Structural Change and Innovation in the Global Agricultural Input Sector

Nicholas Kalaitzandonakes and Kenneth A. Zahringer

Abstract Recent proposed mergers and acquisitions (M&As) in the agricultural input industry, especially among developers of crop protection products, seeds, and biotechnology, have attracted much attention. Vertical and horizontal consolidation in this sector has been ongoing, however, and such restructuring both makes possible and is driven by technical innovation. In this chapter, we review the emerging innovation and business model in the agricultural input sector and discuss the factors that have enabled it.

Introduction

Over the past 2 years, proposed mergers and acquisitions (M&As) in the agricultural input industry, especially among developers of crop protection products, seeds, and biotechnologies, have attracted much attention. The media has chronicled advances among members of the so-called Big Six in great detail.[1] Much of the activity began in May 2015, when Monsanto announced that it had made an acquisition offer to Syngenta (Sutherland 2015). Syngenta's directors and stockholders were reportedly not eager to pursue the deal, some of them citing concerns about antitrust regulatory hurdles. Even though Monsanto subsequently increased their bid and included a breakup fee in the offer, in case regulators did block the acquisition, Syngenta was not won over, and Monsanto ultimately dropped the offer in August of that year (Gara 2015).

Just a few months later, Dow and DuPont announced that they had agreed on a merger-of-equals plan to combine the two firms. Subsequently, within 2 years, the merged firm DowDuPont would split into three separate firms, specializing in agricultural inputs, industrial materials, and specialty products, respectively (Harwell 2015). The proposed merger came under intense regulatory scrutiny, especially in the European Union (EU) but also in the USA (Kosman 2017). On March 27, 2017,

[1] BASF, Bayer, Dow, DuPont, Monsanto, and Syngenta are often referred to as the "Big Six."

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the EU Commission announced that it would allow the merger to proceed under the condition that DuPont's entire crop protection R&D platform as well as other assets be divested.

Even though their initial plans did not work out, Monsanto and Syngenta were not out of the acquisition market. In early 2016, the China National Chemical Corporation, known as ChemChina, made an offer to acquire Syngenta. Although US regulators soon approved the deal (Bray 2016b), the acquisition came under more intensive scrutiny by EU antitrust officials (Bray 2016a). After few changes to the original proposal, the deal was approved by US and EU regulators in April, 2017 (Petroff 2017). About a year after Monsanto walked away from its Syngenta offer, it became the target of an acquisition bid by another Big Six firm, Bayer, in an offer announced in September, 2016 (Harwell 2016). Antitrust regulators in different parts of the world have been closely examining the potential consequences of this proposed acquisition (Varinsky 2017).

All three proposed M&As have been slow to consummate, but they have been cheered by investors. Industry observers expect all of them to close, even if some divestments become necessary. Still, opposing views have continued to come in from various stakeholders. On March 17, 2017, the Congressional Record included a letter from US Senator Grassley to the President of the US summarizing the main points of the opposing view, stating that "the mergers of these international agrochemical and seed giants will significantly reduce competition and innovation in the agricultural sector, and will cause irreparable harm to the American farmer via increased input costs" (pp. S 1775).

Given these considerations, important questions remain: What drives the recent interest of firms to merge and consolidate? How are such structural changes related to innovation and what might be the level of innovation in the agricultural input sector in the future if such structural changes were consummated? In order to answer these questions, in this chapter we first analyze the market environment and the strategic intent of the key players that are driving the current cycle of reorganization and consolidation in the global agricultural input industries. Since the potential outcomes of the M&A actions are uncertain, we explore scenarios of alternative futures and discuss their implications for R&D spending and innovation in the biotechnology, seed, and crop protection industries.

The rest of the chapter is organized as follows: In order to provide historical context in the relationship between structural change and innovation in the agricultural input sector, in the next section we review the factors that initiated the vertical integration and consolidation of the US biotechnology and seed industries almost 20 years ago and examine the realized impacts. Following that, we review a new round of structural changes underway in the biotechnology, seed, and crop protection industries and the factors that have triggered them. As we discuss, innovation induced by both challenges and opportunities has given rise to the structural changes and has been enabled by them. Along the way, the agricultural input sector has begun to pursue a new and expansive innovation model which we subsequently discuss in some detail. Because many of the structural changes are ongoing and the possible outcomes are uncertain, we next examine potential structural futures and their implications for innovation in the agricultural input industry and beyond. In the final section, we summarize and conclude.

The Restructuring of the Seed, Biotech, and Crop Protection Industries: Some Historical Context

Understanding the structural evolution of the USA and global seed, biotech, and crop protection industries and its relationship to innovation in these industries requires historical context. Since the emergence of a commercial seed industry in the USA over 150 years ago, assets have changed hands frequently. Until the late 1960s, assets in the seed industry were primarily traded among seed firms. Starting in the 1970s, however, multinational petrochemical and pharmaceutical firms became the primary acquirers. Much of this activity has been traced to the introduction of the Plant Variety Protection Act of 1970, which promised to increase returns from plant research and attracted R&D-minded multinationals (Kalaitzandonakes and Bjornson 1997). However, this wave of M&As had little subsequent discernible impact on the structure of the seed industry because the petrochemical and pharmaceutical multinationals mainly acquired and merged small- and medium-size regional seed firms, which lost market share over time (Kalaitzandonakes et al. 2010). Both independent market leaders (e.g., Pioneer, DeKalb) and smaller regional and local seed firms maintained their market positions despite the significant capital resources of the multinational entrants.

At that time, only a few large seed firms maintained extensive breeding efforts and developed proprietary varieties. A few foundation seed firms and some universities also developed and broadly licensed proprietary varieties to a large number of small regional and local seed firms. In turn, these regional seed firms scaled up and distributed a small number of licensed varieties within limited geographic regions and remained competitive through superior local market knowledge and by avoiding the excessive inventory costs that frequently hampered national seed firms (Kalaitzandonakes et al. 2010).

By the early 1990s, many of the multinational firms that led the M&A activity in the previous two decades had divested their seed assets and exited the industry. A handful of multinationals with significant investments in biotechnology and crop protection, however, maintained or expanded their presence in the US seed industry. Indeed, since the advent of agricultural biotechnology research in the mid-1970s, superior seed genetics (germplasm) were recognized as an essential complementary asset for delivering biotechnology traits. For the commercial introduction of a new biotechnology product to be successful, the intellectual property, the biotechnology know-how, and the seed germplasm base had to be coordinated. This need for coordination led to a wave of strategic vertical M&As that changed the structure of the seed, biotechnology, and crop protection industries in the late 1990s.

