promote linkages between industry and public education and research institutions – given that it is a technology strongly linked to science – the results have been scarce for various reasons (Villavicencio 2009, 2012), particularly due to the lack of policy coherence in its promotion. For instance, in 2000 the Mexican Special Program of Science and Technology 2001–2006 (PECYT) defined Biotechnology as a fundamental technology of great relevance for the country's development. However, this statement did not imply any specific strategy or prioritization for

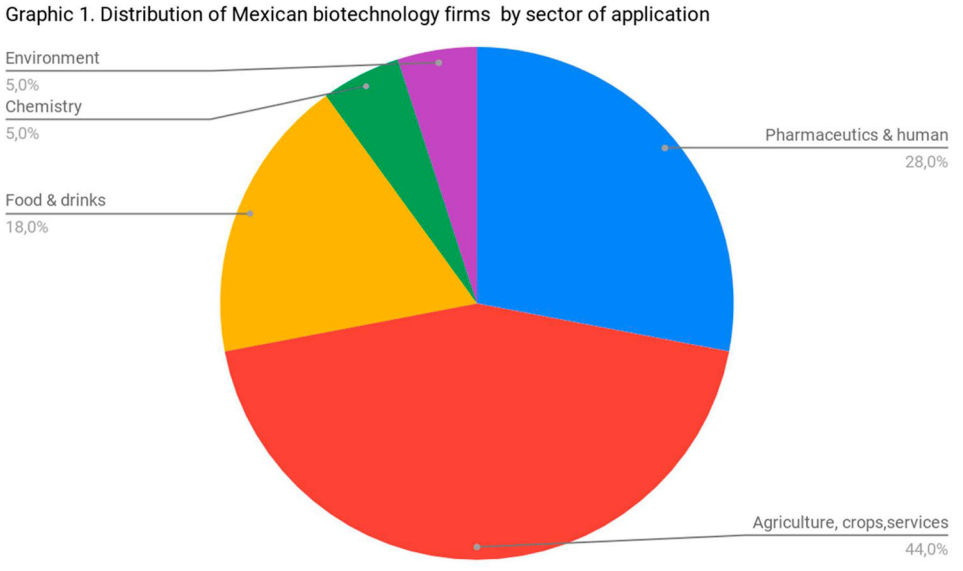

Figure 1. Distribution of Mexican biotechnology firms by sector of appication. Source: Authors' elaboration based on The First Survey of Biotechnology Development Firms in Mexico.

creating or strengthening biotech firms; it only came with a program focused on the promotion of biotechnology research activities in the oil, agricultural, and environmental application sectors (Gómez and Rodríguez 2008).

3. Analytical framework and hypotheses

In this paper, our aim is to analyze the relationship between TCA and Mexican biotech firms' internationalization strategies. In a nutshell, we want to study the interactions between different TC levels and the selected internationalization strategy in Mexican biotech firms from the agriculture, agroindustry, food and pharma sectors; and we have called agro-food.

We start from the TC matrix (Table 1) to identify different capability levels in Mexican biotech firms. Given the high level of intensive knowledge activities in this sector, we will not analyze the routine capabilities. We will also take a disintegrated approach to TC: we will not follow a sequential and progressive course (from Basic to Advanced TC level). For each of the three activities, we propose considering a heterogeneous path instead. This implies that firms could have a higher TC level in *Investment Capabilities* while exhibiting a lower level of *Production Capability*. With this, the assumptions of TCA as a homogenous process are relaxed and allow us to better characterize the complexity of high-tech firms, such as those related to biotechnology.

Another important dimension is firms' capital investment level, we established three categories: low, medium and high. As observed from the characterization of biotech firms (Section 2.3.1), the required capital investment is one of the main determinants of firms' activities and growth opportunities. The different strategies (whether national or international) are strongly correlated with firms' capital investment level. In fact, when analyzing the evolution of biotech firms, OECD documents use firms' capital level to define differentiated strategies and future trends (OECD 2009a, 2009b).

