Oligopoly Strategies in Agricultural Innovation: Biotech and ICT Acquisitions

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Abstract: This article explores technological convergence in the seed and agricultural machinery industries, focusing on mergers and acquisitions (M&A) between 1990 and 2021. Its aim is to understand the global capital restructuring in these industries and its relationship with agriculture 4.0 and advancements in biotechnology. The assessment of changes in technological hierarchy emphasizes cooperation and rivalry in oligopolies for the diffusion of technologies. Using Crunchbase, the methodology identifies 221 acquisitions and classifies companies according to their technological capabilities, focusing on interaction with new technologies. Preliminary results indicate M&A patterns suggesting different strategic adaptations to emerging technologies. Leaders in agricultural machinery seek to integrate ICT tools in the agricultural sector, hinting at a possible transition to information services, with metallurgy as a complementary asset. In contrast, the seed industry follows a path of innovation centered on genetic engineering, considering ICT as complementary assets.

Keywords: Technological convergence; Mergers and Acquisitions (M&A); Agricultural Machinery; Agriculture 4.0; and Biotechnology.

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1. Introduction

The diffusion of new technologies in agricultural systems is driven by the need to increase productivity, decrease production costs and reduce capital turnover times, despite these being limited by the biological nature of the production processes. Leading firms in the seed and agricultural machinery industries are currently deploying different strategies in order to incorporate capabilities associated with Information and Communication Technologies (ICTs) and the biotechnological paradigm.

In the 1970s, the biotechnological paradigm became widespread thanks to the adoption of agrochemical-resistant seeds and the introduction of new cultivation techniques. This process was enabled by the complementarity between new biotechnology tools (such as the use of transgenesis) and accumulated experience in seed breeding (Sztulwark, 2012). Large corporations in the seed industry in the mid-2000s sought to accelerate innovation processes and the regulatory approval of new varieties, based on different strategies, including the development and adoption of gene editing techniques (CRISPR, TALEN/Fok1, among others) (Gupta *et al*, 2021).

In parallel, the dissemination of ICTs also created fresh opportunities for boosting the agricultural system's productivity. Since the 1990s, one of the main vectors for disseminating such technologies was the computerization of the agricultural machinery industry, facilitated by the confluence between metalworking and electronics specializing in Agriculture 3.0 or Precision Agriculture (PA). The popularization of the Internet and advances in robotics, Artificial Intelligence (AI) and Big Data saw the emergence of Agriculture 4.0 (or AgTech), through the development of subscription-service platforms with recommendations for farmers on how, where and when to plant seeds, irrigate, apply pesticides and/or fertilizers, among other topics (Karunathilake, et al 2023; Liu *et al.* 2021; Vidosa *et al.* 2022; Lowenberg-DeBoer and Erickson, 2019).

This context favored opportunities for collaboration and/or convergence between sectors. With the diffusion of ICTs and biotechnology, large agricultural input firms committed themselves to exploiting the complementarities offered by these new enabling technologies. To take this technological leap, the companies implemented various strategies, among which the merger and/or acquisition (M&A) of companies specializing in new technologies played a prominent role.

Understanding technological change as an inseparable process from the rivalry and cooperation relationships established between oligopolies, the objective of this article is to study capital destructuring/restructuring processes on a global scale within the context of alternating ICT and biotechnology diffusion waves. To this end, M&A activity in the seed and agricultural machinery industries will be analyzed for the 1990–2021 period. Inter-sectoral operations and their relations to new technologies will be identified to determine whether changes in

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the hierarchy of dominant technologies in the sectors studied can be observed. In this framework, the research questions guiding this work are: What M&A patterns emerge in response to technological advances in biotechnology and ICT? How have M&A influenced capital restructuring in these industries? In what ways have companies integrated new technologies into their productive capacities?

The topics discussed will follow this order: first, we will discuss the conceptual and methodological aspects of the present work, then the preliminary results for the sectors studied and, finally, we will dwell on some reflections and questions which emerged throughout the research process.

2. Theoretical-contextual elements

The diffusion of new technologies often redefines the role and hierarchy of economic sectors and territories, while strongly affecting the dynamics of capital accumulation (the permanence, displacement and restructuring of firms, economic sectors and productive areas or regions) (Lavarello et al, 2023; Vlados et al. 2022; Brito et al 2021; Chesnais, 1995; Malerba and Orsenigo, 2002).

Since the 2008 crisis climax, the main capital of the global agri-food chain has relentlessly experienced a crisis and its productive structure continues to be recomposed. With the dissemination of ICT and biotechnology, firms in the seed and agricultural machinery industries have reoriented their strategies to exploit the complementarities offered by these new enabling technologies. The otherwise stable relationships among oligopoly members come into tension, insofar as competition for the control of new technologies arises. Technologies become the theater for cooperation and rivalry relationships between capital stakeholders. Intra and inter-sectoral rivalry between firms is exacerbated, through the absorption of companies within the same sector, or new segments in ICT and biotechnology (Lavarello *et al*, 2019 ; Vidosa *et al* 2022; y Sztulwark and Girard, 2020).

Despite these developments, technological complementarity presents its own challenges. The inverse relationship between diffusion and appropriation largely hinges on the simultaneous interaction of technological specificities, knowledge management, and prevailing market structures (Yoguel et al., 2007). The opportunities for appropriation of the economic benefits generated by new knowledge depend on firms' efforts to restrict its circulation beyond the boundaries of the organizational form in question. Firms must possess the requisite capabilities to develop the complement internally or, failing that, acquire, license, or partner with entities that manufacture the technologies associated with the new paradigm (Teece, 2018).

Irrespective of the fact that acquisitions may be motivated by reasons other than strictly technological ones (Trautwein, 1990), it is also possible to interpret them as a tool for companies to access external expertise and expand their knowledge bases, and/or acquire the capabilities they have failed to develop internally (Robert *et al*, 2021; Vermeulen and Barkema, 2001; Cloodt *et al.*, 2006; Makri *et al.*, 2010; Berkovicht and Narayanan 1993; Chapman, 1999; 2003; Cooke, 1988; Chesbrough and Teece, 1996; Lavarello, 2018).

According to Teece et al. (1994), coherent diversification is the strategy through which companies can address a demanding competitive environment by leveraging complementarities between production lines and markets. In contrast, conglomerate diversification can only ensure the profitability of the firm in uncompetitive contexts. Business coherence does not imply a static portfolio of capabilities, but rather varies in its composition in a non-random manner, influenced by competitive selection mechanisms or specific public policies. Therefore, alliances and mergers can serve as a vehicle for the incorporation of capabilities in new technologies, which operate as a pivot. This means that a set of technologies or assets that may have been complementary at one point can later become innovations of fundamental, disruptive, and structuring nature for the industry itself. Throughout its history, the organization into a group or holding has allowed large leading companies, through coherent diversification, to maintain their competitive advantages by pivoting their complementary capabilities with their core capabilities (Lavarello and Gutman, 2019). These elements are crucial for analyzing acquisitions and mergers of firms over time.

