Alternative technological paths in new NR-related industries: the case of seeds in Argentina and Brazil

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Abstract

The article examines the accumulation of innovation capabilities in natural resource-related (NR) industries. More, specifically it addresses the case of seed firms operating in Argentina and Brazil by investigating both the level of capabilities attained and the type of technological paths followed by the examined firms. To address these issues, the paper presents exploratory case studies of eight seed firms in Argentina and Brazil, including private domestic and foreign firms as well as a public company. Our study shows that highly innovative seed firms have emerged in Argentina and Brazil, in connection with the recent expansion of the agricultural sector in both countries. They have developed advanced level of scientific and technological capabilities as well as some outstanding innovative outputs, however, in some cases, results suggest that some kind of non-technological capabilities have limited their ability to fully capture the rent generated by their innovations. The analysis also shows that firms have opted for different technological paths. Regulatory burdens, market and knowledge discontinuities and context-specific agro-ecological requirements contribute to explain the technological paths chosen. These findings raise important issues for research and policy, as they are crucial for understanding the effective development potential of newly developed and fast changing NR industries in developing countries.

Keywords:

Natural resources; innovation capabilities; technological paths; seed industry; Argentina, Brazil.

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1. Introduction

A vast amount of understanding about the accumulation of innovation capabilities at the firm level in developing economies has been amassed over the last forty years. At the centre of such an understanding is the observation that technological capability accumulation tends to follow a cumulative and sequential path from imitative to generative technological change (Katz, 1987; Lall, 1992; Bell and Pavitt, 1993; 1995; Kim, 1997). Yet, the industrial coverage of the empirical analysis of capability accumulation has remained rather selective: according to Andersen *et al.* (2015), between 1994 and 2013, around 66% of innovation studies examined manufacturing industries and only 6%, out of a total of 10,529, dealt with natural resources (NR) and NR-related industries. We know little, therefore, about capability accumulation and innovation in NR-related industries. This is a major gap in knowledge because of the importance of NR activities for developing countries and, new recent insights that indicates that innovation dynamics in NRs may take rather different forms as compared to manufacturing and service industries (Andersen, 2012; Dantas and Bell, 2011; Iizuka and Katz, 2010; Marin *et al.*, 2015; Marín and Stubrin, 2015; Pérez, 2010; Smith, 2007; Ville and Wicken, 2012).

Focusing on the case of the seed industry in Argentina and Brazil, the overall objective of this article is to contribute to understanding of opportunities for the accumulation of technological capabilities in NR-related industries in developing countries. Our analysis is based on the framework developed by the literature on technological capabilities (Bell and Pavitt, 1993; 1995; Katz, 1987; Kim, 1997; Lall, 1992), which has been adapted to incorporate specificities of the seed industry.

The seed industry is a very interesting case to study because it is a relatively new industry displaying recent important market, technological and institutional discontinuities. Regulations are a contested terrain in permanent evolution. Furthermore, a single technological approach has not been accepted in all markets, and knowledge is continuously evolving and questioning the supremacy of existing approaches. A single best technological approach to innovate in seeds, therefore, has not been consolidated yet, and alternative market and technological approaches co-exist opening opportunities for different types of firms to attend different and new niches.

To be able to take advantage of these opportunities firms do not only have to make decisions about the amount of resources devoted to technological learning, but also about the technological path and market approach to be adopted. This aspect of the capability building process has been often neglected in the literature on technological capabilities of firms from developing countries.

This article aims to advance our understanding of this particular dimension of the capability building process by investigating both the *level* and the *type* of technological paths followed by seed firms operating in Argentina and Brazil. To address this issue, the paper presents an exploratory study of eight seed firms in Argentina and Brazil, including private domestic and foreign firms as well as a public company. These two developing countries are interesting cases, not only for their prominent role in world agricultural production, but also because they have pioneered the adoption of technology-intensive inputs in NRs industries.

We propose to explore the following research questions in this article with the objective of understanding the opportunities for capability accumulation in the seed industry:

1. What are the technological paths followed by the different types of firms examined in Argentina and Brazil?
2. What level of technological capabilities were achieved by firms in the different paths?
3. What kind of capabilities are required to purse and nurture the different paths?
4. Which factors affect the decisions of firms regarding the path to follow?

The results suggest that a vibrant domestic seed industry has emerged in Argentina and Brazil, in connection with the recent expansion of the agricultural sector in both countries. Interestingly, we also found that firms have opted for different technological and market paths with a relatively high level of success. Whereas one of the domestic firms has achieved an advanced level of capability in the transgenic paths, all the others have accumulated advanced capabilities in non-transgenic technological paths. Interestingly also, although large MNCs are very committed to the transgenic path at a global scale, the subsidiary analysed in this article has achieved a low level of capability in this technological path in the local market.

Finally, the analysis shows that besides the classical challenges related to innovation (e.g. developing R&D capabilities, skills, absorptive capacities, etc.), in this industry, domestic firms possessing advanced levels of technological capabilities face also significant challenges regarding the acquisition and development of some non-technological capabilities which are necessary to effectively take advantage of the technological capabilities in the market. These are, for instance, capabilities that allow them to deal with regulations, to patent and defend their IPR rights, to commercialise their products in different markets, etc. Our findings suggest that current weakness in this particular kind of non-technological capabilities limits the ability of technologically advanced domestic firms to fully capture the rent generated by their technological innovations and/or to diversify paths.

The paper is structured as follows. Section 1 outlines the conceptual framework guiding the analysis of empirical evidence. Section 2 introduces the research methods and the case study companies. Section 3 provides an overview of the sectoral context of the cases by discussing recent developments in the global seed industry and, in particular, in Argentina, Brazil. Section 4 presents the empirical evidence reporting on the co-existing technological paths followed by studied firms in Argentina and Brazil. Section 5 discusses implications and questions for future research. Finally, in Section 6 concluding remarks are offered.

2. Innovation Capabilities in a Context of Knowledge and Market Discontinuities: A Conceptual Framework

Building upon Bell and Pavitt (1995), technological capabilities are defined here as the collection of resources, skills and knowledge bases possessed by firms that can be deployed to generate and manage technological change. It is well understood in the extant literature on capabilities in late industrialising economies, that there is a great variation both among firms and within single firms over time in the levels of complexity of the technological changes they are able to introduce (Ariffin and Bell, 1999; Ariffin and Figueiredo, 2006; Bell and Pavitt, 1993; Dantas and Bell, 2011; Fagerberg and Godinho, 2005; Fagerberg *et al.*, 2010; Figueiredo, 2001; 2003; Hobday, 1999; Hobday and Rush, 2007; Katz, 1987; Kim, 1997; Lall, 1992). Technological change ranges from minor modifications in products and processes to major innovations that contribute to push forward the technological frontier and regulations, among other things. Following this well established approach in the capability literature, as the first step for the development of our framework, we generically classify technological capabilities from low to high in accordance to their complexity: i) basic; ii) intermediate and; iii) advanced.

The pattern of accumulation of capabilities and innovation, however, differs across sectors, which are characterised by very specific 'technological regimes' and dynamics of change (Castellacci, 2007; Malerba, 2002; 2007; Malerba and Orsenigo, 1997; Peneder, 2010). As discussed in the introduction, the seed sector is currently characterized by substantial knowledge and market discontinuities, as a consequence of the massive advances in biological sciences and the advent of biotechnology in the 1980s[1] as well as the fast changing and conflicting consumer attitudes. As a consequence of these, a single best option to innovate in seeds has not consolidated yet, and a diversity of options and alternative technological approaches co-exist. In order to grasp this sector-specific characteristic, we propose to widen the generic capability framework to include multiple technological approaches and possible firms' technological paths of capability accumulation (see Figure 2).

The best known of these technological approaches is that of genetic manipulation (see Table 1). Nevertheless, advances in molecular biology have also allowed to improve classical phenotype selection (based on plants' observable characteristics) by using genetic information (genotype selection) in the breeding process (see Table 1). Genotype information (obtained by biotechnological tools) allows breeders to anticipate and explain plants' phenotype, and to significantly shorten the length and to increase the efficacy of the breeding process[2]. Something similar has happened with other traditional techniques, such as mutagenesis, which can now be performed with higher levels of efficiency and outstanding results using biotech tools.