Finally, we integrate the internationalization strategies into the analysis, using exports, the different stages of multinationalization and participation in GVC. The different strategies are not mutually exclusive. Firms may follow one or more internationalization strategies simultaneously. In order to account for the possible outcomes of this dimension, we do not establish a linear path for firms' internationalization processes. As has been recently recognized by the advocates of the

Table 1. 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	Negotiating primary contract. Securing and disbursing financing. Officiating at opening ceremony.	Outline of preparation of initial project. Basic construction. Simple plan implementation.	Routine operation and maintenance of basic facilities. Improvement in efficiency with experience in existing tasks.	Replication of fixed specifications and design. Guiding QC 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
Capabilities that use existing production techniques						
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 of 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.

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

Uppsala Model, internationalization is a complex process that could not be determined *a priori*: it is path-dependent; persistently heterogeneous; open to novelty; and co-evolutionary between actors, environmental factors and levels of analysis (Vahlne and Johanson 2017).

Table 2 is a schematic representation of our analytical framework. Because of our non-deterministic approach, this proposal is flexible enough to identify a variety of TCA processes and related internationalization strategies in firms with different capital investment levels. We believe that this is suitable for Mexican biotechnology firms, since their trajectories show that their TCA depends not only on technical functions and activities, but also on learning processes and the national and global environment.

In this analysis, we expect to find high levels of complexity. Firms' learning opportunities are widely distributed and their TCA processes could follow many alternative paths. Also, in a developing country like Mexico (where there are difficulties in accessing financial resources and there have not been clear strategic policies to support these firms), firms' capital investment levels might be decisive for the implementation of their TCA processes and internationalization strategies. Therefore, we outline two hypotheses:

Hypothesis 1: TCA process does not follow a linear path in Mexican biotech firms; TC levels are heterogeneously distributed among the different activities.

Hypothesis 2: Firms with lower capital investment levels exhibit a lower level of TCA and less complex internationalization strategies (exporting activities, setting up marketing subsidiaries abroad or participating as suppliers of GVC); while firms with higher capital investment levels are associated with higher TCA levels and more complex internationalization strategies (establishing production facilities abroad and taking leadership positions in GVC).

4. Data and methodology

To investigate the validity of our hypotheses, a mixed methodological approach was used (Brewer and Hunter 1989; Greene, Caracelli, and Graham 1989): we combined quantitative data from a micro-level survey, information from interviews and documentary analysis. Our starting point is the database of *The First Survey of Biotechnology Development Firms in Mexico*, which was taken during 2014–2015, and contains relevant data on biotechnology in Mexico. We combine this information with in-depth interviews: (i) with managers and technical personnel of industrial biotechnology firms (people in charge of R&D, owners or CEOs of the company). Different interview guidelines (with a reference set of questions) was developed to ensure comparability while leaving room for open-ended answers, following a semi-structured approach.

The context of the industrial biotechnology firms and markets was analyzed through desktop research using public sources (for example, commercial data, websites and press releases). In addition, 20 case studies on biotechnology firms in Mexico were systematized to identify stylized facts. There were three complementary interviews with key persons in the industry to clarify open-ended questions. It is worth mentioning that all the companies analyzed are of Mexican national capital.

We followed a sequential approach to systematize the various sources of information, as follows.

(1) We segregated firms based on their sector and retained only those in agriculture, food and health (human and veterinary).
(2) We grouped selected firms based on the criterion proposed by the OECD (2009a). Out of the five categories, we grouped into three (from lower to higher level of investment): start-ups, dedicated and diversified small and medium-sized firms (SMEs), and dedicated and diversified multinational companies (MNEs). To classify firms according to capital investment level, we created the low, medium and high category. Since the level of investment required in human health can vary from that in agriculture, we used the data reported by the firms to obtain the sector-average investment: firms with capital investments below the average are located in the low group,

Table 2. An analytical framework to study Biotech firms' TCA and internationalization strategies.

Level of capital investment	Technological Capabilities Matrix						Internationalization strategy
Low	Investment		Production		Supporting Activities		
Medium	Facility user's decision making and control	Project preparation and implementation	Process and organization of production	Product	Developing linkage	Supply of capital goods	Export
High	*Technological Capabilities: Capabilities to generate and manage technical change*						Multinationalization stage
	Basics Intermediate Advanced	Basics Intermediate Advanced	Basics Intermediate Advanced	Basics Intermediate Advanced	Basics Intermediate Advanced	Basics Intermediate Advanced	GVC

Source: Authors' elaboration and modification based on Dutrénit, Vera-Cruz, and Arias (2003).

those around the average are assigned to the medium group and those above are placed in the high group. We validated these ranges with the help of two expert R&D managers in industrial biotechnology in Mexico.