Recent research on acquisitions and technological platforms (Gawer, 2021; Bronson, 2022) highlights that the accumulation of power in the digital age involves not only the acquisition of technological capabilities but also the control of data and technological standards, which creates new barriers to entry and limits the space for autonomous innovation. At the same time, Watzinger et al. (2020) emphasize the importance of antitrust policies in fostering innovation by promoting access to key technologies. However, the convergence of ICT, agricultural machinery, and biotechnology remains an underexplored area in the literature, particularly regarding its impact on traditional sectors. This article seeks to address this gap by analyzing how mergers and acquisitions in these sectors reshape technological hierarchies. In doing so, it provides a foundation for future studies to explore how these structures affect both sectoral technological innovation and the development of technological capabilities, opening a research field that addresses these challenges in both peripheral and central industrial contexts.

3. Methodology and sources

The data matrix utilized in this study was created on the basis of secondary sources drawn from Crunchbase (CB)[1]. The purpose in the use of this database was to identify the acquisitions made by the seed and agricultural machinery industries. The analysis comprised a total of 221 acquisitions made during the 1990–2021 period.

[1]Crunchbase was founded in 2007 and contains information on 1.2 million entities, located in 199 different countries. Although the database has been compiled since 1908 (the year when it was created, information mainly being drawn from companies and investors), the number of M&A included in it mostly date from after the year 2000.

As Crunchbase proposes an industry classification with various overlapping categories (sectors, business areas, etc.), it is virtually impossible to use the industrial taxonomy typical of sectorial codifications or traditional products -International Standard Industrial Classification (ISIC), Industrial Classification of Products by Activities of the European Community (ICPAEC)-. To counter this, the following steps were taken: first, the universe of purchasing companies was reduced to the industries of interest (seeds and agricultural machinery) via a keyword search in the extended descriptions of the company's activity. In order to narrow the search to the most relevant firms in each sector, smaller firms were excluded. Depending on the sector2, a number of employees/income level criterion was retained. As a result, a universe of 17 purchasing companies in the seed industry was obtained (companies providing agricultural inputs and biotechnology services to seed developers or other associated inputs), together with 14 purchasing companies from the agricultural machinery industry (tractors, harvesters, sprayers, seeders, agricultural parts, among others). Finally, the firms acquired (221) by the previously selected companies were identified.

The data obtained from Crunchbase were analyzed by grouping the most relevant companies in each sector, which allowed for the identification of significant trends and relationships. The questions guiding the analysis focused on identifying which types of companies had been acquired by the major players in each sector, what activities these acquired firms were engaged in, and how many acquisitions had been made by the leading firms in their respective segments. This approach revealed important dynamics that might have gone unnoticed without a thorough analysis. However, it is important to acknowledge potential biases in the methodology, such as the underrepresentation of acquisition processes by medium -sized or smaller firms. Additionally, there is a limitation in determining whether other industries or sectors of the economy are also engaging in acquisitions linked to digital agriculture.

To analyze the evolution of acquisitions, a new classification was created by recoding the taxonomy of Crunchbase "industries", based on the technological core of the firms studied. This categorization was applied to both the purchasing companies of the industries studied (seeds and agricultural machinery), as well as the acquired firms. Regroupings were carried out so that the operationalization of the analytical dimensions underlying our research was eased. Regarding the purchasing companies, the firms corresponding to the seed industry were classified as agricultural inputs and biotechnological services. For their part, all the firms in the agricultural machinery industry were included under that same label. For the classification of the acquired firms, special emphasis was placed on the distinction between ICTs (3.0, 4.0, PA, AgTech and Bioinformatics) and biotechnology (See Tables 1, 2 and 3). From this, we identified a total of 126 acquisitions made by companies belonging to the seed industry, and 95 by the agricultural machinery industry.

Table No. 1. Classification of companies acquired by the Agricultural Machinery industry

Agricultural machinery	Agro-parts
	Harvesters
	Agricultural implements
	Sprayers
	Seeders
	Tractors
	Others
Other machinery	Municipal machinery
	Forestry machinery
	Industrial machinery
	Vehicles

Source: own elaboration

[2] With the purpose of determining a manageable number of companies, striving to capture the largest ones in each sector, the following search criterion was established: for the seed industry, only companies generating over 500 million dollars in revenue were included. This criterion enabled us to include the main actors in the seed industry (see Section 4.1), without ruling out some special cases belonging to the group of large global seed companies related to the chemical industry. For the agricultural machinery industry, we only retained those companies hiring over 51 employees (size criterion). For the same reason as for the seed industry, the number of companies was restricted, keeping only on the largest ones. In this case the number of employees was used for two reasons: first, because in that way, we avoided excluding many medium-sized companies that were actually making acquisitions and, on the other hand, because it was difficult to identify companies solely on the basis of their reported income.

Table No. 2. Classification of companies acquired by the Seed Industry

Seed industry	Biotechnological services – General Genomics		
	Agricultural inputs	Biotechnology companies	Seed development
			Crop protection
		Non-biotechnology compañnies	Crop protection
			Seed multiplication
	Other sectors	Food and animal health	
		Agronomic and stocking assessment	
		Automobile	
		Biopharmaceutical	
		Industrial biotechnology	
		Energy	
		Pharmaceutical	
		Inputs for the food industry	
		Industrial inputs	
		Laboratories	
		Non-agricultural machinery	
		Other biotechnological industries	
		Other chemical industries	
		Poultry products	
		Gardening products	

Source: own elaboration

Table No. 3. Classification of ICT-acquired companies

ICT	3.0	Electronic and communication devices (cell phones, computers, network hardware, satellite systems, embedded software)
	4.0	Cloud computing, AI, Augmented (virtual) reality, advanced robotics, Big Data, Blockchain technologies, 3D printing, drones
Agro-specialized ICTs	PA (Precision Agriculture)	Automated guiding, sensors, seeding and yielding monitoring systems, satellite flaggers, GPS, automated pilots
	AgTech	4.0 ICT specializing in agro industries
	Bioinformatics	4.0 ICTs specializing in genomics (Genomics-oriented Cloud computing and Big Data, genomic data zipper, etc.)

Source: own elaboration

4. Restructuring of global capital in the seed and agricultural machinery industries in the face of biotechnology and ICT diffusion

A process for strengthening corporate capabilities in two key industries within the agricultural inputs sector is currently at play: the seed and agricultural machinery/equipment industries. Some of the main features of the restructuring processes accompanying the diffusion of biotechnology and ICT-related novel technologies will be outlined in the following paragraphs.