Strategies to vertically integrate seed and biotechnology assets were as old as the agricultural biotechnology industry itself. Early biotechnology startups, like Agrigenetics, began to acquire regional seed firms in 1975 in order to finance biotechnology research and deliver products to the market. Other leading biotechnology startups (e.g., Celgene, Biotechnica International, and Mycogen) had similar strategies and acquired a number of small- and medium-size seed firms in the 1980s and 1990s (e.g., Kalaitzandonakes 1997; Kalaitzandonakes and Bjornson 1997). It was not, however, until Monsanto and DuPont began their acquisitions that the structure of the seed industry changed. They acquired the two largest independent seed firms, DeKalb and Pioneer, respectively, and kicked off a round of M&As that vertically integrated the biotechnology and seed industries. Dow, Syngenta, Aventis, and AgrEvo (later merged into Bayer) all entered into a number of M&As of seed firms in the last 15 years.

The Impacts of Structural Change on the Global Input Sector

The M&As that drove the restructuring of the USA and global seed industry in the 1990s and the 2000s were vertical in nature and sought to accelerate the commercialization of biotechnology innovations in agriculture. Because all of the multinational biotechnology firms that led the M&As in the seed industry also had significant presence in the crop protection industry, a close integration of these three industries occurred during this time. With the benefit of historical perspective and a number of published studies, we now have a better understanding of the impacts these structural changes had on innovation, new product development, and the competitiveness of agricultural producers.

First, it is now clear that an R&D-minded, vertically integrated industry emerged from the restructuring. Annual spending in the research and development of new biotechnology traits and seed germplasm grew from just over $1 billion in 2000 to more than $4.4 billion in 2015 (Fig. 1). For comparison, the global seed industry was spending less than $300 million on R&D prior to 1996. Indeed, R&D investment in biotechnology traits and seed germplasm development outpaced investment in the development of crop protection products, but both types of R&D investment increased in the last 15 years. In particular, R&D spending for crop protection products increased from almost $1.9 billion in 2000 to $3.3 billion in 2015 (Fig. 1).

Second, the increased R&D spending in the biotechnology and seed industries has generally translated into greater product variety and choice for agricultural producers. For instance, the number of hybrids and varieties sold (Brookes and Barfoot 2015) in the US corn and soybean seed markets more than doubled over the last 15 years (e.g., Magnier et al. 2010). Similarly, a large number of novel biotechnology traits conferring insect resistance, herbicide tolerance, and other useful traits to corn, soybeans, cotton, rapeseed, and other crops were introduced and broadly adopted by agricultural producers in 28 countries over the same period (James 2015).

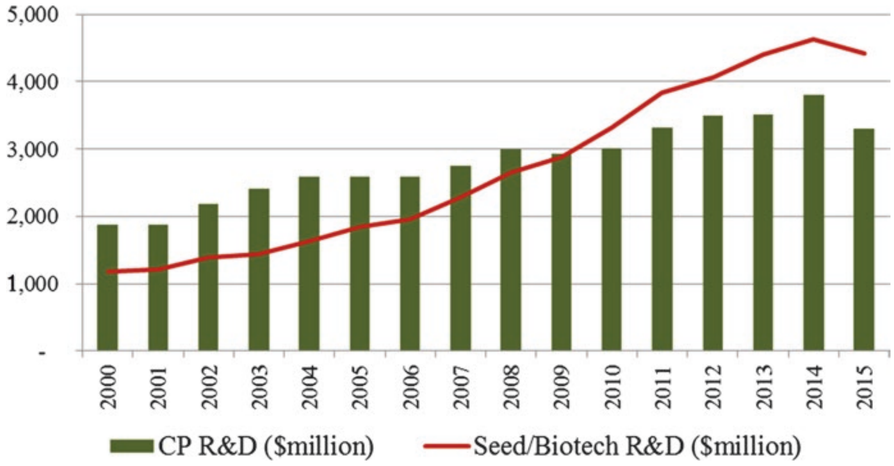

Fig. 1 R&D spending on crop protection, seeds, and biotechnology traits, 2000–2015 (Source: Company data, Phillips McDougal, GfK, Author calculations)

Third, the new seed genetics and biotechnology traits developed through the increased R&D spending in the biotechnology and seed industries led to improved agricultural productivity and farmer profitability (e.g., Qaim 2009; Carpenter and Gianessi 2010; Klümper and Qaim 2014). Economists have estimated the annual economic benefits from new biotechnology traits and seed genetics that were commercialized during this period to be in billions of dollars, with the largest share going to agricultural producers (Falck-Zepeda et al. 2000; Konduru et al. 2008; Alston et al. 2014; Brookes and Barfoot 2015).

Recent Structural Changes in the Crop Protection, Biotechnology, and Seed Industries and their Causes

Successful commercialization of biotechnology innovations as well as improved economics in the global agricultural economy drove the growth of the biotechnology, seed, and crop protection industries in the last 15 years. The global sales of the vertically integrated biotechnology and seed industry grew by $20 billion during this period, from less than $17 billion in 2000 to more than $37 billion in 2015. More than 90% of the sales growth came from the commercialization of novel biotechnology traits. Sales of crop protection products also increased, though at a slower rate – from $28 billion in 2000 to an estimated $51 billion in 2015 (Fig. 2).

During this period of strong growth, however, the integrated biotechnology, seed, and crop protection industries faced some unique challenges and opportunities. On the one hand, a worsening regulatory environment for crop protection and new biotechnology products added costs and delays to R&D, while increased pest

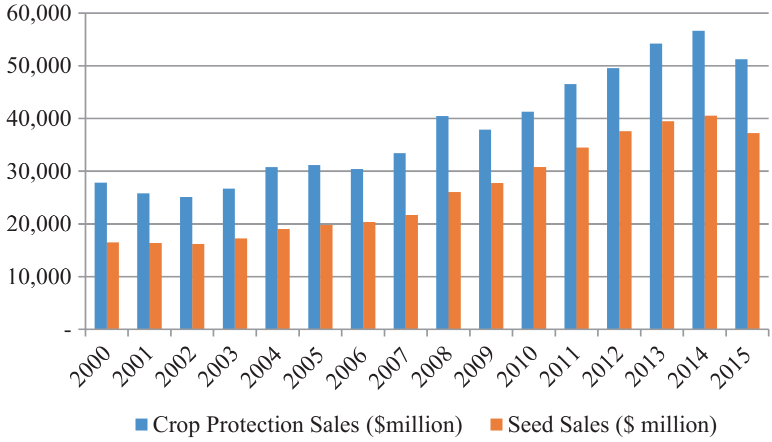

Fig. 2 Global crop protection, biotechnology, and seed sales, 2000–2015 (Source: Data from Phillips McDougal, GfK, and companies; author calculations)

resistance hastened the depreciation rate of the existing crop protection products and biotechnology traits. On the other hand, the emergence of fundamental new discoveries and technical developments (e.g., gene editing and digital agriculture tools) enabled expanded innovation and accelerated new product development in biotechnology, seeds, and crop protection. These challenges and opportunities have shaped the future business model of these industries and have kicked off another round of structural change. As we discuss below, the recent M&A announcements among the Big Six should be understood as part of this latest round of restructuring and consolidation.