Seed companies and public institutions, thus, can now choose between different approaches to invest in the search of new features for seeds (such as resistance to certain diseases or weather conditions; higher productivity, etc.) and in which paths to build up capabilities. They can invest in the discovery of genes from different species to look for characteristics that are unknown within a species –i.e. using transgenesis–, or invest in equipment, infrastructure and skills to perform crossbreeding or mutagenesis activities assisted by the most advanced biotechnology tools.

Given that new genetic constructs obtained by transgenesis have to be "pasted" into existing varieties, which can only be obtained with crossbreeding, it is often emphasized the complementary nature of the different approaches. Nevertheless, to the extent that the different approaches can deliver similar solutions to the same agronomic problems[3] we understand that they are also competing. Besides, it seems important to distinguish them and emphasize their competing nature given that they differ markedly as regards costs, regulatory frameworks, IPR restrictions, market´s acceptance and application environments, among others.

Very large firms have more chances to invest in more than one of the approaches at the same time to search for new characteristics. However, given that resources are limited, and that the knowledge, market and regulatory requirements of each approach are very different, as well as the non-market capabilities medium-sized companies usually privilege one or two technological paths to perform their main technological efforts to accumulate capabilities.

Table 1
Co-existing technological paths in the seed industry

1) Crossbreeding: based on sexual recombination of parents to introduce improvements. Genetic modifications for plant varieties improvement –including both conventional breeding and molecular breeding techniques– are carried out at the organism level. This involves normal mating processes, but manipulated through human selection of the parents and of their offspring so that evolution is directed towards the production of crops with desirable characteristics.
2) Mutagenesis: based on genetic improvement implanting genes from the same species, or a sexually compatible partner. Past knowledge of causes of mutations (such as exposure to radiation or extreme temperature), known as mutagens, are harnessed to generate intentional changes in the genetic make-up of a cell or plant tissue.
3) Transgenesis: based on genetic improvements carried out at the genetic level through the implantation of genes from different species (mostly from bacteria) or engineered genes. This process is carried out through genetic engineering techniques, which use DNA from different sources, and combine them into one molecule to create a new set of genes. This DNA is then transferred into an organism, giving it modified or novel genes.

Source: own elaboration

Figure 2 summarises our approach to explore capability building in the seed industry, which identifies three possible technological paths that firms can follow with different levels of capabilities. Transgenesis is sometimes represented as the superior of these approaches (FAO, 2004; Jauhar, 2006; 2010; Moose and Mumm, 2008; Sense about Science, 2009; Smith, 2000). Nevertheless, as we understand that there is not enough evidence to classify it as superior (see Box 2), in our framework, we use the nature and level of complexity of the innovative efforts carried out by firms within each path as evidence of different levels of capabilities–i.e. what type of technological efforts are carried out by firms and which outputs are obtained and delivered into the market.

Box 1
Is transgenesis the superior approach?

The main argument supporting the position that transgenesis is the superior option is largely based on the fact that this technique exploits advanced scientific molecular biological knowledge. Yet, the same bodies of advanced knowledge are being used to support cross breeding and mutagenesis too, enhancing the speed and precision of seed innovation (Beddington, 2010; Biochemical Society, 2011; McCouch *et al.*, 2013; Morrell *et al.*, 2011).. As to the claim that genetic engineering can improve the *outcome* of seed innovation it is

striking that this is based largely on expectations about what the technology may be able to achieve in the future (e.g. Smith, 2000). For the time being, the traits obtained through genetic engineering can often be achieved with other techniques (Arundel, 2001; Brumlop and Finckh, 2011). On the contrary, some complex 'quantitative' traits, such as those improving crop yields, which can be modified with cross breeding techniques cannot be achieved through genetic engineering (Fernie *et al.*, 2006).

Within the crossbreeding path, firms with basic capabilities are those that rely on the observation of plants' phenotype and basic scientific knowledge (i.e. the external appearance and performance of the plant), which makes the process of development of a plant variety slow, uncertain and difficult to control. Firms with an intermediate level of technological capabilities still rely on cross-pollination of the parents to initiate sexual recombination. However, they are able to identify and carry out some type of genotype selection (i.e. using molecular markers developed by others) which requires well-equipped experimental facilities. Firms with advanced crossbreeding capabilities are able to apply biotechnology knowledge on genomic selection and possess experimental facilities necessary to exploit this knowledge. For instance, they use molecular markers developed by themselves to assist in the selection of desirable genetic traits and in vitro techniques and tissue culture for propagation. These types of techniques significantly increase the possibilities of controlling the breeding process, thus reducing hazard and developing time[4]. The most advanced biotechnology tool to be used in the cross-breeding path is 'genomic selection'. This technology requires advanced technological capabilities in molecular biology and genetics, high investment levels as well as strong capabilities in crops' agronomic characteristics. This technology is widespread among big world-leading seed firms, allowing them to perform sexual recombination using molecular breeding assisted by bioinformatics.

Firms with basic level capabilities in the mutagenic path are able to produce a modification in plants' DNA by exposing them to physical or chemical agents (such as radiation or nitrous acid). Most seed companies have the knowledge and technological capabilities necessary to pursue this type of activities. However, substantial gains in productivity and precision can be gained by using the more sophisticated techniques of sequence analyses indicating an intermediate level of capabilities. Advanced capabilities involve the use of a molecular technology named TILLING (Targeting Induced Local Lesions in Genomes), which requires frontier genetic engineering knowledge and specialized equipment.

Finally, within the transgenic path, firms with basic capabilities are those capable of operating with genes obtained by other firms through more advanced transgenic techniques. They have the capacity to insert transgenic traits into their own plant varieties. Firms with intermediate capabilities possess skills to develop process-related technologies. However, they lack the capabilities to develop transgenic events on their own. Firms with advance transgenic capabilities are those able to identify genes (that code for certain desirable traits), isolate them and create new traits by incorporating the isolated genes into plant varieties. R&D efforts at the frontier within this path are, therefore, based on knowledge of genetic engineering and molecular biology.

Figure 1
Levels of innovation capabilities at co-existing technological paths in the seed industry
Source: own elaboration.

3. **Research Methods**

3.1 *Multiple-case studies research strategy*

A firm-level multiple-case study research design was adopted in this study (Yin, 2009). Qualitative methods are built around experiential understanding (Stake, 2010) and allow for a better grasp of the interaction between variables in a great level of detail as well as the identification of causal relations in this particular empirical context. Furthermore, the case study strategy is suitable to enlighten situations in which the intervention being evaluated has no single set of outcomes (Yin, 2009). The research design was motivated by the objective of the study to identify paths of capability accumulation followed by companies in the seed industry. The multiple-case approach allowed the comparison of the types and levels of capabilities attained by firms in the various technological paths.

A purposive sampling strategy was applied to select the cases, guided by the research questions and the conceptual framework discussed above (Miles and Huberman, 1994). Two basic criteria underpinned the sample selection: i) firms had to be engaged in innovation activities; and ii) the sample had to contain different types of firms (i.e. private domestic firms, MNC subsidiaries and public firms). Existing documentation and open-ended interviews conducted with key informants during a pilot phase allowed for the identification of eight firms in Argentina and Brazil, which seemed to fulfil the sampling criteria. Box 2 presents the main features of the selected companies.

Since the analysis deals with units operating in the two countries under examination, in the case of MNC subsidiaries the focus was exclusively put on their activities and knowledge assets in the host country, not those of their parent companies or other fellow subsidiaries.

Box 2
Brief description of the cases

Bioceres is a relatively small locally-owned Argentinian firm established in 2001, employing more than 100 people in 2015 (60% of which are researchers) with sales over US$ 65 million per year. The company was created by a co-operative of 23 agriculture producers linked to two Argentinian agricultural trade organisations: the Argentinian Association of Seed Producers and the Argentinian Association of Regional Consortia for Agricultural Development. It is supported by several public funds and it operates strongly linked to different scientific institutions, like the

Agency of Science and Technology and National Scientific and Technical Research Council (CONICET). It is mainly devoted to the transgenic path, but it also carries out crossbreeding activities, and develops, produces and commercialises seed varieties (e.g. wheat, soybean) and hybrids (e.g. maize, sunflower) and Chymosins based on plants.