4.1 Biotechnology in the seed industry

Agrobiotechnology refers to the application of various biological techniques aimed at boosting agricultural production. In historical terms, these practices experienced a turning point with the development of modern biotechnology, a now established knowledge base which gave rise to genetic engineering as a fundamental technique. The application of the new production technique prompted the development of new products, among which transgenic seeds particularly stand out. These crops were widely disseminated across the planet after a group of multinational companies paved the way for a new dynamic in the seed industry, supporting a palette of complementary innovations (Parayil, 2003).

The main protagonists in the development of the knowledge base required for deploying modern biotechnology were research centers and universities in the United States. Nevertheless, after the passage of the Bayh-Dole Act in 1980, the fundamental tools for developing a new transgenic crop and the genetic bases for new functionalities were exclusively licensed to private companies (Graff et al., 2003a)[3].

[3] For example, the transformation mediated by *Agrobacterium,* developed by Washington University (St. Louis), was exclusively licensed by Ciba-Geigy (now Syngenta, owned by ChemChina); the particle bombardment technique, developed at Cornell University, was also solely licensed by DuPont; the patents for the most often used selection markers were granted to Monsanto, among others (Graff *et al.,* 2003a; Thomas, 2005).

At the same time, the costs and deadlines required by R&D, intellectual property management and regulation of transgenic crops operate as barriers to entry for smaller companies or public institutions in the agrobiotechnology industry (Graff et al., 2003b; Pellegrini, 2013). In the 1990s, these elements led to an economic restructuring within the sector, making room for the entry of companies specializing in chemicals, which in turn provoked greater economic concentration in the agrobiotechnology industry. As a result, this sector became dominated by six large companies: three from the United States (Monsanto, DuPont and Dow) and three European ones (Bayer, Syngenta and Basf). Needless to say, they all strengthened their oligopolistic position in the world market for seeds and agricultural inputs, mastering transgenesis techniques[4]. Although the income structure of these companies did not reveal a transformation in the firms' main activity, in strictly economic terms, the relationship between the chemical industry and the seed industry enabled these firms to position themselves as key players in the seed industry, starting with the assembly of an input package.

Concomitantly, the development of modern biotechnology made room for differentiation into two productive stages within the seed industry, segmenting it at the technological and economic level. The first of these stages contemplates the design and transformation of the plant's genome, whereas the second stage focuses on conventional genetic improvement and reproduction (Sztulwark, 2012). As a consequence, large transnational companies—with access to the main patents for the development of innovations in biotechnology—dominated the activities during the first production stage, whereas other smaller, local actors (ruling out a few exceptions[5]), were reduced to the role of providers of complementary innovations (adapting the developments of large biotechnology companies to local agro ecological conditions, for instance).

Despite an existing high concentration (due to that particular scenario6 and as a consequence of the maturation of transgenesis as a fundamental innovation[7]), a new M&A process was set in motion in 2015. As a result, the agricultural biotechnology industry was territorially configured into three nuclei which currently constitute its dominant pole: United States, after the merger between Dow and DuPont; Germany, through Bayer's purchase of Monsanto; and China, following the acquisition of Syngenta by ChemChina (Bonny, 2017). What is particularly remarkable in the formation of each of these new cores is that a dominant company in the agrochemical market (Dow, Bayer, or ChemChina) joined another firm with a track record in the development of seeds and biotechnology (DuPont, Monsanto or Syngenta). This point proves that, despite the gravitational movement towards the development of products of a "biological" nature (as compared to those of chemical origin, produced in the seed industry since the advent of modern biotechnology), the link between both knowledge bases is persistent and, at least so far, complementary.

For its part, the maturation process of transgenesis as a fundamental innovation was accompanied by the appearance of new crop improvement techniques. Among them is gene editing, one of whose advantages would be the reduction of costs and deadlines in plant improvement. In this case, the main companies in the agrobiotechnology industry made sure to exploit the new techniques for the development of new seed varieties, especially through the procurement of rights and licenses rather than M&A with other companies (Sztulwark and Girard, 2020). Given the recent nature of this innovation, it is difficult to predict the scope and impact this technique will have on the industry. Due to certain characteristics of the gene editing process and the initial phase of its life cycle, it is now possible for new actors to profit from an unprecedented window of opportunity, and to set themselves apart from those who have dominated the agrobiotechnology industry so far.

Finally, two additional factors have influenced the trajectory of the agrobiotechnology industry. One of them is the problem of the inappropriateness of innovations intended for crops of autogamous species (such as soybeans), which can be reproduced by farmers without facing large yield losses (Rapela, 2020). The second element refers to the limitations imposed on the dissemination of biotechnological seeds by the controversies and conflicts in public opinion around the consumption of transgenic foods (Wunderlich&Gatto, 2015). At this point, the diffusion of gene editing techniques (by dispensing with the introduction of foreign genes in the species to be improved), raises a still unresolved question regarding consumer acceptance or rejection of these products.

ICTs in the agricultural machinery industry

Following the crisis of 2008, a global restructuring process has been observed in the agricultural machinery industry, resulting in increased intra-sector rivalry. Major firms in the sector have expanded their market power by acquiring a large number of agricultural machinery and other types of machinery companies. As a result of this process, the agricultural machinery oligopoly has concentrated technological capabilities associated with the main linkages in this sector, i.e., metalworking activities, including the casting and/or machining of mechanical parts, such as structural components from steel inputs, and the assembly of these sets and subsets with other components of variable complexity (engines, transmissions, differentials, cabins, air conditioners) for the construction of the final product (Vidosa et al, 2022).

Although the agricultural machinery industry is highly dispersed worldwide—there being over 1,500 companies in more than 50 countries—the importance of barriers to entry associated with R&D, the preferences for existing brands and extensive distribution and financing networks explain the fact that 15 transnational companies concentrate over 85% of the global market, thus constituting a global oligopoly (Lavarello, et al., 2019).

[4] These six companies had developed 80.5% of the transgenic events approved until 2018 (ISAAA, 2018).
[5] For further detail see Sztulwark and Girard (2016).
[6] Among them are, on the one hand, the fall in prices of agricultural products, which had an impact on sales in the seed and agrochemical markets and, on the other hand, the existence of low interest rates throughout 2016, which favored the financing of M&A processes (Clapp, 2017).
[7] This can be inferred from the decrease in the appearance of new innovations with high productive impact and the difficulties of this technology to offer new products whose novelty lies in qualitative improvement (PROCISUR, 2017).