A Worsening Regulatory Environment and New Product Development

In recent years, regulatory requirements for crop protection products have become increasingly more stringent, with added demands on environmental, nontarget, and toxicological product profiles. As a result, crop protection firms have had to spend more money and time in their search for new active ingredients that provide improved efficacy and selectivity while at the same time meeting more stringent regulatory requirements. In practice, this has meant screening more molecules in order to find a marketable new active ingredient; carrying out more toxicology, safety, and environmental chemistry tests, both in the greenhouse and in the field; and submitting more voluminous dossiers for regulatory approval and registration. In turn, the average R&D costs for bringing a new crop protection product to the market have increased by more than 50% in the last 15 years – from $181 million in 2000 to $287 million in 2010–2014. This is, in large part, due to the tripling of

Table 1 Average R&D spending for new crop protection product, $ million

	1995	2000	2005–2008	2010–2014
Research	72	94	85	107
Development	65	76	146	147
Registration	13	11	25	33
Total costs	150	181	256	287

Source: Phillips McDougall (2016)

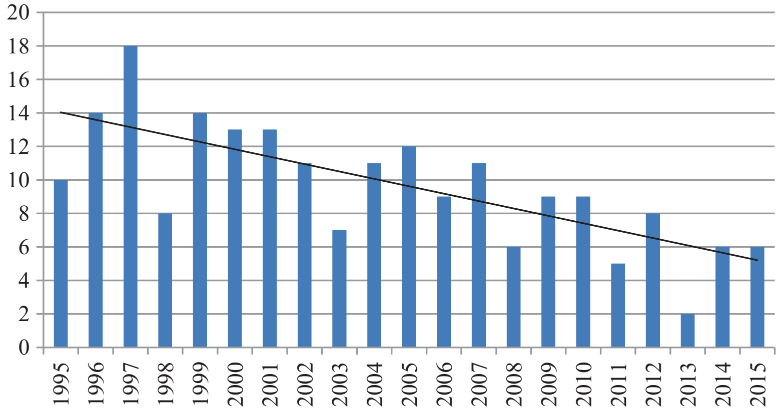

Fig. 3 New product introductions for crop protection, 2000–2015 (Source: Phillips McDougal, various years)

development costs associated with an increased number of field trials and safety assessments and the more than doubling of registration costs (Table 1). The time required to get a new crop protection product approved and on the market has also increased – from 8 to more than 11 years.

Because of the higher average R&D costs, and despite a significant increase in the total R&D spending, the number of new product introductions, with new active ingredients, continued to decline in the crop protection industry over the 2000–2015 period (Fig. 3).

Increasingly stringent regulations, especially in the EU, have also pushed firms to discontinue the sale of a large number of existing crop protection products as reregistration could not be achieved. The combination of deregistration of existing chemistries and the slowdown in new product introductions has left the crop protection industry with a smaller product portfolio and a smaller cohort of proprietary, patent-protected products. In 2015, more than 60% of the crop protection market was composed of generics, up from 36% a decade earlier (Table 2). As such, over the last 15 years, the global market for crop protection products has experienced significant competitive price pressure.

Increased regulatory costs and delays have also been experienced in the development of new biotechnology traits. Regulatory costs for the approval of a new biotechnology event in the mid-2000 were estimated to be $7.5–$15 million

Table 2 Share of proprietary and generic crop protection products

Chemistry/AI	1995	2005	2015
Proprietary	34.9%	29.9%	19.5%
Proprietary off patent	34.9%	34.1%	19.6%
Generic	30.2%	36.0%	60.9%
	100.0%	100.0%	100.0%

Source: Philips and McDougal, various issues

(Kalaitzandonakes et al. 2007). Preliminary estimates of regulatory costs for the approval of new biotechnology events during the 2014–2015 period suggest that such costs have almost doubled (author unpublished data and estimates). Similarly, the amount of time for the regulatory review and approval of new biotechnology events has increased in almost every jurisdiction. For the moment, regulatory cost increases and delays have not visibly affected the rate of submissions of new biotechnology events, which has remained constant during the last 10 years (though it has declined since the previous decade).[2] Some studies have estimated that regulatory delays alone can substantially diminish the economic value of new biotechnology traits (e.g., Kalaitzandonakes et al. 2015). It is therefore possible that in the absence of higher regulatory costs and delays, the rate of new biotechnology trait introductions could have been higher than the one realized.

Pest Resistance Buildup and New Product Development

The biotechnology and crop protection industries have also faced worsening pest resistance[3] to many of their products over the last 15 years. Across the globe, an increasing number of insect pests, weeds, and pathogens have been reported as demonstrating resistance to various chemistries (Fig. 4).

Pest resistance to commonly used pesticides is not a new issue. Early reports of resistant insects and weeds both date from the early twentieth century (Retzinger and Mallory-Smith 1997; Sparks and Nauen 2015). What does seem to be new, though, is the number of resistant species and the rate at which newly resistant species are appearing, particularly among weeds and pathogens. A number of factors contribute to the development of resistance, including the reproductive biology and ecology of the pest and the frequency and intensity of pesticide application (Whalon et al. 2008). Resistance is most closely associated with the intensive and exclusive use of one pesticide or a small group of pesticides with the same or similar modes

[2] The estimated rate of submission of new biotechnology events is based on data from USDA APHIS.

[3] Pest resistance is defined as a "genetically based decrease in susceptibility to a pesticide" (Tabashnik et al. 2014).

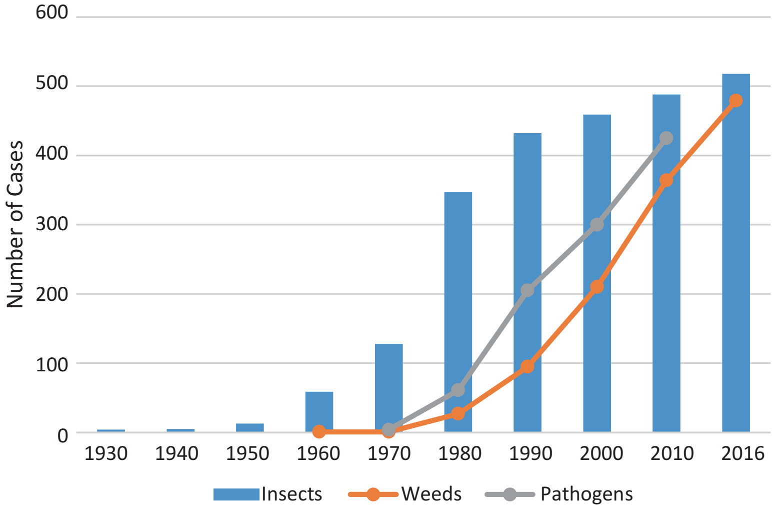

Fig. 4 Pest resistance buildup over time (Source: Data from FRAC, APR database, and Weedscience.org; Author calculations)

of action. Such a pattern of use places pest populations under extreme, focused selection pressure that greatly increases the probability of resistance (Powles 2008).