Nidera Argentina was, at the time of the fieldwork, an Argentinian-Dutch MNC. Since 2014, the company is controlled by China's largest grain trader, the state-owned company Cofco Corp. Nidera Argentina was founded in 1929, whereas the seed unit was created in 1990. In Argentina, it employed 1200 people in 2015. It focuses both on the mutagenesis and crossbreeding paths and develops seeds for different crops (such as sunflower, wheat, soya and corn). It also produces, conditions and sells its own seeds. In addition, it produces vegetable oils, fertilizers and bioenergy. In Argentina, in 2014 the company accounted for 39% of the soybean market, 20% of the corn market, 28% of the wheat market and 21% of the sunflower market.

Sursem is a small-sized Argentinean seed company founded in 1989. Between 2008 and 2011, a foreign investment fund, Pampa Management, which has a representation in Argentina through Pampa Capital, invested around US$ 35 million to re-structure the firm. The company had 250 employees in 2014. It mainly operates in the crossbreeding technological path and develops, produces and commercialises seeds. Its main products are seed varieties (e.g. wheat, soybean) and hybrids (e.g. maize, sunflower).

Don Mario is an Argentinian MNC founded in 1982 that has established subsidiaries in six countries (Brazil, Uruguay, Paraguay, Bolivia, South Africa and the United States). The company focuses on the soybean seeds market. In 2013, had a share of 48% of the Argentinean soybean seed market and 35% of the whole Latin American market. Overall, the company has 700 employees and an annual turnover of US$ 220 million. The company specialises in the crossbreeding path and perform seed development and production of soybean seeds.

Embrapa (Brazilian Agricultural Research Corporation) is a state-owned enterprise associated to the Brazilian Ministry of Agriculture Livestock and Food Supply. It was founded in 1973 to conduct agricultural research and development. It employed 9600 staff in 2014, 520 of which were dedicated to the seed business. It is organised in product, thematic and regional units, including the soybean, maize and sorghum, and wheat units. Embrapa operates in the crossbreeding and mutagenesis paths to develop and produce seeds for various crops such as soybean, maize, cotton, wheat, sorghum, and vegetables.

Syngenta Brasil is the subsidiary of the Swiss MNC Syngenta, an agribusiness company, established in 2001, after the merger of Novartis Agribusiness and Zeneca Agrochemicals at a global level. In 2015, it employed 1800 people in Brazil. The Brazilian subsidiary of Syngenta is dedicated to the production of soybeans, maize, vegetables and flowers as well as agricultural inputs such as fungicides, herbicides, insecticides and seed treatment. Seed development in Brazil is focused on the crossbreeding path. The company has three seed processing units located in the states of Goias, Minas Gerais and Sao Paulo.

Coodetec (Central Cooperative of Agricultural Research), a seed company operating in Brazil and employing 700 staff, was established in 1995, when the Organization of Cooperatives of Parana State decided to extend its research and development area on hybrids and new varieties. Based on the crossbreeding path, the firm is focused on the genetic advancement of the three main crops in Brazil: maize, soybean and wheat. In January 2015, Coodetec was acquired by Dow AgroSciences.

TMG is a medium-sized Brazilian seed company founded in 2001. It is controlled by Unisoja (which owns a share of 70% of the company), an association of seed producers of the Mato Grosso State, and TGX, a research organization focused on genetics. It employs 300 personnel. The company relies on the crossbreeding path to develop and produce soybean and cotton seeds and also provides genetic services to other seed companies. In the Brazilian soybean market, it has the third largest market share with around 17%. Having started to sell cotton seeds in 2013, in 2015 it accounted for 16% of the cotton seed market. In the near future, the company plans to also offer their own maize varieties in the local market.

3.2 *Data collection*

In order to ensure data triangulation, information was collected from multiple sources within and outside the examined firms (Yin, 2009). Qualitative and quantitative data were combined. Data-gathering efforts sought to obtain information about the innovative efforts (e.g. R&D and engineering investment, directions of search and technological paths being pursued), technological assets or resources (e.g. genes, germplasms banks), and innovative outputs (e.g. patents, registered varieties, innovative products) of the case study firms.

First, we obtained data on patents and plant variety protection certificates granted to the selected firms, providing information about product innovations introduced by them. Information on patents granted to the selected firms was retrieved from the European Patent Office database, whereas data on the plant varieties certificates was collected from the national cultivar offices databases.

Second, 25 in-depth interviews were conducted with managers, engineers and R&D personnel of the eight selected companies. The fieldwork was conducted in two phases: firstly, from August 2009 to September 2011 and, secondly, between July and December 2014. On average, firms were visited twice. Most interviews lasted two hours. They were semi-structured and followed a research protocol which included an interview guideline addressing three types of issues:

i. *technological capability issues*: the types of resources/assets, skills, knowledge bases that the firm possessed, the innovative efforts it carried out to change technologies and innovative outputs;

ii. *institutional issues*: regulatory conditions and barriers affecting firms' innovative behavior;

iii. *background issues*: business strategies, main products, clients, and partners, etc.

In addition to the interview guide, the research protocol contained two sets of guidelines for the interviewers. The first one was a generic technological capabilities framework derived from the existing literature, detailing the levels of innovation capabilities in terms of the degrees of complexity of innovative efforts and outputs. The second was a capability framework adapted to the specificities of the seed industry (see Figure 1) that was elaborated during the pilot phase of the study based on interviews and interactions with industry experts (see Section Multiple-case studies research strategy). The capability framework contained concrete illustrations of the types of resources/assets, skills, knowledge bases, innovative efforts and outputs relevant to firms operating in the seed industry at different levels of complexity. This guided the interviewers about key specific issues to be explored in the interviews. After face-to-face interviews, follow-up questionnaires were sent to interviewees in order to collect specific information on each of the main issues detailed above.

Outside the companies, information from industry experts, business associations, universities, research centres and government units was gathered through both open-ended interviews and a closed seminar held in 2009[5]. The seminar was organised in the context of the project and representatives of the main companies were invited to debate together with academics about the future of the seed industry. The interviews and exchanges with industry experts occurred before and in parallel with the firms' interviews, and fed into the latter by helping to refine the framework guidelines and interview questions used in the interviews.

Finally, evidence from documentary sources was also collected to corroborate and complement information from interviews. We obtained specialized documents, company reports, and accounting sheets provided by the firms. In addition, academic articles, websites and articles published in trade magazines and newspapers with information on the seed industry were examined.

3.3 *Data Analysis*

The analysis of the empirical evidence was guided by the conceptual framework (Section 1) and applied the innovation capabilities scale described in Table 2. For each case study firm, the empirical information was coded and classified in a matrix depicting the main categories comprising innovation capabilities, such as types of resources/assets, skills, knowledge bases, innovative efforts and outputs. We then compared the attributes of each firm in the different categories with the technological capability framework to arrive at a position for each firm in the capability levels represented in the framework. This was followed by a cross-case analysis in which we compared the paths of capability accumulation of the different firms in terms of capability levels attained and technological paths followed. As a result, we built a matrix summarizing the level of technological capability of different types of firms.

It is important to stress that the capability scale only grasps the capabilities of firms in the field of technological activities. As in the conventional technological capability framework, the capacity –or lack of capacity– of the company to commercially exploit its technological outputs is not considered as an attribute to distinguish technological capabilities. The scale has not been conceived and, therefore, it is not capable of assessing the economic performance of the analyzed companies. This entails that firms might be considered to have advanced technological capabilities, even if they have a low market share or are not able to commercialize their own products in global markets.

Companies were classified with advanced technological capabilities if they performed both R&D in the technological frontier, utilising state of the art equipment, processes and technologies *and* if they managed to obtain significant technological outputs through these innovative efforts.

For the case of the transgenic and mutagenic paths we used patents as an indicator of innovative output. In the case of the crossbreeding path, however, this is not a good indicator of innovation, given that plants and varieties cannot be patented. In this case, we used the information collected in the interviews with the companies' managers and key informants about innovative outputs and the number of registered varieties in the National Registry of Cultivars (RNC) in Argentina and Brazil. In these countries, new seeds that are traded have to be certified as reaching minimum standards of genetic purity, identity and quality. This is a good indicator of innovation, as all new plant varieties registered have to be novel and distinct from all other existing registered and traded varieties. The RNC contains information on the name owner of the plant variety, the year of registration in the RNC, the year of registration in the National Registry of Property of Plant Varieties (RNCP)[6] (if applicable), the country of origin of the variety, and, only for some crops, other technological characteristics of the cultivars (for example, whether the cultivar has transgenic traits). The RNC in Argentina covers the period 1977-2013, whereas in Brazil, data collection on new varieties registration started in 1998. In this paper we covered the period 1998-1013.