These oligopolistic relationships in the sector have a solid foundation represented by a leading group of companies. The first six of them (measured by their turnover in the sale of agricultural machinery) are: Deere & Co., Kubota, CNH Industrial, AGCO, Yanmar and CLAAS. These companies have particular characteristics which allow them to be differentiated from the rest. Some of these characteristics are: in 2021, they concentrated over 75% of the global production and sale of agricultural machinery[8] and are firms which have been positioned as leaders in the international market for over two decades (Lavarello et al. 2009), they are full liners (they produce a complete range of agricultural equipment)9, they are present on all five continents and offer the full range of highly specialized equipment and after-sales services and, finally, they are headquartered in central countries. It is for all these reasons that we refer to this group of companies as leading firms in the agricultural machinery industry (Lavarello, et al. 2009; Lavarello, et al. 2019). Among the 15 above-mentioned firms, the remaining [9] have characteristics which identify them with another subgroup or class. They are companies that generally specialize in a single product and have a smaller, regional geographic scope. We call this subgroup non-leading firms10. The companies in question are: Mahindra&Mahindra, Same Deutz-Fahr, TAFE, Bucher Industries, First Tractor Company Limited (Subsidiary of YTO Group), Iseki & Company, Exel, Amazone and Alamo Group. This subgroup also includes companies from the Asian powers of India and China, which have been participating dynamically in the world market for some years now[11].

Now, in parallel to the intra-sector restructuring, the agricultural machinery manufacturing chain has been restructured by the incorporation of new activities. Having to recompose the market, the oligopoly has accelerated the incorporation of ICTs into agricultural machinery.

The incorporation of new ICT technologies has progressed non-stop since the 1990s. Precision Agriculture (PA) or Agriculture 3.0 emerged from the confluence between the agricultural machinery and electronics industries (Lowenberg-DeBoer and Erickson, 2019; Vidosa et al. 2022). Global Positioning Systems (GPS) and other electronic devices—green index, temperature and humidity sensors, remote sensing sensors, yield monitors, etc.—are mounted or integrated into agricultural machinery. The collected data are transmitted through portable ICT devices, and processed with Georeferencing Systems (GIS). From these, yield maps and intensive sampling are generated, which will later facilitate the variable dosage of inputs according to soil heterogeneity.

Later on, the reduction in the costs of sensors and microprocessors, together with the spread of the Internet, promoted the digitization of data collected by PA, allowing for better wireless connection between devices (Karunathilake, et al 2023). These transformations (in convergence with robotics), enabled automation capabilities in agricultural machinery and PA equipment. In turn, digital communication led to a significant increase in data flows, which made it possible to apply algorithms (Big Data) and Artificial Intelligence (AI) to the information collected by PA teams (Jha, 2019; Shaikh, et al 2022). Agriculture 4.0 or AgTech emerged in this scenario (Liu et al. 2021; Dayıoğlu & Türker, 2021), whereby a set of algorithms transforms data and engages AI systems for the provision of agronomic, meteorological, financial services, as well as the monitoring of agricultural machinery, all of which are managed through digital media (mobile applications, platforms, etc). This technological leap was favored by different strategies: the opening of internal departments for the development and/or improvement of new technologies; the M&A of PA and AgTech companies; and the formation of corporate venture capitals to invest in 4.0 projects (ETC Group, 2021; Lavarello, 2019; Passero, 2021; Vidosa, et al. 2022).

In this context, the control of digital agriculture and data platforms are transformed into areas for cooperation and rivalry between firms. In the last decade a group of oligopoly firms has undoubtedly manifested a strong interest in obtaining companies that develop, produce and sell ICT electronic devices associated with the agricultural sector.

As from 2020, international grain prices reversed the downward trend, reaching record prices for wheat, soybeans and corn in 2021 and 2022. This means that at the beginning of this decade the firms saw their investments mature, with a strong increase in demand.

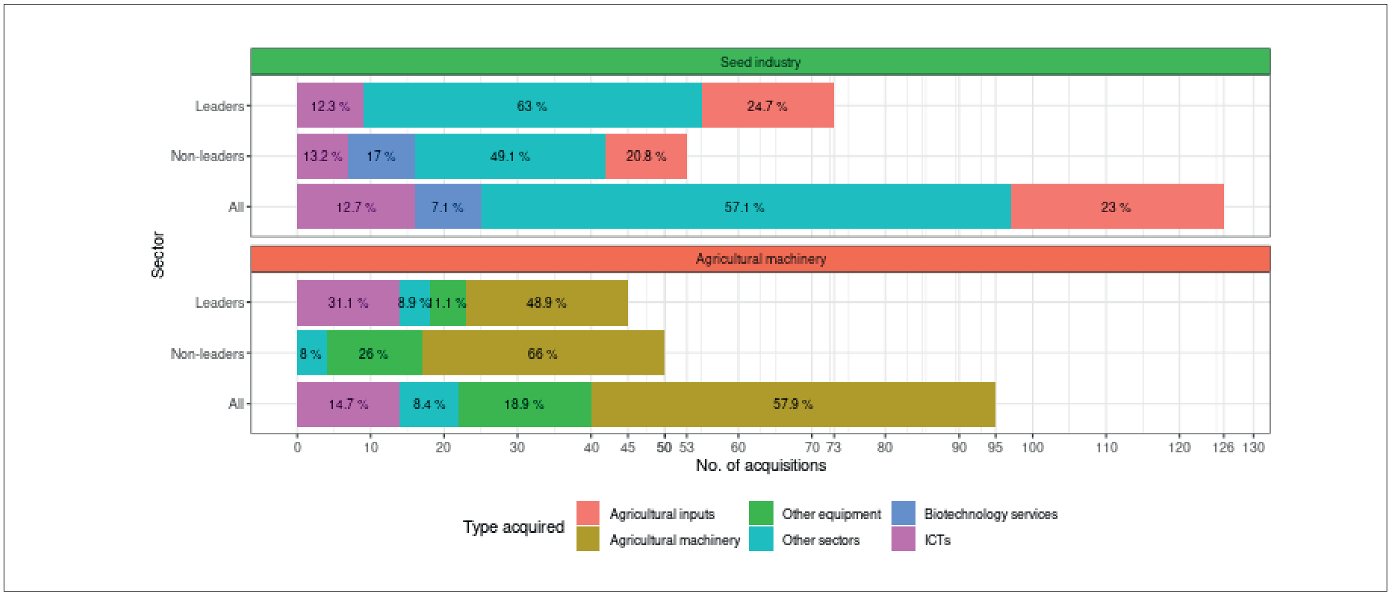
4.3 Acquisitions in the seed and agricultural machinery industries

An analysis of the different acquisitions in the seed and agricultural machinery industries in the last 30 years is presented below (sample used for the present study).