Global adoption of insect-resistant (IR) and herbicide-tolerant (HT) biotechnology crop varieties, along with sustained use of the herbicides associated with HT crops, mainly glyphosate, has also placed significant selective pressure on many pests, resulting in increasing pesticide resistance. Worsening resistance to glyphosate has been documented in various studies (e.g., Tabashnik et al. 2014; Heap 2015). Insect resistance to biotech IR crops has also been documented in a few occasions. In 2005, one species of insect pests of cotton or corn had populations reported to be sufficiently resistant to a Bt protein so as to significantly reduce its effectiveness in pest control. In 2012, it was reported that five pest species had developed significant resistance to four different Bt toxins (Tabashnik et al. 2013).[4]

The reduced efficacy of existing biotechnology traits and chemistries in the face of increased pest resistance limits the size of the effective product portfolio and the potential income stream of the biotechnology and crop protection industries. In response, these industries sought to slow down pest resistance to existing products and to develop new ones with novel modes of action. The crop protection industry has faced the most significant challenges and has made the biggest adjustments. In the last 15 years, firms in the crop protection industry, especially those who spend

[4] Insect resistance is managed by two main strategies: Newer biotechnology cultivars have groups of multiple Bt traits, known as pyramids, among which cross-resistance is rare, making it highly unlikely that pest species will develop resistance to all members of the pyramid. Farmers also plant refuges of non-Bt crops that will harbor populations of susceptible pests, diluting the genetic influence of resistant individuals in future generations. Natural refuges of non-Bt plants other than the target crop can also serve this function but are generally less effective (Jin et al. 2015).

significant sums on R&D,[5] progressively directed more resources toward the development of:

- New product formulations that combine multiple existing chemistries in order to improve product efficacy and protect from pest resistance buildup through the use of multiple modes of action.
- New seed treatments in order to improve delivery of an effective bundle of multiple crop protection products, applied at low rates and with improved application convenience.
- New biologic products[6] in order to reduce the regulatory burden of bringing new products to the market and develop new modes of action. Particular attention has been paid to the development of biologicals that can be used in combination with synthetics, especially in seed treatments.

R&D Portfolio Changes

A number of firm strategies have been put to work in order to enable the above portfolio and R&D adjustments in the crop protection, seed, and biotechnology industries. More specifically:

First, a large number of licensing and marketing agreements as well as strategic research collaborations were put in place across the whole crop protection industry in order to allow the broad use of available chemistries in proprietary formulations and in seed treatments. For instance, determining which foliar pesticides may be used as seed treatments requires significant R&D effort. As such, Dow AgroSciences and Syngenta established a long-term agreement so that Dow's active ingredients could be screened by Syngenta for use in new seed treatments. Similarly, Monsanto came into the seed treatment business in 2011 through collaborations with some 25 firms which provided access to synthetic active ingredients and biologicals.

Second, significant R&D effort was expended in order to expand the market scope and efficiency of seed treatments. Technical advances from such R&D efforts include:

- New product formulations with expanded functionality (e.g., moving from a single fungicide application for early-season seed protection to the use of multiple active ingredients that provide insect, disease, and nematode protection and can stimulate growth for up to 45 days)

[5] It is important to note that Syngenta, Bayer, BASF, Dow, and DuPont represent almost 80% of the total annual R&D budget and the bulk of spending in the discovery of new active ingredients in the crop protection industry.

[6] Biologics are crop protection products based on microorganisms, biochemicals produced from biological sources, microbials, and other similar sources.

- The ability to combine biologicals and synthetics in seed treatments (e.g., Bayer's initial use of the Votivo biological seed treatment that disrupts nematode feeding along with the synthetic Poncho, in 2011)
- Various improvements in the use of spray and other application equipment (e.g., improvements in the flow of seeds through treater equipment, flow through standard grower planters, etc.)
- The ability to apply overtreatments at a retailer location or at the farm in order to enhance the scope of seed treatments according to local needs
- The development of polymers and coatings that improve product effectiveness and usability

Based on such adjustments in the R&D portfolio of key firms, particularly the Big Six, sales of seed treatments have grown fast. The market was valued at $2.65 billion in 2011, $3.6 billion in 2013, and between $4 and $5.6 billion in 2016. Bayer, Syngenta, Monsanto, and BASF are the most significant suppliers with some 80% share of the seed treatment market.

Third, a large number of research strategic alliances have been put in place between the Big Six and a number of startups and other firms that specialize in the development of biologicals in order to accelerate innovation in this area (Table 3).

Fourth, a number of specialists and startups with R&D in biologicals have been acquired, mostly by the Big Six, and their research assets have been internalized and integrated into the firms' R&D portfolios (Table 4). For instance, through the acquisition of specialist Backer Underwood for $1 billion, BASF formed the core of its biologicals unit in 2012. Accelerated product development has led to increased sales in biologicals in recent years. As a category, biologicals were valued at $2.25 billion in 2015 and are projected to grow to $4.5 billion by 2023.

Table 3 Selected agreements among firms with R&D in biologicals

Year	Firm 1	Firm 2	Type of agreement
2010	Bayer	Heads UP Plant	Research agreement – Seedling
2011	FMC	Chr. Hansen Biologicals	Commercialization agreement
2011	Bayer	Koppert biological	Commercialization agreement
2011	Syngenta	Pasteuria	Research agreement
2013	Syngenta	Isagro	Commercialization agreement
2013	Monsanto	Novozymes	Joint venture – Research
2013	Monsanto	SGI	Research agreement
2014	Syngenta	Stockton	Distribution agreement
2014	Monsanto	Preceres	Joint venture – Research agreement
2014	Syngenta	AgBiome	Research agreement, investment
2015	Dow	Radiant genomics	Research agreement
2015	Dow	Synthace	Research agreement
2016	Monsanto	Second genome	Research agreement
2016	Dow	TeselaGen	Research agreement

Source: Author

Table 4 Selected M&As of firms with R&D in biologicals

Year	Firm 1	Firm 2	Type of agreement
2009	Bayer	AgroGreen	Acquisition of assets
2011	Syngenta	Marrone bio innovations	Equity investment
2012	Syngenta	Pasteuria	Acquisition
2012	Syngenta	DevGen	Acquisition
2012	BASF	Becker underwood	Acquisition
2012	Bayer	AgraQuest	Acquisition
2013	Bayer	Prophyta	Acquisition
2013	FMC	Center for Agr and Env sol	Acquisition
2013	Monsanto	Agradis	Acquisition
2013	Monsanto	Rosetta green	Acquisition
2014	Bayer	Biagro	Acquisition
2014	Bayer	Belchim crop protection	Acquisition
2014	Monsanto	Preceres	Firm establishment
2015	DuPont	Taxon biosciences	Acquisition

Source: Author

Discoveries and New Market Opportunities

In addition to making investments in response to regulatory and pest resistance challenges, the Big Six (and others) has also made large R&D investments in areas of opportunity. Fundamental innovations, such as digital agriculture and genome editing, have created such opportunities.