Table 2
Technological capability matrix in the seed industry

Levels Technological paths	Basic	Intermediate	Advanced
		INNOVATIVE EFFORTS	
Transgenesis/Mutagenesis	R&D lab dedicated to paste existing genetic constructs. Capacity to expose a plant to physical or chemical agents (such as radiation or nitrous acid) in order to produce a modification in the plants' DNA.	R&D activities oriented to develop genetic process technologies. Capacity to develop models, algorithms and tools in bioinformatics and computational biology for genomic research (e.g. sequencing, comparison, prediction).	R&D activities oriented to the identification of genes. Firms are able to identify genes (that code for certain desirable traits), isolate them and create new events by incorporating the isolated genes into plant varieties. Application of molecular technologies (e.g. TILLING -Targeting Induced Local Lesions in Genomes) in performing mutagenesis that requires frontier genetic engineering knowledge and specialized equipment.
Crossbreeding	Breeding mostly based on phenotype selection for the development of new plant varieties. R&D activities in selection processes of	Breeding based on phenotype and genotype selection using molecular markers developed by others agents.	Capacities to exploit synergies between biotech, agronomic and field capacities. R&D activities on molecular markers to assist in the

	cultivars or development of varieties adapted to very specific and a few geographic regions. Development of statistical models and analysis to conduct seed performance evaluation. Development of procedures for access and preservation of plant germplasm. Limited germplasm banks and capacities to exploit it.	Well-developed experimental facilities necessary to test different varieties in different locations. Relatively rich germplasm bank and capabilities to exploit it. Firms are capable of developing and managing a germplasm bank or collection of genetic resources for an organism. Implementation of processes to improve adaptability and stability of cultivars under different and specific environmental/regional conditions. Implementation of processes to improve cultivars by segregation (e.g. pedigree, population [bulk], genealogical modification [SSD - single seed descent] and simple backcrossing).	selection of desirable genetic traits. Capacity to develop molecular markers and other biotech tools to assist the breeding process. Biotechnology knowledge on genomic selection. World-class testing network, with facilities in different countries. World-class germplasm banks and advanced capabilities to exploit it. Advanced data bank and specialist applications to mapping and analysing the use of seeds at regional or world levels. R&D activities in tissue culture for obtaining genetic material free of pathogens (viruses) or specific diseases for artificial propagation and control

INNOVATIVE OUTPUTS			
Transgenic/Mutagenesis	No patents	At least one patent on processes related to genetic engineering applied to crops.	At least one significant patent on product, i.e. genetic constructs
Crossbreeding	Low share of total registered varieties. (Less than 5%) No significant innovations beyond adaptations of other companies' innovations to local agro-ecological conditions.	Medium rank share of total registered varieties. (Between 5 and 15%) Localized standard innovations (e.g. disease resistances).	High share of total registered varieties. (More than 15%) Significant innovations that allow reaching high market shares.

4. **The Context**

4.1 *Industry size, organization and capabilities*

Argentina and Brazil are heavily specialised in agricultural production, and are among the greatest food-producing and food-exporting countries of the world. Brazil has the fourth largest market of seeds in the world (after USA, France and China), valued in US$ 2625 million (2012); Argentina has the ninth largest seed market valued in US$ 990 million (see Table 3). The position of Brazil and Argentina as seed exporters is 14th and 16th, respectively.

In Brazil, there are over a thousand seed developers and multipliers listed in the National Register of Seeds and Seedlings (RENASEM). However, only 137 firms invest in breeding programs in the country. For "platform crops" –cotton, maize and soy– less than a hundred different firms are responsible for all genetic material listed at National Register of Cultivars (*Registro Nacional de Cultivares*). Data from the Argentine Seed Association (ASA) indicates that in 2012 there were registered over three thousand companies involved in the multiplication, production, processing and packaging of seeds for agricultural use in the country, but only around 40 of these companies develop seeds.

Between 1999 and 2013, Argentina and Brazil registered 2303 and 3741 varieties, respectively. Maize and soy are the most important crops in both countries but sunflower and wheat are also important, particularly in Argentina (see Table 3).

Table 3
Importance of the seed market per country
(2012; US$ million)

Country	Seeds			
	Estimated market value	Total exports of seeds for sowing	Total varieties registered per year (1999-2013)*	Distribution of registrations (1999-2013)
Argentina	990	150	153 per 1000 hectares**	Maize: 47.6% Soy: 23% Sunflower: 19.8% Wheat: 7.8% Cotton: 0.9% Rice: 0.9%
Brazil	2626	165	249 per 1000 hectares	Maize: 54% Soy: 27.4% Sunflower: 6.3% Wheat: 4.6% Cotton: 3.8%

				Rice: 3.8%

Sources: International Seed Federation, Instituto Nacional de Semillas (Argentina), Registro Nacional de Cultivares (Brazil).

* The following seeds are covered: maize, soy, wheat, sunflower, cotton and rice.

**Although the Argentinian register office opened in 1979 and the Brazilian in 1998, averages for each country were calculated for the same time period (1999-2013). In Argentina, a total of 3764 varieties were registered between 1979 and 2013. In Brazil, a total of 4557 varieties were registered between 1998 and 2013.

The Brazilian market is dominated by two types of players: MNCs and the public company Embrapa. Four MNCs –Monsanto (13.8%), Dupont (10.7%), Syngenta (6.5%) and Dow (4.8%)– and, Embrapa (12%) explain 48% of the registered varieties. In Argentina, although MNCs have gained a prominent position from the 1990s, domestic firms and the National Institute for Agricultural Technology (INTA) dominate the market, with more than 55% of the new varieties registered.

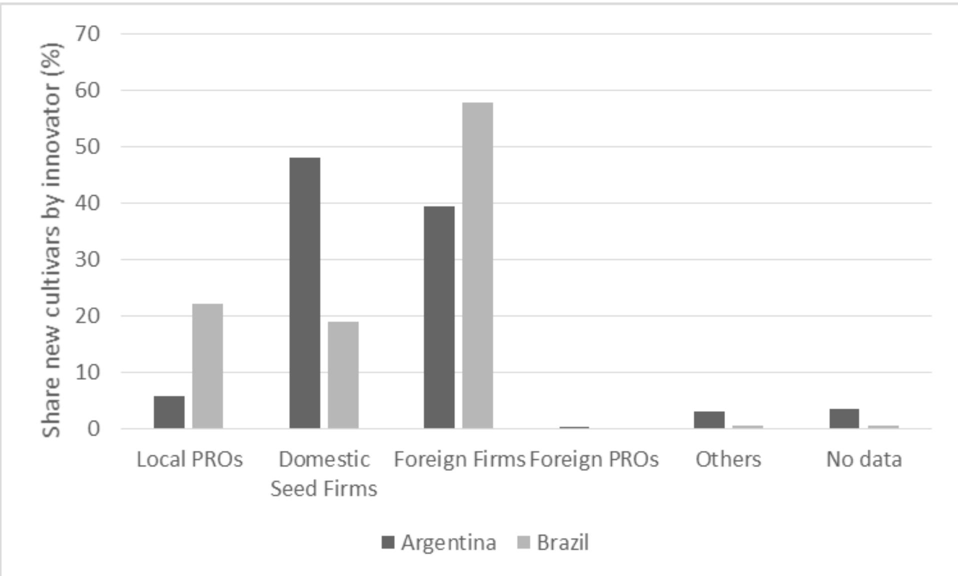

Figure 2
Introduction of new cultivars by type of innovator in Argentina (1979-2013) and Brazil (1998-2013)*
*PROs are public research institutions

Source: Based on data from RNC in Argentina and Brazil, from Marin et al, 2015.

4.2 *Institutional framework*

In a relatively new industry like seeds, where no single dominant technological path has consolidated yet – due to, among other things, disputes about the adequacy and the safety of some of the technological options and the conflictive and changing attitude of consumers towards the technologies–, institutions and regulations are crucially important to define what is legally possible and economically viable. In this sub-section we discuss the main institutions and norms regulating the seed industry in Argentina and Brazil.