Graph No.1 depicts the acquisitions carried out by firms within the seed and agricultural machinery industries over the past three decades. Notably, the seed industry companies have undertaken a greater number of acquisitions (126) compared to their counterparts in the agricultural machinery sector (95), as illustrated along the horizontal axis. Moreover, while the distribution of these acquisitions suggests a prevailing trend towards intra-sectoral purchases, it is noteworthy that significant extra-sectoral acquisitions of ICT companies within the analyzed industries have also occurred.

[8] Based on the information provided by the companies' annual reports, the firms' official websites and CRUNCHBASE.
[9] They are companies that produce tractors, harvesters, self-propelled sprayers, seeders and agricultural implements.
[10] In the United States, there is also a small group of medium-sized agricultural machinery firms, outside the global oligopoly (always measured in income) which are mentioned in this research project because they have acquired other companies. These companies are: Salford Group, Art's Way Manufacturing Co. and Rite Way Mfg. Co
[11] It is important to mention that some Chinese-origin companies may have been omitted as it is not feasible to find the annual reports publicly (for example: LOBOL).

Graph No.1. Acquisitions of the seed and agricultural machinery industries per sector, divided into oligopoly leaders and non-leaders. In percentages. Years 1990–2021



Source: own elaboration based on CRUNCHBASE.

A more detailed analysis of the seed industry reveals a prominent presence of the category "Other sectors" over the total acquisitions made by the industry. This includes acquisitions of companies which are not (directly or indirectly) related to agricultural production or to ICTs. This means that half of the acquisitions made by the companies in the seed industry were made from companies with no direct link with the development of said activity. In contrast, when exploring the "Other sectors" category, one finds that almost 50% of those acquisitions were made by the company BASF, and if Bayer and Dow are included, they account for 74% of the acquisitions.

Graph No. 1 shows the acquisitions made by companies belonging to the seeds and agricultural machinery industry in a disaggregated manner, based on the classification of purchasing companies between "leaders" and "non-leaders"[12]. In the seed industry, leading firms have a high percentage of acquisitions of companies falling under the "Other sectors" category. This is related to the fact that such companies are chemical-based groups having ventured into the biotechnology sectors since the 1990s. Among the acquisitions classified as "Other sectors", 54% correspond to chemical-based companies, while 23% were acquisitions of non-agricultural biotechnology companies.

The next significant category of acquired companies are those classified as "Agricultural inputs" suppliers, mostly related to seed development and multiplication, as well as crop protection. These acquisitions are predominant among the leading companies, with a large participation of biotechnology-based firms (75%), mainly those oriented to the development of seeds (see Table Nº2). As a general remark, all the main companies that make up the agrobiotechnology oligopoly acquired firms classified as Agricultural inputs (76%) and account for 86% of the acquisitions of biotechnology-based companies related to the agricultural sector.

The same graph shows that 12.7% of the total acquisitions were made on companies classified as ICT, where 56% of them are explained by purchasing companies directly belonging to the seed industry, and the rest are companies classified as providers of "biotechnology services." In turn, the proportion of ICT company acquisitions seems to be similar in both groups of seed industry companies. It should be noted that in the case of non-leading companies, the percentage of ICT firm acquisitions is explained by purchases made by Illumina (a provider of biotechnology services) and Cargill, but not by acquisitions made by the major agro-biotechnology companies. Consequently, only the large firms that make up the global agro-biotechnology oligopoly acquired ICT companies.

Finally, Graph No. 1 shows that the acquisitions of companies classified as "biotechnology services" were only made by purchasing companies belonging to the same sector. Illumina made eight of the nine acquisitions surveyed, whereas BGI Group tackled the remaining acquisition. What particularly stands out, as a consequence, is the absence of acquisitions of biotechnology service companies by leading firms.

Regarding the agricultural machinery industry, we can see from Graph No. 1, that the purchasing structure of leading and non-leading companies exhibits notable similarities and differences worth highlighting.

[12] This classification weighs the relative importance of each company within the analyzed industry. In the case of the seed industry, BASF, Bayer, Monsanto, Syngenta, Dow Chemical, DuPont are considered leading companies (MacDonald, 2017); for the case of the agricultural machinery industry, please refer to Section 4.2.

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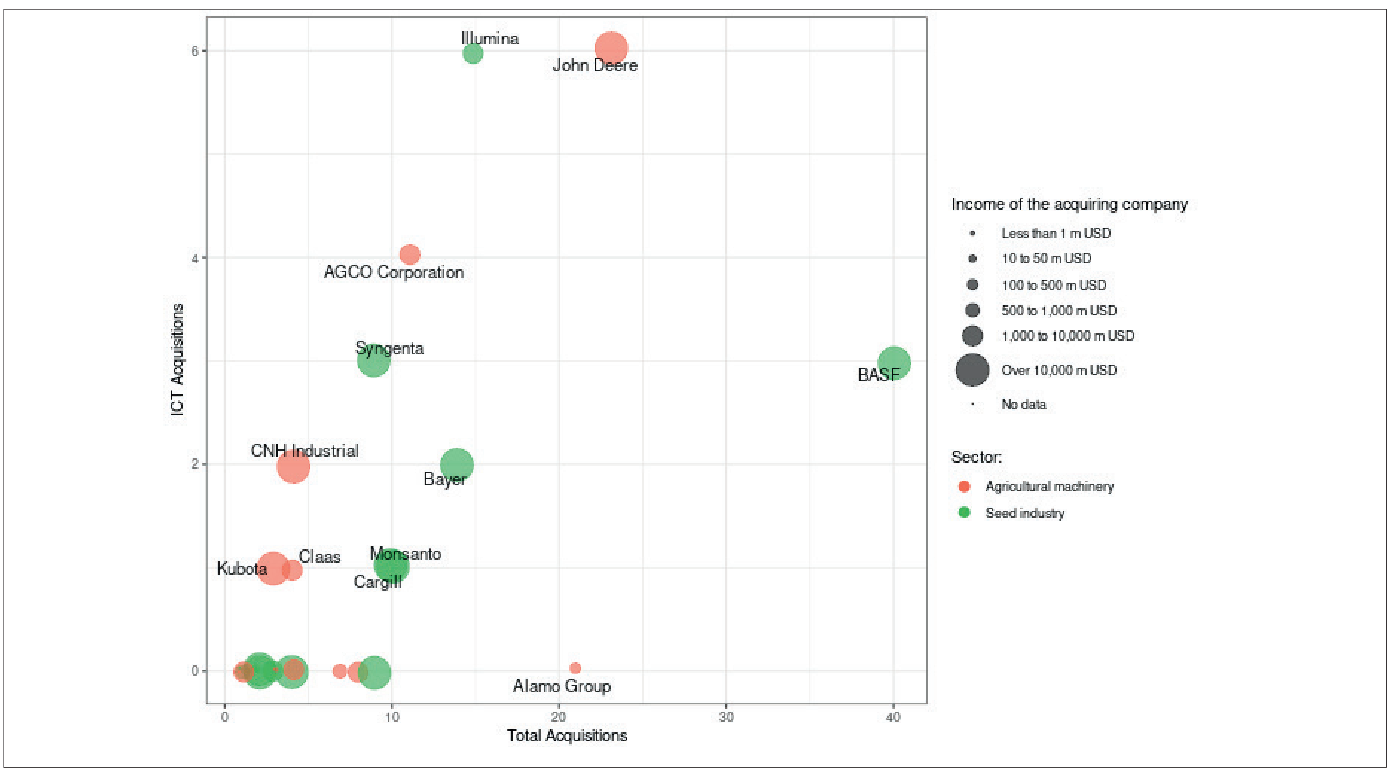
A notable affinity between both groups is their predominantly acquiring companies within their own sector (firms producing agricultural machinery and other machinery), indicative of a market concentration process. However, between the two groups of firms, it can be observed that non-leading companies acquire a greater number of metallurgical companies relative to leading companies, reflecting a sector consolidation strategy aimed at valorizing their specific capabilities.

