Innovation and Technology Transfer Among Firms in the Agricultural Input Sector

Nicholas Kalaitzandonakes, Alexandre Magnier, and Christos Kolympiris

Abstract Firms in the agricultural biotech and seed sectors have increased their R&D spending exponentially over the last three decades. The number of patents secured by major integrated biotechnology and seed firms also increased exponentially over this period. We find no evidence of strategic patenting to explain the increase in volume; the increased number of granted patents, therefore, most likely indicates accelerating product innovation in the industry. Technology transfer among private firms in this sector has been increasing as well, as reflected in a large number of licensing and cross-licensing agreements for the commercialization of patented biotech traits and seed germplasm across different suppliers. New product introductions and variety (new biotech traits and hybrids) increased significantly over the last two decades, while the average product life cycle of hybrid seeds declined. All these indicators point to accelerating product innovation and augmented product choices in this market segment.

Introduction

Firms in the US agrifood sector have continued to increase their research and development (R&D) spending over the last several decades and since the 1980s private sector R&D investments have outpaced those of the public sector (Fuglie et al. 2012). Growth in private R&D spending has been particularly significant in the agricultural input sector where investments in biotechnology and improved seeds have expanded quickly in this period.

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N. Kalaitzandonakes et al. (eds.), *From Agriscience to Agribusiness*, Innovation, Technology, and Knowledge Management, https://doi.org/10.1007/978-3-319-67958-7_9

Private R&D investments in the agricultural input sector have been motived by increased technical opportunity (Schimmelpfennig et al. 2004; Heisey et al. 2005; Fuglie and Walker 2011), improved appropriability (Alfranca and Huffman 2003; Fuglie and Walker 2011), and the worldwide expansion of input markets (Pray and Fuglie 2001; Shoemaker et al. 2001; Fuglie and Walker 2011). Innovations from private sector R&D investments have been found to raise agricultural productivity and to increase social welfare. For example, private R&D in agricultural biotechnology has produced novel insect-resistant and herbicide-tolerant crops which have been broadly adopted since 1996, when they were first introduced (James 2012). Economists have estimated the annual social benefits from such biotech crops to be in the billions of dollars (Falck-Zepeda et al. 2000; Qaim 2009; Brookes and Barfoot 2010; Alston et al. 2014).

A portion of those benefits have to be captured by the innovating firms in order to finance continuing R&D investments. Thus firms engaged in the development of new genetics, novel biotech traits, or other agricultural input innovations are expected to charge prices that are higher than their marginal costs in order to recoup their fixed R&D costs (Kalaitzandonakes et al. 2010).

Ensuring that firms are able to charge sufficiently high prices is the main function of the patent system. A patent gives the innovating firm a certain amount of market power, in that it confers the exclusive right to control the market supply, and hence the price, of the new product for a given period of time. Without the prospect of earning prices above marginal costs through the exercise of that market power, firms would have no incentive to invest in R&D.

Patents are not an unqualified good, however. Some researchers in this area have noted the potential for overly aggressive patent strategies to produce thickets, a situation where one product is covered by multiple patents. This can go beyond the initial logic of patent awards and inhibit further innovation through fear of patent infringement (Cockburn and MacGarvie 2009; Jaffe and Lerner 2011). In fact, Boldrin and Levine (2008) argued that such inhibition is an unavoidable feature of the patent system. At a minimum patents represent an intentional barrier to the wider adoption of the patented innovation, for the benefit of the innovator. Transferring the patented technology to another firm for some purpose may still be in the innovator's interest, though. Licensing and cross-licensing agreements serve to effect the transfer of patent rights to protected innovations to the benefit of both firms involved in the transaction. Hence, licensing of patented innovation can promote technology transfer across firms and support innovation.

While there is much research on the transfer of technology from the public to the private sector, very little is known about licensing activity between firms. In this chapter we examine recent trends in R&D spending, patent acquisition, and licensing activity involving seeds and biotech traits in the USA. Because time lags between research, discovery, technology patenting, new product development, and commercialization can be rather long in the case of agricultural biotechnologies and crop improvements, all such indicators provide different but complementary windows in the innovative activity and technology transfer in this industry. We focus on the US biotech and seed industries because in the last two decades, they have been the locus of the largest increases in private R&D investments and the most significant structural changes.