4.2.1 Patents

The patent systems of Argentina and Brazil have similar characteristics. They both permit to patent the use of genes for specific constructions, but patenting of life forms and/or genome (or genes) as found in nature is not allowed.[7] The process of patenting is complex and expensive, particularly if as it is usual the case, companies aim to exploit their innovations and patent in more than one country. This is because: i) to grant a patent in several countries may take years; ii) it requires attorneys specialised in intellectual property regulations, in the country and abroad; iii) a large amount of resources are necessary to monitor and ensure the correct enforcement of the law and; iv) the actual value of the patent may not be clear until it has been opposed (which can also lead to long legal procedures).

4.2.2 Regulation of transgenic events

The two countries have now a very similar regulatory system to approve genetically modified events, which is not significantly different from the system utilised in United States. It takes between 10 and 15 years to authorise a new transgenic event after the required trials and risks assessments are performed, and these are very complex and expensive. Studies about how costly is to deregulate an event in Argentina and Brazil have not been performed, however, from studies in other countries it is known that the figure the regulatory costs to bring a genetically modified crop to the market can vary from US$ 15-30 million to US$ 100-180 million (Schenkelaars et al., 2011). It is not, thus, surprising the argument that maintain that companies following this approach have to spend more on legal counsel than on R&D expenditure resulting in the patented invention (Louwaars et al., 2009).

4.2.3 *Plant Certificates*

The two countries have adopted a similar intellectual property protection system for plant breeding. They both adhered to the International Union for the Protection of New Varieties of Plants[8] in its version of 1978 (UPOV 1978) –Argentina, joined the club in 1994, whereas Brazil did it in 1998. The system protects breeders that develop a new variety for a period of between 15 and 20 years by means of plant certificates. However, differently from the patent system, it allows two exceptions to the rights granted to breeders: first, to farmers that save seeds for using them in their own farm or to sell it to their neighbours[9] and; second, to researchers, who are allowed to conduct research activities using existing varieties without paying royalties.

5. **Empirical Analysis**

In this section, we present and analyse the empirical findings collected through the fieldwork process in accordance to the analytical frame discussed in Section 2.

5.1 *Innovation capabilities and technological paths followed by seed companies in Argentina and Brazil*

Building upon the innovation capability framework presented in Section 1, Table 4 below depicts the level of capabilities achieved by the examined firms in the three technological paths identified above –i.e. crossbreeding (C), mutagenesis (M) and transgenesis (T).

Three general observations from Table 4 are worth to mention: i) only two out of the eight selected companies, TMG and Nidera, are simultaneously committed to the three technological paths identified in the industry; ii) none of the companies managed to achieve advanced capabilities in all the three paths and; iii) five out of the eight companies reached an advanced level of capabilities in at least one of the technological paths: Bioceres is the only firm which reached an advanced level in the transgenesis path –in which Embrapa attained an intermediate level and; Don Mario, Nidera and Embrapa reached an advanced level of capabilities in the crossbreeding path, whereas Nidera and TMG did it in mutagenesis.

Table 4

Technological capabilities in case study firms

		Domestic Firms							Foreign Firms
		Domestic Firms				Emerging Country Multinationals		Public Firms	MNCs
Technological capabilities	**Advanced**				M	C M	C	C	
	Intermediate		C	C	C				C
	Basic	C							
		Bioceres (AR)	Codetec (BR)	Sursem (AR)	TMG (BR)	Nidera (AR)	Don Mario (AR)	Embrapa (BR)	Syngenta (BR)

References

Source: own elaboration based on fieldwork.

Table 5 below summarises our findings about innovative efforts and innovative outputs attained by the selected companies that justify our classification.

Table 5
Main innovative efforts and innovative outputs of case study firms

<table>
<tr><th rowspan="2"></th><th rowspan="2" colspan="2">Main technological assets</th><th rowspan="2" colspan="3">Innovative efforts</th><th colspan="2">Innovative outputs</th></tr>
<tr><th>Patents[a]</th><th>Share of varieties registered by the firm over total</th></tr>
<tr><td>Nidera</td><td rowspan="2">Own genes and genes from other large MNCs</td><td>Well-developed network of testing</td><td rowspan="7">• Culture tissue
• Selective breeding</td><td rowspan="5">• Own molecular markers</td><td>• Genetic engineering: mutagenesis
• Conventional breeding
• Robots</td><td>7 United States
4 Argentina
4 WIPO
4 Australia
3 EPO</td><td>Soy: 19.43%
Maize: 8.12%</td></tr>
<tr><td>Bioceres</td><td>Emerging network of testing</td><td>• Genetic engineering: transgenesis
• Molecular breeding</td><td>5 in Argentina
5 Canada
4 Unites States
4 Australia
3 Brazil</td><td>Sunflower: 2 varieties
Maize: 3 varieties (2010-2013)</td></tr>
<tr><td>Embrapa[b]</td><td rowspan="2">Genes from large MNCs</td><td rowspan="2">Well developed and internationally significant network of testing

Developed germplasm bank</td><td>• Genetic engineering: mutagenesis
• Conventional breeding
• Bioinformatics</td><td>n/a</td><td>Soy: 16.97%
Maize: 4.25%</td></tr>
<tr><td>Don Mario</td><td>• Molecular breeding
• Bioinformatics
• Robots</td><td>n/a</td><td>Soy: 27.55%</td></tr>
<tr><td>TMG</td><td>Own genes and genes from other large MNCs</td><td rowspan="3">Well-developed network of testing

Developed germplasm bank</td><td>• Genetic engineering: mutagenesis
• Molecular breeding
• Robots</td><td>1 United States
1 WIPO
1 Brazil
1 Argentina
1 Colombia</td><td>Soy (2007-2013): 6.14%</td></tr>
<tr><td>Coodetec</td><td rowspan="2">Genes from large MNCs</td><td rowspan="2">• Conventional breeding</td><td>n/a</td><td colspan="2">Soy: 9.07%
Maize: 1.8%</td></tr>
<tr><td>Sursem</td><td>n/a</td><td colspan="2">Maize: 2.22%</td></tr>
</table>

						Sunflower: 3.5%
Syngenta	Genes from the corporation and other large MNCs			• Molecular markers developed by others	n/a	Maize: 10.43% Soy (2012-2013):20.51% (c)

Source: own elaboration based on Espacenet database from the European Patent Office, National Registers of Cultivars, and fieldwork.

(a) Information corresponds to the following codes of the Cooperative Patent Classification:

- A01H: New Plant or Processes for obtaining them; Plant production by tissue culture techniques

- C12N: Micro-Organisms or enzymes, compositions thereof (biocides, pest repellents or attractants, or plant growth regulators, containing micro-organisms, viruses, microbial fungi, enzymes, fermenters or substances produced by or extracted from micro-organisms or animal material A01N63/00 ; food compositions A21 , A23 ; medicinal preparations A61K ; chemical aspects of, or use of materials for, bandages, dressings, absorbent pads or surgical articles A61L ; fertilisers C05); Propagating, preserving or maintaining micro-organisms (preservation of living parts of humans or animals A01N1/02); Mutation or genetic engineering, culture media (micro-biological testing media C12Q)

(b) Embrapa has patents under the two codes considered in this paper. However, none of them refer to products but only to processes.

(c) This figure was calculated for the period 2012-2013, when the company was active in the registration of soybean varieties.

5.2 *Innovative efforts*

A distinctive feature of all companies with advanced technological capabilities is that, independently of the technological path followed, they carry out substantial innovative efforts at the technological frontier. Each firm at this level has biotechnology and breeding R&D facilities working on different research programmes. The number and characteristics of the breeding R&D programmes depend on the number of crops developed by the company. For instance, Nidera, one of the most diversified firms analysed in this paper, has five R&D breeding programmes and one biotechnology R&D laboratory in Argentina and Brazil; Don Mario, a company that currently only develops soybean seeds, has one biotechnology R&D laboratory, and one breeding programme in each of the six countries where the company operates.

Independently of the technological path they follow, all companies with advanced capabilities invest in state-of-the-art biotechnology tools (e.g. genetic engineering, rDNA, genomic maps, molecular markers, etc.) and other advanced techniques, such as bioinformatics and robots, with the purpose of improving seeds. An important difference between companies classified with advanced and intermediate technological capabilities is their capacity to develop their own molecular markers –molecules which reveal whether certain traits are present or not in a plant– and other biotechnology tools utilised to conduct research activities (see Table 4). Advanced companies such as Don Mario, Embrapa, Nidera and TMG have the capacity to develop their own molecular markers and have advanced equipment, such as robots, which allow research activities to be performed in a more efficient and controlled way. In 2013, TMG invested US$ 5 million to acquire the first robot that performs genotyping in South America.