(3) To identify the TC level, we used variables from the survey and grouped them to have a proxy variable for each TC category. Since the matrix in Table 1 was originally designed to analyze the manufacturing sector (Dutrénit, Vera-Cruz, and Arias 2003), we focused on the concept behind each dimension when using it to analyze the information from the survey.

(4) The internationalization strategy was identified as follows: (i) the export variable was directly taken from the survey; (ii) multinationalization processes and participation were taken from the survey (presence of foreign capital or subsidiaries in foreign countries) and identified through interviews and public information.

(5) Out of the 20 available cases, we selected 6 to present a series of detailed characteristics about the relationship between TCA, internationalization strategies and investment levels. With these 6 detailed cases, we do not aim at presenting a representative sample of Mexican biotech firms, we aim at offering an in-depth description of firms' internationalization process. We selected the cases with two criteria: (i) firms' sector and (ii) access to quality data.

In order to maintain confidentiality, the names of the firms will not be disclosed, and we will only refer to their industrial sector. In the case of start-ups, the one chosen is a firm dedicated to the production of technological solutions in food and nutrition and biofungicide. In the category SMEs, our subjects are a pharmaceutical laboratory producing biosimilars and a firm specialized in food. In the category MNEs, it is a firm that provides veterinary health and a firm focused on human health.

4. Results

Firm segregation processes from *The First Survey of Biotechnology Development Firms in Mexico* identified 48 biotech firms (out of the 53 available) in the agro-food and health sectors. We applied our classification (based on the OECD proposal) and identified 27% as startups, SMEs as 63% and 10% of them as MNEs. We applied the rest of the steps described in the previous section to only those 48 biotech firms. Industrial sectors with greatest development, use, and application are food, agriculture and pharmaceuticals.

Table 3 reports the summary of our results. *Start-ups* have a tendency to Basic TC. However, there is high heterogeneity among the different firms included in our data. Some *start-ups* exhibit advanced TC in *Investments* (facility user's decision making and control and project preparation and implementation) and one of the *Production* dimensions (process and organization of production). Similarly, another nurtured group has intermediate TC in the other *Production* activity (product) and in one *Supporting Activity* (developing linkages). The only activity in which we find a full concentration of Basic TC is in Supply of capital goods (a *Supporting Activity*). We found consensus in our interviewees about the effects of the constraints to access financial resources on the TCA process: *start-ups* are limited in attracting investors to develop innovation projects. This has relegated them to providing specialized technological services to Mexican firms and to act as suppliers of technological solutions for multinational companies. This is what we have called 'biotech maquila': *start-ups* have specialized human resources – with scientific capabilities at levels of international standards – but they lack financial capacity. This is the main reason why they place themselves in the GVC as knowledge providers. These firms do not take part in the stock market and rely heavily on public funding to generate infrastructure. Almost 30% of these types of firms undertake exporting activities, mostly through agreements with firms devoted to international commerce of specialized biotech products.

Mexican biotech SMEs have a clear tendency towards *Intermediate* (in the first place) and *Advanced* TC (Table 3). Nevertheless, they also show a heterogenous TCA path. This is expected since the majority of the firms are placed within this group. We observed a mixture of Basic and Advanced capabilities in *Production* and *Supporting Activities*. The two specific *Investment* activities

Table 3. Matrix of Biotech firms' TCA and internationalization strategies in Mexico.

Level of investment in capital	Technological Capabilities Matrix						Internationalization strategy
	Investment		Production		Supporting Activities		Export
Low							Multinationalization stage
Medium							
High	Facility user's decision making and control	Project preparation and implementation	Process and organization of production	Product	Developing linkages	Supply of capital goods	GVC
	*Technological Capabilities: Capabilities to generate and manage technical change**						
	Startups (% of firms)						
Low	B (63.63)	B (18.18)	B (9.09)	B (54.54)	B (72.72)	B (100)	Export (30)
	I (9.09)	I (45.45)	I (63.63)	I (45.45)	I (27.27)	I (0)	
	A (27.27)	A (36.36)	A (27.27)	A (0)	A (0)	A (0)	GVC Suppliers
	SMEs (% of firms)						
Medium	B (23.07)	B (0)	B (26.92)	B (15.38)	B (26.92)	B (7.69)	Export (50)
	I (76.92)	I (34.61)	I (30.76)	I (57.69)	I (69.23)	I (84.61)	
	A (0)	A (65.38)	A (42.30)	A (26.92)	A (9.09)	A (7.69)	Marketing subsidiaries
	MNEs (% of firms)						
High	B (0)	B (0)	B (0)	B (0)	B (25)	B (0)	Export (100)
	I (0)	I (0)	I (25)	I (50)	I (25)	I (0)	Marketing and production subsidiaries
	A (100)	A (100)	A (75)	A (50)	A (50)	A (100)	GVC Leader