It is worth noting that acquisitions of agricultural machinery and other machinery companies account for 60% of the total purchases made by leading firms -John Deere, AGCO, CNH, Kubota, and Claas-.In contrast, among the group of non-leading companies within the global agricultural machinery oligopoly (Mahindra&Mahindra, Same Deutz-Fahr, TAFE, Bucher Industries, First Tractor Company Limited —Subsidiary of YTO Group—Iseki & Company, Exel, Amazone and Alamo Group) and the non-leading group outside the global oligopoly (Salford Group, Art's Way Manufacturing Co. and Rite Way Mfg. Co.), the acquisitions of companies belonging to the agricultural machinery and machinery industry in general reached 92% of the total.

It is important to clarify that, on one hand, although non-leading agricultural machinery firms have made a great number and proportion of company acquisitions within the same sector in the considered period, leading companies have made purchases for higher monetary amounts[13]. On the other hand, the lower proportion of purchases within the sector by leading companies is due to their strategic need to acquire firms from other sectors with developments in new technologies outside the core capability set of the agricultural machinery industry. The acquisition of ICT companies, which amounts to 31% of leading firms total acquisitions, becomes a distinctive characteristic that differentiates them from non-leaders, who did not acquire any ICT firms[14]. Furthermore, three of the largest agricultural machinery companies obtained at least one flagship ICT company. Deere & Co. purchased Blue River in 2017 and Bear Flag Robotics in 2021, CNH acquired AgDNA in 2019 and Raven in 2021, and AGCO acquired Precision Planting in 2017.

Subsequently, the data for the period under analysis reveals that both the seed industry and the agricultural machinery industry reinforce their core activities through the acquisition of companies within their respective sectors. At this juncture, a significant difference is observed in the proportion of acquisitions of ICT companies between the leading agricultural machinery firms (31%) and the leaders in the seed industry (12%). The agricultural machinery industry demonstrates a more pronounced shift in the composition of its asset portfolio towards these technologies, reflecting a more marked process of technological convergence, whereas the seed industry exhibits a mixed behavior by continuing to acquire companies in the realm of basic chemistry.

Graph No. 2. ICT-company acquisitions by sector, firm and income. In absolute values. Years 1990–2021



Source: own elaboration based on CRUNCHBASE.

[13] For example, the most expensive purchase of Deere & Co. was for a total of $4.6 billion. However, Álamo Group, a company classified as a non-leader, second in the number of acquisitions at the oligopoly level, paid $15 million for its most expensive acquisition.
[14] The remaining 9% corresponds to "others" according to our classification.

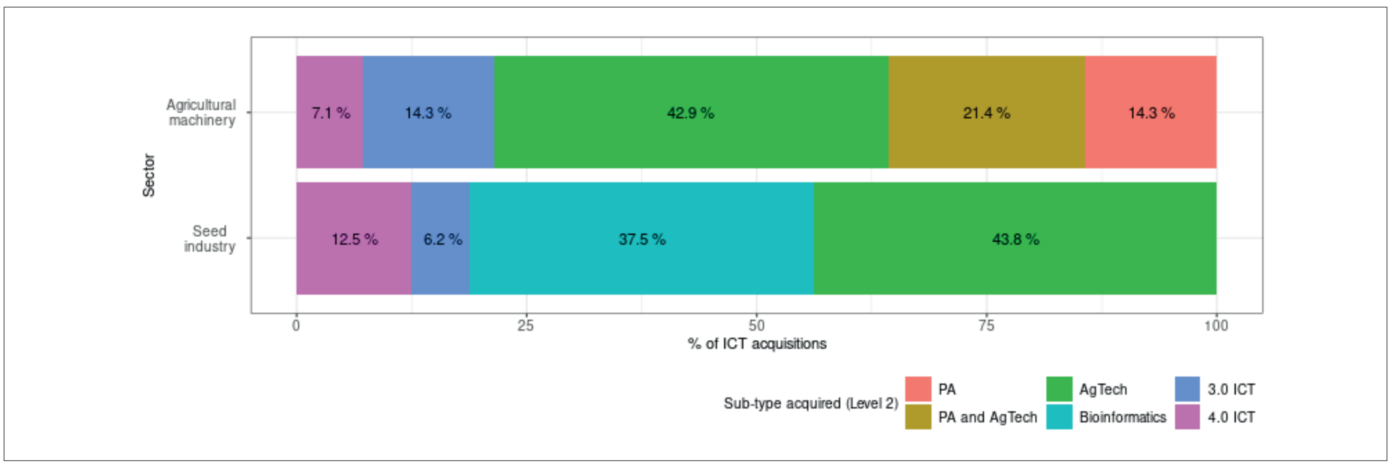
Regarding the seed industry, the performance of BASF stands out, as its acquisitions account for almost 32% of the total acquisitions analyzed. When observing the relative weight of the main companies in the global agrobiotechnology oligopoly, one finds that they made 70% of the total acquisitions acknowledged in this work, and that four of those companies acquired ICT companies. However, out of the total purchasing companies considered, only 35% made acquisitions of ICT companies.

On the other hand, it is important to highlight the participation of Illumina as a purchasing company. Based in the United States, this company is one of the leaders in the development and commercialization of biotechnology services and, despite its not participating directly in the seed industry, offers key services to the development of new varieties. Illumina acquisitions account for 12% of the total considered. Not only is it the main acquirer of ICT companies, but also the only one having made this type of acquisitions without belonging to the group of oligopolistic companies in the agrobiotechnology industry.