Differences across technological paths are reflected in divergences in the type of infrastructure and the R&D strategy pursued by companies. Firms devoted to the transgenic and mutagenic paths are more oriented to the identification of genes sequences, whereas the R&D labs of companies in the crossbreeding path are more oriented at supporting the breeding programmes through the exploitation of synergies among genetic information, the testing of genetic material and the use of greenhouses.

The network of experimental field testing stations is a key asset for companies following the crossbreeding path. Since they offer a diversity of products, which have to be adapted to different environments, it is necessary to assess how materials developed in the lab or in greenhouses perform in different locations.

Field-testing takes several years and demands high investment in specialized machinery and trained human resources (mostly agronomists) that are able to identify the best plants. The size and magnitude of the experimental testing network, as well as the number of greenhouses that each firm has developed, are key to explain the success of firms to develop timely better performing seeds. According to a study by Marin et al (2015), the size of Nidera's experimental network (as measured in number of plots) in maize in Argentina is 1500 times higher than that of ACA, a less successful company, which holds around 5% of market share (whereas Nidera holds more than 20%). In addition, Nidera performs experimental work in other countries which is key to contribute to increase the variability and richness of its germplasm bank. The same study shows also that Don Mario, in soy, has five times more experimental plots in Argentina and Brazil than Nidera (Marin et al 2015). TMG has a network of testing similar to Don Mario in Brazil, but has not experimental stations in Argentina.

The large size and diversity of the germplasm bank –i.e. the collection of live plant matter in the form of seeds– is another key asset for technologically advanced seed firms, particularly for those in the crossbreeding path. Don Mario, for instance, currently has the fourth largest soy germplasm bank in the world, after MNCs such as Monsanto, Pioneer, and Stire. TMG has the most important germplasm bank in Brazil, similar to the one owned by Embrapa.

5.3 *Innovative outputs*

Here we distinguish firms according to the level of capabilities they attained.

- Evidence of advanced level of capabilities (see Box 2 for a description of all innovative outputs)

The three companies classified with advanced level of capabilities in the transgenic (Bioceres) and the mutagenic paths (Nidera and TMG) managed to patent some of their product innovations. Bioceres, in collaboration with the National University of Litoral and the CONICET patented three genes in Argentina, Brazil, the United States and China; the Hahb4, COX5c and the Hahb-10[10].

Within the mutagenic path, Nidera developed hybrid sunflower seeds, patented in various countries –e.g. Argentina, Uruguay, United States, Australia–, which are resistant to the herbicide Clearsol Plus, produced by BASF. It also developed a gene controlling the height of sunflower crops, which improves the performance of this crop. In the same path, TMG was granted in 2014 a patent in the United States, Brazil, Argentina, among other countries, for a soybean gene resistant to Asian rust –an aggressive disease that appeared in Brazil for the first time in 2002–, being the first company to launch a commercial soybean variety resistant this particular disease in the world.

In the crossbreeding path, companies are not allowed to patent their innovations in Argentina and Brazil. Therefore, as explained in Section 2, in order to be able to assess their performance we looked at the number of new varieties registered and, collected qualitative and quantitative evidence from companies and key informants about the main innovations developed by each firm.

Three companies –Embrapa, Nidera and Don Mario– reached advanced technological capabilities in the crossbreeding path. They have been able to develop significant innovations and hold a high share of the new seeds registrations in their own countries[11]: Don Mario and Nidera accounted for 28% and 20%, respectively, of total registered varieties in soybeans in Argentina between 1999 and 2013 –a share that increased significantly over the years–, and Embrapa accounted for 17% of new registered varieties in soybeans in Brazil, during the same time period[12]. Although, plant certificates do not explain the characteristics of each innovation (as patent certificates do), from in-depth interviews we were able to find out that some of these new registered varieties represented major innovations.

For instance, Don Mario introduced an innovation that had a major impact in the soybean markets of Argentina and the South of Brazil. The company developed varieties of short maturity cycles that work well in the North of Argentina and the South of Brazil, replacing seed varieties of long maturity groups, i.e. varieties that take long to mature and were the only ones that worked well in these regions. Nidera improved the quality of long maturity varieties by transforming them into indeterminate soybean cultivars. One of the advantages of indeterminate soybean varieties compared to determinate varieties is that they can recover after periods of dry weather, and so they yield better under these conditions.

Another very important innovative output of these companies has been the development of varieties with higher productivity. Don Mario and Nidera's varieties systematically showed productivity increases higher than the average for the industry. The varieties developed by Don Mario have shown in the field an average genetic gain of 1.6% per year during the last 14 years. The varieties of Nidera incorporate yearly 1.5% increase in yields. These figures have been significantly higher than the average of the industry for the same period estimated in 1% per year.

A major innovation by Embrapa within the cross breeding path was to develop varieties that work well in tropical areas, which allowed mechanized soybean cultivation to be conducted in regions with less than 15° latitude, thus expanding the area for soybean cultivation in Brazil.

Box 3
Description of main innovative outputs

Company	**Description of main innovative outputs**
Bioceres	The Hahb4 is a sunflower protein, which provides seeds resistance to water stress and salinity. It has been tested in soya, maize and wheat. The gene COX5c is a gene promoter or enhancer, which allows to increase the expression level of genes in plant cells. The transcription factor Hahb-10 can be used in DNA constructs to transform host cells and plants. Transgenic plants that overexpress this transcription factor are more tolerant to herbicides, and have a shorter life cycle.

Nidera	Nidera developed hybrid sunflower seeds resistant to the herbicide Clearsol Plus, produced by BASF. Nidera's R&D project on sunflower seeds also yielded innovative findings on the gene controlling the height of sunflower crops, opening opportunities for the development of more stable crops, reducing lodging risks, and allowing for improvement in planting density and the use of fertilizers. In the crossbreeding technological path, Nidera managed to improve the quality of long maturity varieties by transforming them into indeterminate soybean cultivars. This innovation was massively adopted in the Northern area of Argentina and the South of Brazil until the end of the 2000s.
TMG	TMG developed, in the mutagenesis path, a soybean gene resistant to Asian rust –an aggressive disease that appeared in Brazil for the first time in 2002. The company discovered a cluster of genes, originally from Asia, which proved resistant to that fungus. The first rust-resistance variety, named Inox, was developed in in seven years, a record time since it normally takes 15 years to develop a new variety.
Don Mario	Don Mario developed varieties of short maturity cycles that work well in the North of Argentina and the South of Brazil, replacing seed varieties of long maturity groups. Among other advantages, by advancing the period of maturation, these varieties allow for double cropping of soy and corn, which in Brazil has explained the boom in production volumes of both crops during the recent years (Marin *et al.*, 2015).
Embrapa	In the 1990s, researchers at Embrapa developed the long juvenile period (LJP) trait. As a result, mechanized soybean cultivation could be introduced in regions with less than 15° latitude (Neumaier and James, 1993), thus expanding the area for soybean cultivation in Brazil, previously constrained to areas South to the 22º latitude.

Source: own elaboration based on fieldwork

- Evidence of intermediate level of capabilities

Companies classified as intermediate innovators in the transgenic and mutagenic paths are those able to patent process technologies but not products. Embrapa, for instance, patented a method of inoculation of biological nitrogen fixers for soybean seeds before planting electro-chemical sensors and bio-sensors based on nanotechnology. However, it has not been able yet to identify and patent a genetic construct with value for the markets.[13]

In the case of the crossbreeding path, Coodetec, Sursem, TMG and Syngenta were classified with intermediate capabilities because, despite having achieved some innovative outputs, according to the interviewed managers and key informants, the quality and complexity of these innovations was not as relevant as the ones developed by the firms in advanced capabilities. Their intermediate position is reflected in the relatively lower share in total new registered varieties compared to companies with advanced level of capabilities, which is the result of a less systematic success in obtaining new significantly innovative varieties over the years (see Table 5). Coodetec achieved its highest share of registered varieties in soy, with 9.0%; Sursem in sunflower, with 3.5% and, TMG in soy with 6.1%.

Syngenta is a special case. Although the company achieved a high record in terms of share of new registered varieties, in soy 20.5%, in a short period of time (2012-2013), the bulk of these registrations corresponds seeds develop by other subsidiaries of the company with the purpose of beginning operations in Brazil.