The rest of the chapter is organized as follows: In the next section, we provide a brief historical account of the emergence of the integrated biotech/seed industry and review its R&D spending for the period of interest. We then go on to review trends in patent acquisition for biotechnologies and seeds and assess whether strategic patenting might be inhibiting innovation in this industry. In section "Product Licensing", we analyze licensing activity among biotech seed firms and draw conclusions about the factors that drive licensing agreements in the biotech and seed industries as well as about their impacts on innovation. In the last section, we summarize and conclude.

Emergence of the Integrated US Biotech/Seed Industry and its R&D Investments

The development of agricultural biotechnology drastically changed the structure of the US seed industry. In the mid-1970s, fundamental discoveries in molecular biology made it theoretically possible to develop desirable traits in plants and animals through the transfer of DNA from other organisms (Boyd 2003). The new genetic engineering methods provided stimulus for research, while seminal legal decisions made it possible to profit from it. In its 1980 *Diamond v Chakrabarty* case, the Supreme Court ruled that genetically engineered microorganisms could be protected through standard utility patents, and in 1985 it extended such patent protection to genetically engineered plants in *Ex Parte Hibberd*.

Technical opportunity and strengthened intellectual property rights (IPRs) stimulated the interest of both R&D-driven multinationals (e.g., Monsanto, DuPont, American Cyanamid) and venture-funded start-ups (e.g., Agracetus, Agrigenetics, Calgene, Mycogen) and gave rise to a new R&D-minded industry. The new biotechnology firms also developed a parallel interest in seed assets. In the fledgling agricultural biotechnology industry, superior seed genetics (germplasm) were immediately recognized as an essential complementary asset for delivering the new biotechnologies. For the commercial introduction of a new biotech product to be successful, the intellectual property, the biotechnology traits, and the seed germplasm base had to be coordinated. This need for coordination led to a wave of strategic mergers and acquisitions. In the 1980s and early 1990s, leading biotechnology start-ups (e.g., Calgene, BioTechnica International, and Mycogen) acquired a number of firms in the seed industry. In the late 1990s, multinationals DuPont and Monsanto reversed their long-standing strategies of being only technology providers in favor of becoming vertically integrated and acquired the two largest independent seed firms, Pioneer and DeKalb, respectively. Other multinationals such as Dow, Syngenta, and Bayer soon followed, purchasing seed firms such as Northrup King and Golden Harvest. The trend has continued into the most recent decade.

The consolidation of seed and biotech assets has led to a bimodal structure in the US seed industry – a few large multinational integrated seed/biotech firms and 150–200 regional seed firms with markets of different sizes.[1] The large integrated firms are responsible for almost all R&D activity in the industry and have drastically increased their R&D spending since their entry into the industry.

Specifically, we estimate that between 1985 and 2012, R&D spending by major integrated biotech/seed firms and their subsidiaries increased, in nominal terms, 17-fold, from a bit more than $220 million in 1985 to over $3.7 billion in 2012 (Fig. 1).[2] While dedicated biotech start-up firms and some independent seed firms made meaningful investments in R&D during this period, the bulk of the R&D spending in these industries was carried out by the multinational integrated biotech/seed firms and their subsidiaries. These firms have had the means to invest large sums for sustained periods without the need for parallel revenues; such investment patterns tend to benefit firms with large scale and scope.