*B: Basic Capabilities; I: Intermediate Capabilities; A: Advanced Capabilities. All figures show percentages of firms within the same group that express the corresponding attribute.

Source: own elaboration based on The First Survey of Biotechnology Development Firms in Mexico (2014–2015).

behave in opposite directions: we find Basic TC level in 'Facility user's decision making and control' (no firm in the Advanced TC level) and Advanced TC level in 'Project preparation and implementation' (no firm in the Basic TC level). Based on the interviews and case studies analyzed (Amaro, Corona, and Soria 2009; Amaro and Morales 2017; Amaro and Borja in press; De Gortari, Medina, and Cabrera 2017; Solleiro 2000; Ramirez and Uribe 2004), we observe that some firms are willing to delegate some of the investment decisions as part of the negotiation of R&D project agreements, but are very attentive to the nature and content of the R&D project that will be executed. In terms of internationalization strategy, we observed that 50% of these firms export mainly to Latin American, Asia and USA and some reach European Union markets. In this case, some SMEs start multinationalizing with marketing subsidiaries mostly located in Latin America. Leverage on a higher capital investment level is crucial to understanding Mexican biotech SMEs: they use contingency management to balance the possibilities of reaching production scale with the high costs and risks associated with the necessary R&D activities (Festel and Boutellier 2008).

Finally, most of MNE firms have Advanced capabilities in all categories. Even when this could be read as an encouraging result for biotechnology in the country, we should keep in mind that these firms only represent 10% of the total (5 out of the 48 firms studied), since they require high levels of capital investments. Nevertheless, despite their number, their presence is very relevant because they exhibit high enough TC levels to have leadership positions or be strong competitors in their GVC. Furthermore, they could generate mechanisms that contribute with spillovers or internal linkages that could allow firms in other segments to become suppliers and thus encourage their growth.

Table 3 presents information to support our *Hypothesis 1*, since we can observe a heterogeneous distribution of TC levels. It also provides information to endorse *Hypothesis 2*, since we observe higher

levels of TCA and more complex internationalization strategies as firms' capital investment level grows. However, Table 3 does not show Mexican Biotech firms' evolutionary path TCA (Dutrénit, Vera-Cruz, and Arias 2003). For this reason, we will highlight distinctive elements from case studies that have been carried out at company level (Morales, Amaro, and Stezano 2019, Stezano and Oliver 2019, Morales and Díaz 2019 and Morales and Chiapa in press). This information provides methodological complementarity between TC levels and international strategies that would be impossible to obtain with the survey alone and that is important for upholding our hypotheses.

In Table 4 we have summarized the most relevant information from selected case studies of Mexican Biotech firms. We aim to describe the TCA process and to show the TCA levels reached and the corresponding international strategy they have developed. In order to do so, we have chosen firms that exhibit the most advanced TC levels within their groups, since those are the ones that contain greater information about the transition through different phases of TCA.

Table 4 shows differentiated behavior for different groups of firms. In the analyzed *start-ups* we observe a strong relationship with universities and public research organizations in developing higher levels of TC. The TCA process is normally limited by capital investment levels and relies mainly on public funding. *Start-ups* internationalization strategies are limited to exporting (assisted by international commercializing firms) and participation as GVC suppliers of multinational companies based in Mexico. *SMEs*' TCA process is leveraged by previous production activities using mature technologies, which are the base for undertaking intensive R&D activities oriented at biotechnology. They combine private and public funding in their R&D projects and strong links with universities and public research organizations. *SMEs* internationalization strategies are more aggressive: they export and even establish marketing and sales subsidiaries abroad. Finally, *MNEs* exhibit advanced capabilities and behave at standard international levels: they combine private with national and international public funding to perform R&D activities and find an acknowledged position in their respective GVC.