Regarding the agricultural machinery industry, the role of Deere&Co. stands out. Ranked behind BASF, as the second firm having made the most acquisitions during the period analyzed, it represents 18% of the total acquisitions analyzed in this work. Alamo and AGCO follow them in order of importance, with 16% and 8% respectively.

As mentioned earlier, the information provided in Graph No. 2 confirms a differentiated behavior in the sector. Only the group of five leading companies, Deere&Co., KUBOTA, AGCO, CNH and Claas[15], were involved in the acquisition of ICT firms. With a total of 6 ICT acquisitions (which represent 26% of the total acquisitions made by the firm), Deere&Co. also has a leading role here. The operations made by firms such as AGCO and CNH are also worth noting. Despite having made a smaller number of ICT-company acquisitions, these represented a greater weight than Deere&Co. in the total acquisitions (36% and 50%, respectively). At the same time, these ICT acquisitions correspond to emblematic and large-scale firms in the PA sector, such as Presicion Planting for AGCO, and RAVEN in the case of CNH. For their part, Illumina and Deere&Co. lead the field, followed by AGCO, CNH, BASF and Bayer. However, it is important to qualify this hierarchy depending to the type of ICT companies these firms have acquired.

Graph No. 3. Distribution of ICT companies acquired by the agricultural machinery industry and the seed industry. In percentages. Years 1990–2021



Source: own elaboration based on CRUNCHBASE.

Graph No. 3 describes the specific ICT technologies corresponding to the core activities of the companies acquired by the firms in the seed and agricultural machinery industries.

In the case of the seed industry, among the acquisitions classified as ICT, the majority were concentrated in the purchase of firms specializing in AgTech technologies (43.8%) and bioinformatics (37.5%), leaving a smaller participation for the acquisition of ICT 3.0 and ICT 4.0.

It is important to draw a difference among the actors who took part in this type of acquisitions. On the one hand, the companies that made AgTech purchases were mainly the leading companies of the agrobiotechnology industry oligopoly (Syngenta, Monsanto, Bayer and BASF). They bought Cloud Computing companies for PA, while Cargill (a leading agribusiness company) made an acquisition of Cloud Computing for precision livestock. On the other hand, the Bioinformatics acquisitions were entirely carried out by Illumina -the biotechnological services company-, which purchased Cloud Computing companies for genomics and, to a lesser extent, software, Big Data and digital microfluidics companies. Finally, the acquisitions of ICT 3.0 and ICT 4.0, not specializing in the agricultural sector, were carried out by the companies Bayer and BASF.

[15] They are five of the largest companies in the oligopoly. Yanmar, the six largest, was left aside, as it is not featured in the CB database as having made acquisitions.

Now, regarding the agricultural machinery industry, the firms having deployed a clear strategy for acquiring ICT companies all correspond to the group of leaders in the sector. In close detail, out of the total of ICT-company acquisitions made by the agricultural machinery industry, 79% refer to ICT firms specializing in agriculture, among which the largest proportion is occupied by the purchase of AgTech companies (42.9%). Unlike the seed industry, which concentrated its AgTech purchases in Cloud Computing firms, the AgTech companies incorporated by the agricultural machinery leaders mostly specialize in robotics (over 80% of AgTech acquisitions), which matches the trend towards machinery automation observed in the sector (ETC, 2021).

Although the progress of the agricultural machinery industry over AgTech firms is remarkable, when one takes a closer look at the most emblematic acquisitions made by the agricultural machinery sector (in terms of the size of the companies acquired and the value of the operations), PA-related purchases rank higher. These large acquisitions are recorded under the PA and AgTech group. In recent years, these PA firms consolidated their position in the development of electronic devices (sensors of various types and geolocation devices) and developed 4.0 technologies specializing in agriculture (platforms, Big Data and artificial intelligence). As a result of this, they can now propose a complete technological package, recycling previously collected data from PA devices and offering tailor-made services. This type of firm occupies 21.4% of the total ICT acquisitions carried out by agricultural machinery leading companies.

The importance of the acquisition of electronics capabilities for the agricultural machinery industry is reinforced if we add (to this 21.4%), the proportions occupied by the purchases of PA firms which haven't made progress in 4.0, and ICT 3.0 not specializing in agriculture. At this point, companies associated with 3.0 technologies occupy 80% of the total ICT acquisitions made by the agricultural machinery industry. This confirms a long-term strategy in the agricultural machinery industry, which would seemingly reinforce the tendency towards convergence between metalworking capabilities and electronics in the leading firms in the sector.

Results and discussion

Based on the approach that considers acquisitions as an indicator of technological capability absorption it is found that there has been a notable diffusion of new technologies related to ICT and biotechnology in the seed and agricultural machinery industries in recent years. A general consistency has been observed in the type of companies acquired, which has remained relatively constant over the study period. These acquisitions demonstrate an interrelationship based on specific technological and market characteristics shared by both sectors. In a context of significant capital restructuring processes and some indications of changes in the roles and hierarchies of certain sectors and/or technological cores, several noteworthy elements are highlighted below.

Firstly, it is important to highlight a substantial difference regarding the two sectors in question: the seed industry is composed of companies with greater market power than those in the agricultural machinery sector. Accordingly, the significant proportion of acquisitions presented by the seed industry is comprehensible compared to the agricultural machinery industry, where the agrobiotechnology oligopoly accounts for 70% of the total purchases analyzed.

An issue shared by both the seed industry and the agricultural machinery industry stands out when examining the structure of purchases: both industries orient their acquisitions to reinforce their main activities and technological cores, focusing on companies within their respective sectors and revealing profound processes of capital concentration and centralization. . Notwithstanding this, it is important to highlight a fundamental difference in the structuring aspects of both industries during the period under analysis. On one hand, the leading companies in the seed industry oligopoly primarily retain, through acquisitions, their production and technological core in the chemical industry, which, in most cases, was the foundation for agro-biotechnology firms' technological base. This supports the notion that in the seed industry, complementarity between chemistry and biotechnology remains a central element in the strategies of major industry players. On the other hand, the purchases of companies in the agricultural machinery industry reinforce a productive structure in which their main economic activity coincides with their fundamental technological core, metalworking.

Although these sectors maintain and reinforce the activities and technological capabilities associated with their main branch, relevant operations are observed that contribute important elements of analysis to the aforementioned restructuring processes, considering the various technology diffusion waves in the current techno-economic paradigm (TEP): biotechnology and ICT (Tylecote, 2019; Perez, 2010; Freeman & Louçã 2001).