Precision agriculture (PA) technologies, first commercialized in the 1990s, are widely regarded as having the potential to make farming much more efficient and productive. With PA, producers have the ability to manage crop inputs on a fine scale instead of treating each field, or their entire holding, as one homogeneous unit. By tailoring the use of inputs to within-field variation, precision agriculture can minimize waste, and thus costs, as well as increase overall yields, thereby enhancing farm profitability while also granting environmental benefits. More recent developments include on-the-go monitors; stationary plant canopy, soil, and atmospheric sensors; and remote imaging sensors carried by drones, aircraft, and satellites that provide additional information inputs for more efficient scouting and even more targeted management.

This increasing number of sensors has multiplied the volume and variety of data available about each agricultural field, and their increasing sophistication speeds the movement of data from collection to analysis to use. Large datasets covering multiple years and a wide geographical area enable scientists to uncover more subtle relationships among variables with a higher degree of confidence. Exploiting "big data" capabilities means that agronomic input performance can be optimized by matching genetics with local growing environments and farm practices.

Progress in hardware, software, analytics, and data provides producers with continually improving ways to visualize and use agricultural data in ways that directly enhance their management decision making. For instance, Internet connectivity, cloud storage, a variety of mobile devices, and other communications capabilities can tie together sensors, variable rate implements, and computing assets to optimize farm management.

Because PA, big data, and digital agriculture have significant synergies with input performance research, biotechnology, seed, and crop protection firms and especially the “Big Five” (the Big Six minus BASF) have made large investments, both internally and through strategic alliances and acquisitions, in this area. DuPont and Monsanto have the most advanced positions.

DuPont (through its Pioneer subsidiary) has developed its Encirca platform – a suite of decision tools that combine soil mapping, local weather, various crop models, and other data that seek to optimize the choice of cultivar as well as seeding populations and seeding rates; create planting prescriptions; track crop performance; manage phosphorous, potassium, and other nutrients; and make real-time adjustments as weather and growing conditions change. DuPont acquired the firm MapShots, a software development company with crop management planning tools and GIS/PA functionality, to add to its digital agriculture platform.

Monsanto has also made significant investments starting with its Integrated Farming System (IFS) program in 2010 which provided field- and zone-level decision support to growers on seed genetics and agronomic management. Through aggressive internal research expansion and several acquisitions, Monsanto has expanded its PA/digital agriculture platform significantly in recent years adding hardware, software, data, and analytics capabilities. It acquired Precision Planting for more than $200 million in 2012, Climate Corp for $930 million in 2013, the soil analysis specialist Solum in 2013, and startup 640 Labs in 2014; the firm has also made a number of investments in other startups.

Syngenta, Bayer, and others have also made acquisitions and investments in a number of digital agriculture specialists in the last several years. For instance, since 2012, Syngenta has made investments in digital agriculture, robotics, and satellite imagery startups including the firms S4, Phytech, Blue River Tech, Planet, and Agworld Pty. Bayer has similarly made investments in Zoner, proPlant, and Agrar.

The Emerging R&D and Business Model of the Agricultural Input Industry

From the description of the recent firm strategies above, it should be clear that several multinational firms in the agricultural input industry have secured a significant presence in the crop protection, biotechnology, and seed industries and have adopted an R&D and business model which brings together multiple product platforms (biologicals, synthetics, germplasm, biotechnology traits, data and analytics, etc.) in order to produce technology bundles that can maximize yields and cost efficiencies in crop production. Multiple chemistries and biologicals can be combined by the

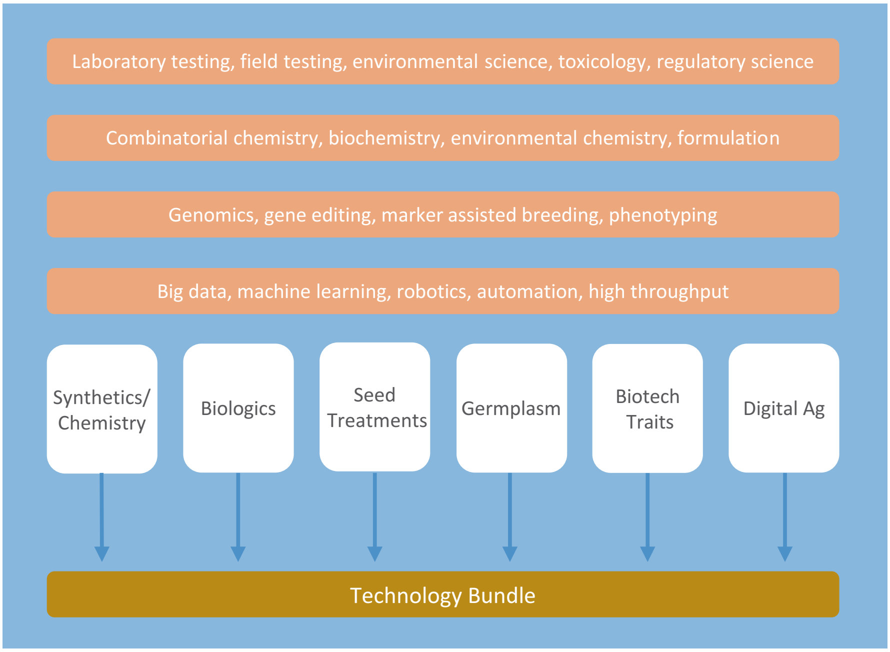

Fig. 5 The integrated technology platform (ITP) R&D model

manufacturer or the distributor in a seed treatment to protect from insects, nematodes, and other pests while enhancing fertility and nutrient availability. Growers or distributors can further "customize" seed defenses through localized overtreatments appropriate to local environments. These seed treatments can be combined with superior genetics that have been developed for native resistance to other pathogens or modified with biotechnology traits that can assist with limited moisture, insect resistance, and weed control through selected herbicide tolerance. Digital agriculture and precision farming can ensure compatibility with soil and the larger environment and can inform the optimal variety choice and seed populations. In effect, this expansive R&D business model calls for the integrated use of multiple vertical technology platforms in the development of technology bundles with maximum yield and cost-efficiency potential (Fig. 5).

Synergies are derived by coordinating the development of technology bundles rather than individual technologies alone. The model therefore calls for maximizing the collective performance of the various technology platforms at minimum development and implementation costs. Synergies may also be possible in the various capabilities and knowledge domains that are needed for the practical implementation of the various technology platforms (e.g., genomics, genome editing, marker-assisted breeding, biochemistry, combinatorial chemistry, robotics, automation, artificial intelligence and machine learning, laboratory and field testing, regulatory science, etc.). These capabilities may use common tools and may be employed across technology platforms.