An additional characteristic that could be observed from Table 4 is the niche strategy that Mexican biotech firms follow. In general terms, they have focused on niches forgotten by large multinational firms, where domestic or specific necessities in developing countries do not find solutions in GVC. Once again, the international dynamics has a great burden on firms' decisions and growth strategy (Yan et al. 2008; Morales, Amaro, and Stezano 2019). This fact calls for further research.

All in all, the available information lets us validate our *Hypothesis 1* (TCA process heterogeneity) and *Hypothesis 2* (relationship between TCA process, internationalization strategy and firms' capital investment level). Company's greater capacity to invest, develops higher levels of TCA and more complex internationalization strategies. Mexican biotech firms must increase their access to financial resources as a necessary condition for developing higher TC levels and competing on a global scale. This result helps us understand why firms from developing countries – such as Mexico – can achieve high levels of TCA in some areas and yet not be able to compete in global markets. It also has implications for public policies directed at these firms and for TC management at firm levels.

5. Conclusions

In this paper, we aim to analyze the relationship between technological capabilities accumulation of Mexican biotech firms and their different types of internationalization strategies. By reviewing the literature of technological capability accumulation and internationalization strategies for Latin American firms and the specificities of Mexican biotech firms, we propose an analytical framework that integrates: Investment, Production and Supporting Activities and different types of interactions with foreign markets (exporting activities, establishment of marketing or production facilities and participation in GVC). Because of the determinant effect of firms' capital investment level, we analyzed three different groups of firms: start-ups, small and medium-sized firms (SMEs) and multinational firms (MNEs).

Table 4. Relevant information from selected case studies of Mexican Biotech firms.

Firm type – sector (Information sources)	TCA process	TCA level	Internationalization strategy
Start-up – Food sector (First Survey of Biotechnology Development Firms in Mexico 2014–2015/Interviews with: (i) CEO and (ii) R&D Manager)	• University spin-off • First independent investment came from public funding. • TCA based on projects with domestic firms by using private and public funding. • Focus on process innovation and intermediate goods for the local food industry • Maintain collaborative networks with universities and public research organizations • Design and installation of pilot plant in collaboration with other start-ups • Recently certified as regular supplier of foreign firms based in Mexico.	Investment • Facility user and decision making and control: **Advanced**. • Project preparation and implementation: **Advanced**. Production • Process and organization of production: **Advanced**. • Product: **Intermediate**. Supporting activities • Developing linkages: **Intermediate**. • Supply of capital goods: **Basic**.	• GVC suppliers of two multinational firms based in Mexico (intermediate goods)
Start-up - Agricultural sector (Galindo et al. 2013; De Gortari, Medina, and Cabrera 2017; Amaro and Borja in press/ Interviews with: (i) CEO, and (ii) R&D Manager)	• Firm's entrepreneurs are two senior biotech researchers, from two universities. • R&D process was performed at university facilities, with public funding (pilot level). They licensed the resultant patent from the universities. • They executed applied research and product development using public funds and problem definition from the government. • Informal partnerships with local agro-producers to pilot testing, supported by public funding. This led to software development and instruments adaptations. • The firm was established to make technology transfer to the private sector. They generated a trademark. • Trademark was licensed to a multinational company.	Investment • Facility user and decision making and control: **Intermediate**. • Project preparation and implementation: **Advanced**. Production • Process and organization of production: **Intermediate**. • Product: **Advanced**.	• Exporting through multinational commercializing firm

(*Continued*)

Table 4. Continued.