One important aspect to consider is that the large firms in the seed industry are those who make the main acquisitions of biotechnology companies related to the agricultural sector. Although these companies retain their technological core -chemistry-, at the same time, they are the ones incorporating biotechnological tools through the acquisitions of companies with these characteristics. This shows the importance of the dissemination of agricultural biotechnology both for the development of new seed varieties (improvement via transgenesis and/or gene editing), and for crop protection, through the use of bio inputs, which are rising as an alternative towards the use of chemicals in agriculture.

Also worth mentioning is that the set of acquisitions analyzed allows us to identify some important aspects regarding the diffusion of ICTs in the industries studied. Although most of the acquisitions are related to the central activities of each of these industries, when one considers the acquisitions altogether, the purchases of ICT companies represent near 30% of the total acquisitions analyzed (distributed in similar percentages between both industries, with a slight difference in favor of the seed industry).

Nevertheless, if we take into account ICT-purchasing companies, quite distinctive elements can be obtained in the strategies deployed by the leading firms in both sectors. At this point, among the group of leading agricultural machinery firms, the values of ICT acquisitions more than double those corresponding to the leading firms in the seed industry. Another contrast: within the agricultural machinery industry, it was only the leading companies of the global oligopoly that acquired ICT companies, whereas in the case of the seed industry (despite observing a similar phenomenon), only some of the leading companies incorporated ICT technologies through the acquisition process. However, the main difference is found in Illumina's participation within the group of ICT-purchasing companies. Illumina was the only firm who—without belonging to the oligopoly of the seed industry—made the largest number of acquisitions aimed at the incorporation of ICT technologies (all purchases in the sector considered).

It is possible to identify yet some other distinctive elements in the industries analyzed regarding the incorporation of new technological capabilities as a result of the acquisition of companies specializing in certain types of ICT, and not others. To begin with, the vast majority of acquisitions made both by the seed and agricultural machinery industries focus on the incorporation of technological capabilities associated with the new ICT 4.0 diffusion wave, particularly those specializing in agriculture, with a preeminence in the purchases of AgTech companies. In detail, the seed industry denotes a behavior consistent with its technological core, since the largest number of ICT-company acquisitions were made on AgTech technologies, specializing in bio-informatics and Cloud-computing for genomics, among which Illumina led the sector purchases. On the other hand, AgTech acquisitions by the agricultural machinery industry primarily target companies specializing in robotics. Such process is exclusively led by the sector leaders, in a clear strategy to incorporate capabilities associated with one of the trends of the new ICT 4.0 diffusion wave: machinery automation.

For their part, agricultural machinery leaders have acquired a handful of AgTech companies specializing in Cloud-computing and data analysis, in line with their strategy for centralizing and analyzing the data they collect through their platforms. Said strategy involves diversifying complementary services to their main products, by simultaneously strengthening internal barriers through customer loyalty. Despite the centrality of these technologies in the firms' strategies, the low number of acquisitions of firms specializing in this type of technologies is striking. This could be due to the fact that the large PA firms acquired were already equipped with such capabilities, or to the fact that (in parallel to the acquisition process), these large agricultural machinery firms engaged in venture capitals to invest in 4.0 Cloud-computing, Big Data and AI projects, generating these capabilities in such a way as to externalize the risks associated with the development of new technologies.

In line with the above, it is important to nuance the hierarchy presented by the acquisitions of the latest ICT 4.0 agriculture-related diffusion wave, and the differences between the AgTech and PA companies (who encouraged the ICT revolution during the previous technological diffusion wave). In this regard, the most relevant companies (in terms of income and market share) are PA firms, who starting from a base of microelectronics and embedded software, shifted towards 4.0 capabilities such as Cloud-computing, Big Data and AI. This is the case of the large PA firms, among which Trimble, Raven, Precision Planting and Topcon stand out. Among these, some have been acquired by the leaders of the agricultural machinery industry. If one considers that ICT 3.0, PA and those firms combining PA with AgTech capabilities essentially correspond to the ones having developed their skills in micro-electronics, the relevance of acquisitions with a knowledge base relying on technologies from the first ICT dissemination wave increases. With this, the advance on 4.0 capabilities is nuanced. In any case, it reinforces the idea that the agricultural machinery industry (continuing an unstoppable trajectory since the 1990s), could become a complex where metalworking capabilities converge with electronics, particularly as a result of the integration of PA capabilities.

Conclusions

The analysis presented suggests key insights into how acquisitions by major leaders in the agricultural machinery and seed industries influence their innovation paths. The incorporation of new technological capabilities has a transformative effect: technologies or assets that were once complementary evolve into fundamental innovations within these industries.

Building on this, it can be hypothesized that the leading firms in the agricultural machinery sector are steadily integrating a full range of ICT tools to enhance their technological base, while maintaining their traditional metalworking capacities as complementary assets. This raises the question of whether the sector is gradually shifting towards becoming an industry primarily focused on the capture and sale of data and information services, leaving metalworking as a secondary component.

On the other hand, the seed industry has a clear trajectory of innovation, focusing on the integration of ICT with biotechnological advances. Their acquisitions are heavily oriented towards developing genetic engineering techniques, such as transgenesis and gene editing, to enhance seed improvement and create bioinputs. These purchases underscore their strategy of capturing the innovation rents associated with biotechnology.

To conclude, the findings reinforce the notion that acquisitions not only consolidate market power but do so by driving technological convergence. This consolidation occurs through the integration of complementary technologies, such as ICT with agricultural machinery and biotechnology, turning these assets into core innovations. Acquisitions allow industry leaders to reorganize their technological priorities, strengthen their competitive positions, and create barriers for new entrants.

These dynamics, however, raise important questions about the opportunities and constraints facing small and medium-sized enterprises, particularly in less developed countries. Furthermore, it is crucial to explore regulatory policies that could mitigate the negative impacts of such concentration on innovation and competition. Designing antitrust policies that promote access to key technologies is essential for ensuring a more inclusive and competitive environment. These considerations highlight the need for further research into the long-term implications of acquisitions on the technological and economic evolution of these industries.

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Availability of data and materials

The database used was: CRUNCHBASE. Available for a fee at: https://www.crunchbase.com/

The companies' annual reports, available free of charge on their websites, were then used.

List of abbreviations

AI: Artificial Intelligence
AgTech: agricultural technology
CB: Crunchbase
CRISPR: Clustered Regularly Interspaced Short Palindromic Repeats
GIS: geographic information systems
GPS: global positioning systems
HC: Harmonized Commodity Description and Coding System
ICT: Information and Communication Technologies
ISIC: international standard industrial classification
M&A: mergers and acquisitions
PA: precision agriculture
R&D: research & development
TALEN: Transcription activator-like effector nuclease
TEP: techno-economic paradigm