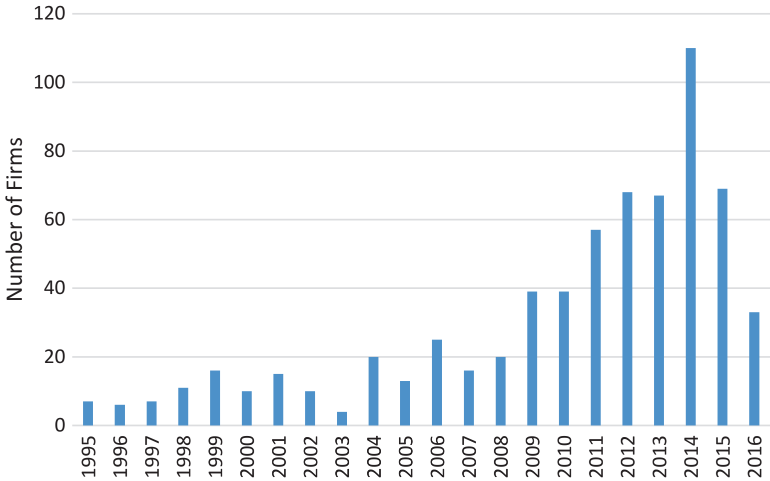

Fig. 6 Entry of VC funded firms in the agrifood sector, 1995–2016 (Source: Author data and calculations)

The success of this R&D and business model depends on its ability to deliver input innovation with maximum performance in the field through superior bundles but also through its efficiency and cost effectiveness in delivering more input innovation per R&D dollar spent. Given the increasing technology performance transparency it promotes at the field and farm level through its digital agriculture and PA tools, it is a maximum performance in a grower's field that will drive economic value and competitive position for the technology suppliers that have adopted it.

Innovation in the Agricultural Input Industry and Firm Entry

While key multinationals have led the development and implementation of the integrated technology platform (ITP) model described above, a large number of other firms have embraced its possibilities. Indeed, M&As and corporate investments in biotechnology, biologics, digital agriculture, and other startups have prompted the interest of entrepreneurs as well as of venture capitalists, private equity firms, and other investors. As a result, there has been a significant uptick in new firm creation and firm entry since 2009. In 2014, when the largest number of new firms entered the agrifood sector, there were more than 110 startups that received funding from institutional investors; most of them specialized in digital agriculture, biotechnology, and biologicals (Fig. 6).

It is expected that this large number of specialists will support the development of the ITP model described above. Some might contribute as parts of research and product development networks through contracts or strategic alliances. Others might be acquired and added to the core capacity of larger entities. Yet others might grow to become independent competitors in the development of product bundles or bundle components. Still others might fail altogether. Whatever their fate, the large population of new entrants suggests more innovation should be expected in the agricultural input industries in the years to come.

R&D Investment and the Influence of the Agricultural Commodity Cycle

The heightened firm entry as well as the increased R&D investments and associated portfolio adjustments made by incumbents in the crop protection, biotechnology, and seed industries in the last 15 years have been enabled by an unprecedented growth in global crop agriculture – a golden era of sorts. For instance, the global farm-level value of corn, soybeans, cotton, and rapeseed grew by more than 300% within just over 10 years – from $116 billion in 2000/2001 to almost $490 billion in 2012/2013. Crop yields, crop acreage, crop supplies, as well as crop prices all grew as the increase in demand for agricultural commodities outpaced supply expansion (Fig. 7).

This increased farm revenue spurred demand for yield-increasing inputs and accelerated the adoption of biotech crops and the use of crop protection products. As such, the revenue of the crop protection, biotechnology, and seed industries grew in parallel. For instance, as Fig. 8 illustrates, global spending on crop protection products, biotechnology traits, and seeds by corn, soybean, cotton, and canola/rapeseed producers grew from an estimated $17 billion in 2000 to $49 billion in 2014 – almost 200%. Given that these four crops account for 70% of global farmer spending

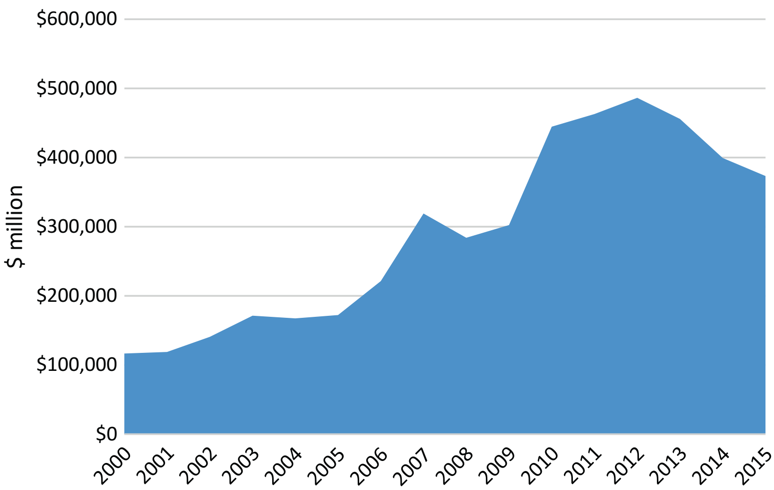

Fig. 7 World crop receipts for corn, soybeans, cotton, and canola, 2000–2015 (Source: USDA data, Author Calculations)

in seeds and just over 30% in crop protection products, they give an accurate depiction of the close link between farm revenue and spending in these inputs.

Crop revenues, however, peaked in 2012/2013 and have since declined by almost 25%, though they still remain well above historical levels. Spending on crop protection, biotechnology, and seeds has also followed the downward trend, though with a short lag. In turn, following the downward trend in industry sales, R&D spending in crop protection, biotechnology, and seeds declined in 2015 for the first time in the last 15 years (see Fig. 8).

Given the close link between crop sales, input sales, and R&D spending in the biotechnology, seed, and crop protection industries, understanding the direction and pace of agricultural commodity cycles becomes essential. Based on our estimates and forecasts, global sales of seeds and crop protection products likely declined slightly in 2016 and will likely decline somewhat in 2017 before they begin to recover in 2018, reaching levels similar to those of 2014 5 years later (Fig. 9). This downturn in revenue confronts the expansive vision of the ITP model in the biotechnology, seed, and crop protection industries. Growing revenue and R&D spending are required to finance the ITP model; in the face of continuing market weakness, consolidation appears to have become a primary strategy among the top firms in the agricultural input sector that are pursuing this innovation model.