- Evidence of low levels of capabilities

Coodetec, Sursem, Don Mario, Nidera, and Syngenta were classified with low level of technological capabilities in the transgenic path because they do not conduct research activities close to the technological frontier with the purpose of identifying new transgenic constructs. Rather, they possess basic capabilities allowing them to license transgenic constructs from other companies and crossbreed them with their own varieties.

The most surprising case here is Syngenta, which is a large MNC with advanced capabilities in this field at a global level. However, interviews confirmed that the Brazilian subsidiary draws most of its main technological assets from its parent company (or fellow subsidiaries in advanced countries) limiting local R&D efforts to perform adaptations to the local context. The subsidiary has not developed any significant innovation locally and does not hold any patents. This performance resembles the typical pattern of behaviour of MNC in developing countries.

Bioceres was classified with basic level of capabilities in the crossbreeding path due to its low level of new registered varieties: in the period 2010-2013 it only registered two varieties sunflower and three varieties of maize.

5.4 *Why firms choose different technological paths*

The analysis above shows that the firms studied have followed different technological paths with a relatively high level of success. Only one domestic firm has achieved advanced level of capabilities in the transgenic path, which is the path favoured by large MNCs. The others have accumulated advanced level of capabilities in the crossbreeding and mutagenesis paths. In this sub-section we discuss four factors that contribute to explain the co-existence of technological paths and intervene in the choices made by existing firms: i) regulatory burden and uncertainties; ii) market discontinuities; iii) changing innovation possibilities and; iv) the context-specific agro-ecological requirements.

5.4.1 *Regulatory uncertainties and requirements*

Firms in the seed industry have to comply with a vast number of regulations regarding, for instance, seed certification and variety registration, plant property rights, biosafety and phytosanitary requirements, seed marketing and labelling. In the transgenic path, the resources involved in patenting transgenic events and complying with regulatory requirements for approval of new seeds are much higher than in the other technological paths and overburden small- and medium-sized firms.

The domestic firms studied –with the exemption of Bioceres– were reluctant to embark in the transgenesis path due to the high costs and the complexity of complying with regulatory requirements and obtaining plant protection rights in the form of patents. Don Mario, for instance, excels in crossbreeding techniques and has become a leading firm in the soy market in Argentina and Brazil, but has decided not to commit to the transgenesis path, even if they could master high technological capabilities in this technology. The decision is fundamentally based on the fact that they do not have the resources to deal with the regulatory costs and demands.

Studied companies that decided to follow the transgenic path –such as Bioceres, Embrapa and Nidera– had to licence their patented genetic events to large MNCs because they lacked legal and regulatory resources to defend them and the capabilities to commercially exploit them. For instance, Bioceres has not been able to introduce its own genes in any germplasm and commercialise them in the seed market. For this reason, the company continues to buy transgenic events from MNCs and backcross them with domestically developed seed varieties –mostly by the INTA. One of the main problems faced by Bioceres concerns the patent application and monitoring process, as well as complying with biosafety regulations. As a response to these constraints, Bioceres develops alliances and subcontracts with international companies. In 2009, the company licensed the gen Hahb4 to the Indian firm Advanta for its application on sorghum, cotton, rice, mustard and colza seeds. In 2012, it created a joint venture with the French company Florimond Desprez for the future commercialisation of transgenic wheat at a global level. However, interviewees stressed that patenting and regulatory hurdles are still serious restrictions.

In the case of Nidera, even though the company is a medium sized MNC and has managed to patent a mutagenic event, the high level of resources demanded by the enforcement of intellectual property rights, among other things, has been a hindrance for the company in profiting from its innovation. Due to the large costs of defending patents at a global scale, it established a collaboration with BASF that allowed the later to exploit the product at a world scale. Something very similar happened with Embrapa and Basf.

Thus, regulatory burdens and costs constrain firms' ability to capture the rent of their innovative efforts in the transgenic path, leading emerging country multinationals and domestic firms to commit more resources to the other technological paths[14].

5.4.2 Market conditions

Consumers in large parts of the world are not keen to consume food based on inputs produced with genetic modifications, and demand for more environmentally friendly and healthier products. This type of consumer attitudes limits the scope to incorporate transgenic events in all crops and has opened opportunities for other non-transgenic paths. For instance, wheat and sunflower markets do not accept transgenic products thus raising demand for innovations based on the other technological paths. The following quote from one of our interviewees at Nidera reflects this point:

> In sunflower, oil consumers are willing to pay a surcharge for quality, and also they are not in favour of acquiring seeds that have been modified by transgenesis. In this context, other technologies, such as mutagenesis, appear as a very helpful tool to improve sunflower, because they do not face resistances or fears,

and can generate new traits. For example, Nidera generated five families of herbicide-resistant sunflower varieties using mutagenesis.

5.4.3 *Changing innovation possibilities*

However, besides the regulatory costs and burdens as well as the negative market attitude discussed above, transgenic techniques are very complex, expensive and time consuming. Significant advances in the knowledge base related to genetics have opened up the possibility to utilise transgenesis to search for innovations in seeds. It is often argued that transgenesis widens the spectrum of search possibilities, since traits from other species can be introduced into seeds through biotechnology techniques. However, the same genetic advances have also benefited the other technological approaches, namely mutagenesis and crossbreeding.

Crossbreeding can now be carried out in a more efficient and cheaper way thus becoming a competing approach to transgenesis. Domestic firms prefer crossbreeding because it allows for a faster and cheaper launch of new seed varieties into market, compared to transgenesis techniques. Whereas it can take up to fifteen years to launch a new transgenic event to the market, products obtained by crossbreeding techniques can be commercialised in a period between three and six years. Furthermore, these techniques can also deliver some innovations that are not viable via transgenesis. For instance, genetic engineering techniques have not yet been able to modify complex traits, which are determined by a large number of interacting genes, such as those affecting yield and stress resistance, while cross breeding techniques managed to achieve results in this areas, especially when using advanced genomic knowledge (Fernie et al. 2006).

5.4.4 *Context-specific agro-ecological characteristics*

Agricultural activities are highly dependent on context-specific agro-ecological characteristics (e.g. water, climate and soil characteristics, type of insects, genetic background of local species, etc.). Thus, seeds developed for one particular context do not work well in others.

Besides, the seed market values diversity and rapid adaptation to continuous changes in agro-ecological conditions. For instance, a region can become drier from one planting season to the next one, be suddenly attacked by a plague, or get affected by heavy rains, etc. As changes affect the performance of seeds, continuous development of new varieties adapted to new conditions is needed.

As pointed out by an interviewee from Don Mario:

> A key element of Don Mario's strategy is positioning itself as a first mover (…). Don Mario's strategy consists of possessing a wide spectrum of seed varieties that are suitable for different climate and soil conditions as well as resistant to pests. Thus, Don Mario attempts to be the first that cater to the market with the type of variety that is more suitable for the problems or agro-ecological conditions of each year and region.

A TMG key informant also asserted that: "Time-to-the market and diversification are our main strategies to compete in the seed market" (quoted in Martin et al 2015).

The transgenic approach, as discussed in the previous point, is an expensive and slow option to meet the need for diversity and adaptation. It fundamentally points to deliver standardised innovations that can be maintained in the market over long periods of time (e.g. resistance to glyphosate has been in the market for more than 15 years). Large MNCs devote significant efforts in supporting this technology, precisely because it allows them to capture rents of the same innovation for a long period of time. They leave, therefore, typically unattended the demand for diversity; an important niche to be fulfilled by domestic firms which meet this need with alternative technological approaches, less resource and time consuming than transgenesis.

6. Non-Technological Barriers to the expansion of High Tech Firms in NRs: Questions for Future research

We understand that a striking finding of our research is that some of the companies examined –despite having developed and accumulated advanced levels of technological capabilities in the transgenic or mutagenic path– had to forego a large share of the potential rent of their innovations by licensing their innovative outputs to large MNCs. At the same time, other cases, while having reached advanced level capabilities in crossbreeding technologies and significant success in regional and international markets –such as Nidera or Don Mario–, have decided not to embark in the transgenic technological path not because of the lack of scientific capabilities, but, rather, due to the non-technological requirements this path poses for firms to be able to capture the rents of the innovation outputs.