Firm type – sector (Information sources)	TCA process	TCA level	Internationalization strategy
		Supporting activities • Developing linkages: **Advanced**. • Supply of capital goods: **Basic**.	
SME – Human pharmaceutical sector (Solleiro 2000; González 2001; Ramírez and Uribe 2004 /First Survey of Biotechnology Development Firms in Mexico 2014–2015 / Interviews with: (i) R&D Project Manager; (ii) Researcher/ Public information: webpage, scientific publications and specialized media)	• They depart from traditional pharmaceutical processes (chemical synthesis): active pharmaceutical ingredients (APIs) and medicine producers using licensed patents. • R&D department was established with own financial resources. • R&D projects were developed with universities and public research centers using own resources and public funding. • Development of biosimilar medicines (patent protected).	Investment • Facility user and decision making and control: **Advanced**. • Project preparation and implementation: **Advanced**. Production • Process and organization of production: **Advanced**. • Product: **Advanced**. Supporting activities • Developing linkages: **Advanced**. • Supply of capital goods: **Intermediate**.	• Exporting to 14 countries (4 continents)
SME – Food sector (First Survey of Biotechnology Development Firms in Mexico 2014-2015/Interview with R&D Project Manager/Public information: webpage and specialized media)	• Firm started as sugar retailers. • R&D project (funded with firm's own resources) was contracted to public university research laboratory to develop low calorie sweeteners. • R&D department and pilot plant was set-up using own resources and public funding. • R&D activities were publicly funded in most cases. • A first patented product, generating economic benefits.	Investment • Facility user and decision making and control: **Advanced**. • Project preparation and implementation: **Advanced**.	• Exporting final product to Europe, Latin America and USA. • GVC leading suppliers of food Multinational firms.

(*Continued*)

Table 4. Continued.

Firm type – sector (Information sources)	TCA process	TCA level	Internationalization strategy
	• They achieved a certification from the USA's Food and Drug Administration (FDA). • Other related patents were granted for different types of low-calorie sweeteners. • - They installed production facilities- all located in Mexico. They supply final and intermediate goods.	Production • Process and organization of production: **Advanced**. • Product: **Advanced**. Supporting activities • Developing linkages: **Advanced**. • Supply of capital goods: **Basic**.	
MNE – Veterinary pharmaceutical health (Villavicencio and Amaro 2014; Amaro and Morales 2017 First Survey of Biotechnology Development Firms in Mexico 2014–2015/ Interviews with: (i) R&D Manager; (ii) R&D Project Manager; (iii) Production Manager; (iv) Researchers/Public information: webpage, scientific publications and specialized media)	• They started with poultry farming (eggs). • Initial R&D projects (low investment with own resources) to generate medical solutions for their chickens' diseases. • Leveraging on their learning processes, they started a diversification strategy including other poultry farms and other animal farms. • Success in the diversification strategy led to creating 5 different divisions, one of them fully devoted to supplying veterinary health solutions. • R&D laboratory was established as a consequence of the veterinary health solutions expansion. • Collaborative R&D projects with universities, public research organizations and other firms, using a combination of private and public funding. • Generated patented products. • Patented product commercialization led to gaining a leadership position in the domestic market (they became suppliers of big Mexican firms). • Group success (all of the 5 divisions) call the attention of a multinational Mexican firm (in the human and veterinary pharmaceutical sector) and they went through a process of Merge and Acquisition (M&A).	Investment • Facility user and decision making and control: **Advanced**. • Project preparation and implementation: **Advanced**. Production • Process and organization of production: **Advanced**. • Product: **Advanced**. Supporting activities • Developing linkages: **Advanced**. • Supply of capital goods: **Advanced**.	• Strong participant of a GVC (mainly rooted in Latin America). • Marketing and sales subsidiaries in Latin American Countries (Argentina, Colombia, Chile and Perú).

(*Continued*)

Table 4. Continued.

Firm type – sector (Information sources)	TCA process	TCA level	Internationalization strategy
MNE – Human pharmaceutical health (De Roodt et al. 2005; Amaro, Corona, and Soria 2009; First Survey of Biotechnology Development Firms in Mexico 2014–2015/ Interviews with: (i) R&D Manager; (ii) Intellectual Property Manager; (iii) 3 Researchers/Public information: webpage, scientific publications and specialized media)	• They depart from traditional pharmaceutical processes (chemical synthesis): medicines producers using licensed patents. • R&D division was established with own financial resources fully oriented towards biotechnology development. • R&D projects were developed with universities and public research centers using own resources and public funding. • Development of antivenoms for bites from poisonous animals (scorpions and spiders) present mostly in developing countries. • They designed and set up production facilities in Mexico with international certifications (European Union, Latin America and USA). • They achieved a certification from the USA's Food and Drug Administration (FDA) to commercialize antivenom products. • World Health Organization granted an R&D project to develop antivenoms for African countries. • They designed an international commercialization strategy with marketing and sales subsidiaries in Latin America and partnerships in the rest of the world. • - They established a production facility in Spain to develop R&D activities and clinical trials. They use own resources and European funding to execute these activities.	Investment • Facility user and decision making and control: **Advanced**. • Project preparation and implementation: **Advanced**. Production • Process and organization of production: **Advanced**. • Product: **Advanced**. Supporting activities • Developing linkages: Advanced. • - Supply of capital goods: Advanced.	• Exporting final product to Africa, Europe, Latin America and USA. • GVC leader in human health (antivenoms).