Given the above considerations, the underlying economics of the global agricultural sector and the fate of the proposed M&As (as well as other factors) should be expected to shape the future R&D model of the biotechnology, seed, and crop protection industries, at least in the short run. Since structural changes are still ongoing and since there are policy uncertainties (e.g., the decisions of antitrust authorities) and market uncertainties (which influence the direction and pace of the commodity cycle, etc.), we might explore possible scenarios of structural futures in the agricul-

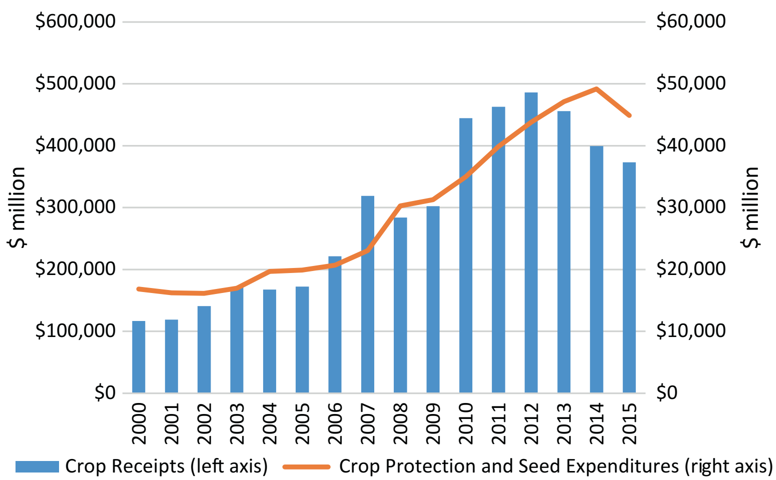

Fig. 8 Receipts and expenditures in crop protection and seeds for selected key crops (Source: Author calculations)

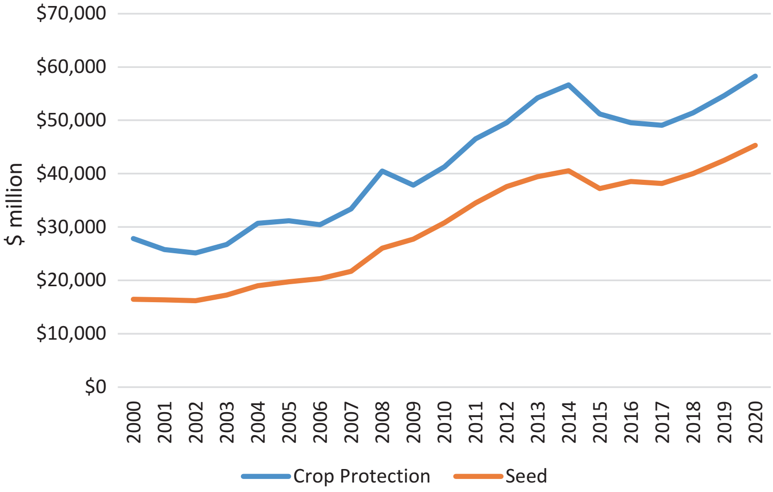

Fig. 9 Global crop protection and seed sales: history and forecasts (Source: Author calculations and forecasts; underlying crop revenue forecasts WAEES and FAPRI, 2017)

tural input industry and draw conclusions about their potential impacts on the firm strategies, R&D spending, industry structure (e.g., entry, M&As, strategic alliances), innovation, and the competitiveness of growers.

Industry Scenarios of Structural Change and Innovation

Future scenarios can be constructed by envisioning discrete potential outcomes in the decisions of the antitrust authorities (they allow the proposed M&As or not) and in the direction of the commodity cycle (return to growth or worsening recession).[7] Such representative potential futures can be illustrated in a 2X2 matrix as in Table 5, and their conditioning effects can be examined in some detail based on the analysis presented above.

[7] There are of course other external factors of consequence. However, the agricultural commodity cycle and the fate of the pending M&As are the most impactful in the short run, so we focus on them for our scenario analysis.

Table 5 Scenario analysis through key drivers

	Agricultural growth	Agricultural recession
M&As allowed	SCENARIO 1	SCENARIO 2
M&As not allowed	SCENARIO 3	SCENARIO 4

Scenario 1: Proposed M&As are Allowed and the Agricultural Economy Grows

A world where the agricultural economy recovers from its current levels and grows again would spur producer spending in agricultural inputs and hence growth in the revenue base of the biotechnology, seed, and crop protection industries. Increased revenue in these industries would support higher R&D spending. A world where the proposed M&As are allowed by antitrust authorities would also support higher R&D spending, as the increased scale and scope of the consolidated firms would enable the pursuit of the more expansive ITP model. As a result, R&D would increase among key players and overall (Table 6).

Pursuit of the ITP model would call for more research alliances among integrated firms, large specialists, and various startups as numerous technical capabilities and solutions would need to be brought to bear in the development of new technology bundles. Entry of new firms would likely increase from current levels as the potential for R&D outsourcing to startups and other specialized firms would expand and M&As of startups would provide opportunities for investor "exits." Increased entry is also supported by the growth in the industry revenue base.

Increased R&D efficiency and spending, a greater number of technology alliances, and increased entry of new firms all imply greater amounts of innovation in crop protection, biotechnology traits, germplasm, digital agriculture, and other technologies. More input innovation leads to economic gains from higher yields and lower costs in crop production, and agricultural producers can capture a share of

Table 6 Summary of impacts in scenario analysis

	Agricultural growth	Agricultural recession
M&As allowed	R&D spending ↑	R&D spending ↓
	Number of new firms ↑	Number of new firms ?
	Number of alliances ↑	Number of alliances ↑
	Input innovation ↑	Input innovation ?
	Producer competitiveness ↑	Producer competitiveness ?
M&As not allowed	R&D spending ↑	R&D spending ↓
	Number of new firms ?	Number of new firms ↓
	Number of alliances ?	Number of alliances ?
	Input innovation ↑	Input innovation ↓
	Producer competitiveness ↑	Producer competitiveness ↓

these economic gains. Producers would therefore gain in competitiveness and profitability under this scenario.[8]

Scenario 2: Proposed M&As are Allowed and the Agricultural Economy Contracts

A world where the agricultural economy continues to contract from its current levels would lead to reductions in agricultural input spending and hence further contraction in the revenue of the biotechnology, seed, and crop protection industries. Lower revenues in these industries would lead to reduced R&D spending. A world where the proposed M&As are allowed by antitrust authorities, however, would support higher R&D spending at the firm level, as increased scale and scope in the consolidated firms would enable the pursuit of the more expansive ITP model. R&D spending would therefore increase among some firms, but the overall industry R&D spending would likely decline, at least in the short run (Table 6).

[8] Producers also benefit from innovation performance transparency in their fields. Yields, costs, and the economic parameters for input innovations produced in the future should be progressively more measurable through the digital agriculture tools which are currently being developed. This increased performance transparency should allow better valuation of benefits and costs for input innovations.

Pursuit of the ITP model by some key firms would encourage more research alliances among integrated firms, large specialists, and various startups as numerous technical capabilities and solutions must be brought to bear in the development of new technology bundles. Whether entry of new firms would increase or decrease from current levels is uncertain. Potential for R&D outsourcing to startups is supported by the ITP model, but M&As of startups would likely become less lucrative as a contraction in the industry revenue base would limit future opportunities for new firms.

While overall R&D spending in the biotechnology, seed, and crop protection industries would decrease, at least in the short run, successful implementation of the ITP model by leading firms could yield efficiency gains in R&D and could lead to greater amounts of input innovation per R&D dollar spent. As a result, the net impact on input innovation across the three industries is uncertain.