An important research question would therefore be: what do companies need to be able to seize the benefits of innovations in the seed market and expand further? An easy answer is: financial resources. However, this is not enough to understand the kind of learning they need to engage with. Our work suggest that the main difficulties faced by these firms originate in the lack of development of some kind of non-scientific or -technological capabilities, which are necessary to bring new technological developments into the marketplace and to effectively seize the profit opportunities derived from innovation efforts. This question raises a point of great importance, which goes beyond issues traditionally investigated by the technological learning strand of research.

Some studies have discussed the importance of non-technological capabilities for profiting from innovation (or "complementary assets" as Teece (1986) refers to them), in particular, in technologically dynamic industries (Colombo *et al.*, 2006; Pavitt, 1998; Rothaermel, 2001; Teece, 1986; Teece *et al.*, 1997; Tripsas, 1997)). For instance, dealing with the case of the biotechnology industry, Rothaermel (2001) found out that, in facing deficiencies related to these types of capabilities, new technology-based firms in the biotechnology industry typically made agreements with incumbents companies, which have better downstream capabilities, such as regulatory management as well as marketing and sales. Although this is an important point, it leaves unanswered the question of what kind of capabilities a firm must possess in order to avoid the need to forego the exploitation of their innovation outputs because this is difficult to achieve with their available resources.

In the seed industry, in particular, some of the non-technological capabilities which seem to be important according to our interviews are: i) the capacity to comply with environmental and biosafety regulations; ii) the ability to defend intellectual property rights; iii) the capacity to ensure the effective enforcement of existing regulations; iv) the capacity to negotiate with other firms issues such as prices and the distribution benefits, etc. –which is difficult since we are talking about intangible assets whose performance features are difficult to establish with certainty; v) the ability to convince clients to try new things; vi) the capacity to identify demand requirements; and vii) the ability to codify, standardised and modularise solutions, which is crucially important to move from local to global markets. In sum, all these capabilities are related to the ability to deal with, to shape or influence the market and institutional context.

Whereas at one extreme some companies are not able deal with and to adapt to the contextual market and institutional variables, on the other, companies with advanced non-technological capabilities are capable not only to comply with contextual variables (e.g. biosafety regulations) but also to shape them by for instance influencing other companies, buyers, government agencies through lobby and other mechanisms. In Argentina, for instance, large MNCs have a set at the board of the National Advisory Commission on Agricultural Biotechnology (Conabia), the institution responsible for de-regulating biotechnology events and therefore crucially important to define what is possible to sell or not in this market, where, by contrast, small and medium-sized firms do not have such a seat.

In our study, firms from Argentina and Brazil show deficiencies in many of these non-technological capabilities even when they proved to be able to acquire advanced technological capabilities. Figure 4 summarises this idea. The empirical evidence collected in the research process does not allow to further precise the nature of these capabilities. However, our evidence strongly suggests that research on the relations between technological and non-technological capabilities needs to be further explored in future research. This issue is particularly relevant for companies originating in less advanced countries which operate in knowledge-intensive industries, such as the seed industry. This is because in order to be able to create better conditions for firms from less advanced countries to seize the opportunities opened up by new technologies it is necessary to have a better understanding of non-technological capabilities and more importantly, how to develop them. Such an effort calls for firm-level empirical studies capable of grasping industry and geographical specificities.

Figure 3
Technological and non-technological capabilities

7. Conclusions

In this study, we analyzed the process of capability accumulation in firms from developing countries in the seed industry, an industry strongly linked to NRs, which is facing permanent changes.

Our study contributes to state-of-the-art research by investigating not only the *level*, as the extant literature does, but also the *type* of technological capabilities being accumulated by seed firms operating in Argentina and Brazil. It is widely accepted that the scope for generalising and extrapolating findings from case studies is limited (Yin, 2009), however our findings point to interesting questions for policy and future research.

We found that firms from Argentina and Brazil have been able to attain advanced levels of technological capabilities. Despite the high levels of concentration in this industry, which at global scale is dominated by a few large MNCs (the so-called "six gene giants"), several firms have been able to obtain significant innovations and to capture large shares of the domestic market. As discussed above, they are taking advantage of significant market, technological and institutional discontinuities, which are permanently opening new opportunities in this relatively new industry, as well as of local specific requirements not satisfied by large foreign firms.

Interestingly, also, and perhaps due to the relatively youth of the industry, not all the firms have oriented their technological and innovative efforts in the same direction. Only one of the firms has concentrated its efforts exclusively in genetic engineering activities to perform transgenesis, a technological approached only commercially exploited by a few large MNCs in the world. All the others firms have chosen to follow a different technological and market trajectory. Two of the analysed firms –Nidera and

TMG– have opted for the mutagenic approach, which is accepted by consumers and demand lower development costs. All the other firms have chosen to invest all their efforts in crossbreeding activities assisted by the most modern biotechnological tools, attending the need for diversity and adaptation which typical of the seed market.

These findings show that for an industry like this, where technology, market and institutions are in permanent dispute and change, it is important to understand not only how much firms invest and in which kind of technological capabilities. It is also important to understand in which direction efforts are oriented.

Finally, as discussed in the Section 6, we identified a set of non-technological capabilities which seems to be crucial for firms to be able to capture the benefit of their innovations. This last finding, in particular, has important implications for research and policy. We need to understand much better what firms have to do to develop these capabilities, which kind of skills have to develop, which kind of investment need to do, etc. In this way, we will be able to understand much better the possibilities of further expansion of firms from less advanced countries. A better understanding of this phenomenon will also help to design policies, beyond subsidies to R&D that can support the expansion of firms in these of industries. This is especially relevant in sectors, like the one studied here, that have important discontinuities and can therefore support the emergence of firms following different trajectories, or that follow the same trajectories of large MNCs taking advantage of local specificities or new market or institutional opportunities.

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1 Coupled with developments in information and communication technologies (ICTs)

2 A similar effect had the use of bioinformatics. Seed companies can use computer-assisted prediction of test results on genetic modification avoiding growing every modified plant in the field or green house. The implementation of bioinformatics certainly shortens the breeding process substantially and helps to improve the innovation process.

3 Key traits achieved by genetic engineering - for herbicide tolerance, coleopteran pest resistance, *b*-carotene enrichment and delayed ripening - have all been introduced in major food crop varieties by advanced cross breeding and mutagenesis techniques (Arundel, 2001; Brumlop and Finckh, 2011).

4 Molecular marker-assisted selection is the most widespread biotechnology tool used in cross-breeding processes and has been very successful in producing a variety of heat, drought, flood and disease tolerant traits in different crops – such as bean, maize, rice, soy and wheat– which have been developed and disseminated in developing countries.

5 The seminar was hold in the University of San Andres in Buenos Aires, Argentina.

6 Plant breeders who wish to protect their varieties under the intellectual property rights system for seeds must apply for registration at the RNPC.

7 Brazil explicitly rejects the doctrine of isolation, according to which isolated or purified products of nature are patentable; Brazilian Industrial Property Law, article 10.

8 UPOV is an intergovernmental organisation established by the International Convention for the Protection of New Varieties of Plants, known as the UPOV Convention, adopted in Paris in 1961. The Convention was revised in 1972, 1978 and 1991. The last two revisions, or "Acts" as they are known, are currently in force. By signing the UPOV Convention, countries obtain guarantees that intellectual property rights over new varieties will be respected by other signatories and reciprocally undertake to respect the rights of breeders in other signatories. UPOV Convention signatories are required to introduce plant variety protection legislation with certain basic characteristics.

9 Recent court decisions have defined who a "farmer" is and how much seed can be saved.

10 Bioceres has exclusivity rights for use and commercialization of the gene

11 It is important to point out that in the case of MNCs, we are only taking into consideration the plant certificates obtained by the companies' units analysed in this paper, and not by the whole corporation. This implies that in the cases of regional MNCs of Argentinian origin with operations in various countries of the region, such as Don Mario and Nidera, only certificates obtained in Argentina were counted. In the case of the Brazilian subsidiary of Syngenta, only certificates in Brazil were considered.

12 As explained in the methodology companies classified with advanced level of capabilities in this technological path have at least 15% of new varieties registered over the period analysed in at least one crop.

13 In the press it appears that association with BASF, Embrapa developed a soybean plants tolerant to the imidazolinone class of agricultural herbicides. The gene, however, was identified and patented by Basf. Embrapa provided the cultivars and field-testing.

14 Although Bioceres is an exception, the economic success of the company in economic success is not clear yet.