Source: own elaboration.

We made use of a wide range of information for use with this analytical framework: *The First Survey of Biotechnology Development Firms in Mexico*, the systematization of 20 case studies, interviews with key persons in the industry (CEOs, R&D Managers, R&D Project Managers and Researchers) and public sources (scientific publications and specialized media). We focused on firms in the agro-food and pharmaceutical sectors. We found that *start-ups* tend to Basic TC but exhibit high heterogeneity levels in Investment, Production and the Supporting Activities that do not require high levels of capital investment. Because of their constraints for accessing financial resources, their TCA is limited, and they only provide specialized technological services to Mexican firms and act as suppliers of technological solutions for multinational companies. We call this the 'biotech maquila'. Mexican biotech SMEs have a clear tendency towards *Intermediate* (in the first place) and *Advanced* TC, with a heterogenous TCA path. 50% of these firms export and start multinationalizing with marketing subsidiaries mostly located in Latin America. Finally, most MNE firms have Advanced capabilities in all categories, they exhibit enough TC levels to have leadership positions or to be strong competitors in their GVC.

Based on these results, we confirmed the two hypotheses outlined: (i) the TCA process does not follow a linear path in Mexican biotech firms; and (ii) firms with lower capital investment levels exhibit a lower level of TCA and less complex internationalization strategies; while firms with higher capital investment levels are associated with higher TCA levels and more complex internationalization strategies. Biotechnology requires high capital investment levels that to a large extent determine the development and accumulation of technological capabilities. Not surprisingly, this technological sub-system is directed by multinational companies. The specialized infrastructure (laboratories and pilot plants), development of R&D projects, input, scaling and production – in addition to mechanisms of distribution, mechanisms for marketing and intellectual protection require access to financial resources. This is a complex scenario for firms in developing countries, like Mexican biotech firms.

According to the evidence shown, we believe industrial biotechnology firms in developing countries such as Mexico, find great limitations in accessing financial resources, which largely determines the accumulation of technological capabilities and their possibilities to reach foreign markets and be competitive globally. This limitation leads them to develop alternative technological strategies in order to survive, such as developing niche strategies (Yan et al. 2008; Morales, Amaro, and Stezano 2019). We call these strategies creative responses (Antonelli 2014; Robert and Yoguel 2014), where the creative effort is focused on the development of capabilities, restricted by the absence of capital to invest. Nevertheless, it is still of much importance for Mexican biotechnology firms to have access to public financing, since it has favored the accumulation of technological capabilities (Stezano and Oliver 2019).

It is obvious that a capitalization program is much needed for fostering Mexican biotech firms' TCA processes and development of internationalization strategies. There are a variety of mechanisms available that should be carefully explored (Mazzucato 2015): public-private partnerships, development banks and the establishment of state-owned firms. Because of the complex nature of biotechnology (a sub-system, not a sector), we strongly believe that context specific analyses are necessary for proposing a feasible strategy. In any case, we suggest that alternatives explored should follow the niche strategy already evidenced in Mexican biotech firms: this might be an opportunity to develop competitive firms oriented at collaborating in the solution of developing countries' issues.

Finally, we would like to briefly discuss some limitations of this paper. Data availability is the main problem we faced when trying to systematize information of Mexican biotech firms; we tried to solve this problem by combining different information sources and yet, we acknowledge that information completeness cannot be ensured. Specifically, we would have wanted to have the possibility of parametrizing firms' TCA evolution processes, looking for patterns that could reveal how internationalization strategies change over time.

Notes

1. There are particularities associated with each sector or industry, for example, in the case of pharmaceuticals, this segment includes both pre-clinical trials and clinical studies (divided into Phases I, II and III).
2. in this segment the distribution is also included.

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