Since the direction of input innovation drives the economic gains from higher yields and lower costs in crop production, some of which are captured by agricultural producers, it is uncertain whether producer competitiveness and profitability improves or worsens under this scenario.

Scenario 3: Proposed M&As are not Allowed and the Agricultural Economy Recovers

A world where the agricultural economy recovers from its current levels and grows would spur producer spending in agricultural inputs and growth in the revenue base of the biotechnology, seed, and crop protection industries. Increased revenue in these industries would support higher R&D spending. A world where the proposed M&As are not allowed by antitrust authorities, however, would lead to lower R&D spending as the scale and scope that are currently considered necessary to support of the more expansive ITP model would not be immediately possible. Overall, R&D spending across the biotechnology, seed, and crop protection industries would likely increase from current levels (Table 6).

As firms could choose to scale back parts of ITP model, they could internalize some of the research and development and limit research alliances with other firms. The expanded industry R&D spending, however, could support some alliances as well as M&As of startups and specialists. Whether alliances or entry of new firms would increase or decrease from their current levels is therefore uncertain in this scenario.

Since the overall R&D spending in the biotechnology, seed, and crop protection industries would tend to increase, the level of input innovation would also increase from its current levels. This increase in innovation, however, would likely be less than in scenario 1 since the ITP would not be fully implemented and associated efficiency gains in the R&D process may not be realized. As a result, agricultural producer competitiveness and profitability would improve but at levels lower than those in scenario 1.

Scenario 4: Proposed M&As are not Allowed and the Agricultural Economy Contracts

A further decline in the agricultural economy from its current levels would lead to reductions in agricultural input spending from current levels and hence further contraction in the revenue of the biotechnology, seed, and crop protection industries. Lower revenues in these industries would lead to reduced R&D spending. A world where the proposed M&As are not allowed by antitrust authorities would also lead to lower R&D spending as the scale and scope that are currently considered necessary to support the more expansive ITP model would not be immediately possible and some portions of this R&D model may need to be scaled back. As a result, R&D spending would decrease among key players and overall (Table 6).

Research alliances among integrated firms, large specialists, and various startups could increase in order to reduce R&D expenses or could decrease as some R&D projects would be shelved in cost cutting measures and some parts of the ITP are scaled back. As such, it is unclear whether research alliances under this state of the world would increase or decrease from their current levels. Entry of new firms would decrease from its current level as M&As of startups would become less lucrative, parts of the ITP are scaled back, and a contraction in the industry revenue base would limit future opportunities for new firms.

Declining R&D spending and a potential departure from the full implementation of the ITP, along with reduced entry of new firms in the biotechnology, seed, crop protection, digital agriculture, and related industries, all imply less input innovation. Lower input innovation implies diminished opportunities for associated economic gains. Unrealized gains in competitiveness and profitability from foregone input innovation would leave agricultural producers worse off in the long run.

Summary and Concluding Comments

In this chapter we have described two cycles of structural change in the biotechnology, seed, and crop protection industries. In the late 1990s, biotechnology firms vertically integrated into the seed industry in order to acquire advanced germplasm as a delivery mechanism for biotechnology traits. Many of the firms that led the M&As in the seed industry also owned assets in the crop protection industry. This cycle of consolidation produced an integrated, research-minded sector that spent copiously on R&D over the last 15 years. Of course, not all biotechnology, seed, or crop protection firms spend significant resources in R&D, and not all have a presence in all three industries. There is a large number of specialized firms in each of the biotechnology, seed, and crop protection industries, many of which have limited R&D capacity. Still, the top firms, and certainly the “Big Six,” do emphasize R&D and stake their market positions on such investments.

Increased R&D spending in the biotechnology, seed, and crop protection industries over the last 15 years was supported by an unprecedented expansion in the global agricultural economy. In turn, high R&D spending in these industries produced innovations which increased yields and created cost efficiencies in crop production. Key challenges (increasing regulatory costs and delays in the approvals of new crop protection products and biotechnology traits, regulatory restrictions for crop protection product reregistration, and increasing pest resistance to crop protection and biotechnology traits) as well as opportunities (fundamental innovations in digital agriculture, gene editing, and other technology platforms) also confronted these three industries in recent years. Through these challenges and opportunities, firms with large R&D assets in biotechnology, seeds, and crop protection, and especially the Big Five, began to envision and implement a new R&D model – one where multiple pest control and yield-increasing input technologies could be coordinated and integrated into comprehensive input innovation bundles.

In effect, coordination of multiple technology platforms in the development of such innovation bundles could reduce the regulatory burden by focusing on less regulated solutions, when available (e.g., biologics, conventional genetic traits); extend the productive life of existing technologies through pyramiding to slow pest resistance buildup (e.g., multiple chemistries in seed treatments or reinforcing stacked biotechnology traits); choose the best solutions among technologies that could substitute for one another (e.g., chemistries, biologics, or biotechnology traits targeting the same pests); coordinate the development of complementary technologies to maximize their value (e.g., new herbicides and herbicide-tolerant traits); and optimize the efficacy of input technologies through improved field placement, scouting, and integrated management through "big data," advanced analytics, and other digital agricultural technologies.

Coordination of multiple technology platforms to produce innovation bundles could, in principle, make spending in R&D more efficient by leveraging synergistic research skills and assets, reducing duplication in product development, and producing more robust and efficacious technology solutions for agricultural producers. Of course, such an expansive and complex integrated research model, requiring coordination across multiple technical platforms with uncertain outcomes and timelines, is not without risks. If successful, however, this R&D and innovation model could produce more agricultural input innovation per R&D dollar spent.

Investments and market strategies implemented by the "Big Five" and others in the past few years indicate that the ITP model of R&D has been embraced in earnest. Indeed, these key firms have made large investments in the development of seed treatments, biologicals, and digital agricultural technologies, while they have reinforced their positions through increased R&D spending and investments in biotechnology, seeds, and chemistry. They have also sought to consolidate through the recently announced M&As. Presumably the integrated innovation model calls for a much higher level of R&D spending that cannot be currently supported by the existing level of firm sales.

The commodity down cycle which began in 2013 appears to have accelerated the perceived need for consolidation among the Big Five as the organic revenue growth necessary to finance the expanding R&D model was not expected, due to the declining agricultural commodity prices and input demand. As such, the recently announced M&As among the Big Five should be understood as one more step toward the implementation of the ITP model pursued in the biotechnology, seed, and crop protection industries.

To the extent that coordination and integration across the different technology platforms as in Fig. 5 can produce more innovation per R&D dollar spent, the ITP model will be implemented irrespective of external conditions. Still, key external factors, such as the antitrust allowances of the proposed M&As and the duration of the ongoing agricultural commodity cycle, can have significant conditioning effects in the short term. These effects were examined through scenario analysis. What the scenario analysis presented above clarifies is that policy choices matter and that industry structure and innovation will continue to be inextricably tied to each other in the agricultural input sector.

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