While seed/biotech R&D spending increased significantly over the 1985–2012 period, certain R&D costs declined at a fast pace during the same time due to improvements in automation, computation, instrumentation, and other enabling technologies which drastically increased research productivity and reduced unit costs. For instance, the costs of gene sequencing, i.e., the process of identifying the sequence of elementary blocks that form the DNA of plants, plummeted from 2000 on (Wetterstrand 2013). While sequencing was originally a slow and expensive

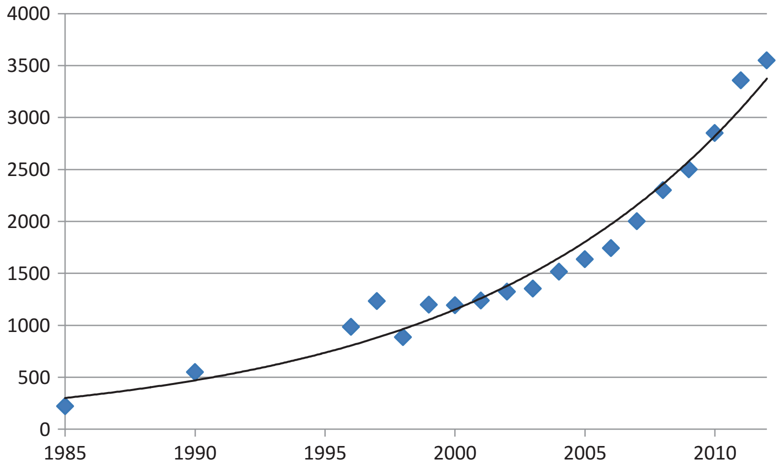

Fig. 1 Nominal R&D spending in Ag-Biotech and seed sectors (in $million) (*Source: Author calculations*)

[1] This structure is characteristic of the corn as well as the soybean seed industries. The US rice, cotton, and canola seed markets are generally smaller in size and have fewer firms.

[2] We constructed this series of R&D expenditures through information and data we collected from financial reports of publicly traded companies, financial analyst reports, consulting reports, trade journals, and information provided directly by individual firms. Because our data on licensing agreements in the biotech and seed industries is incomplete from 2013 on, we use R&D investment and other data until 2012, for consistency.

process (Mardis 2011), high-throughput technologies and advances in bioinformatics and related disciplines greatly contributed to reducing its cost (Metzker 2009; Edwards and Batley 2010). Such R&D cost efficiencies and productivity improvements affected most significantly the early stage development of new biotechnology traits, a rather expensive part of R&D in this sector (Phillips McDougall 2011).[3]

Early stage development of biotech traits was not the only part of biotech/crop improvement R&D that saw efficiency improvements in recent years. Traditional breeding programs for major crops have progressively been supplemented by genomics-based technologies that have made crop selection and the introduction of novel traits much more efficient (Fischer and Edmeades 2010). Marker assisted-selection (MAS) has led the way (Tester and Langridge 2010) by using molecular markers (identifiable DNA sequences found at specific locations of the genome) to verify the inheritance of various genes after cultivars are crossed. This approach greatly increased the reliability and effectiveness of the subsequent selection process and significantly reduced the cost of running breeding programs. With the help of MAS technologies, the presence of genes of interest can be verified in plants before they are fully grown, thereby eliminating most of the costs associated with laborious phenotypic selection and field trials (Hoisington and Listman 1998). The development of related tools such as association mapping, marker-aided recurrent selection, bioinformatics, biometrics, robotics, and remote sensing also contributed to improving the efficiency of breeding programs and the introduction of new traits into conventional lines (Fischer and Edmeades 2010). Of course, the cost-effectiveness of such technologies depends on the availability of cheap and reliable marker systems, which were obtained through inexpensive and fast gene sequencing.

The combination of increased R&D spending and declining research unit costs implies that the effective investment on R&D in the biotech/seed industry increased at a quick pace over the 1985–2012 period. A key question, then, is whether the increased level of private R&D spending in the biotech and seed industries translated into a faster rate of innovation. We address this question next by analyzing trends in patent acquisition in the US biotech/seed industry. We also examine whether any patterns of strategic patenting can be detected.

Patenting Trends in the Agricultural Biotechnology Industry

To identify the outcome of the increased amounts of R&D spending, we examine its most visible and immediate product, patented innovations. In the past, most empirical analyses of agricultural biotechnology patenting activity have focused on the

[3] Phillips McDougall (2011) also found that in recent years, large integrated biotech/seed firms have been able to increase manyfold the number of genetic constructs they evaluate at their early R&D stages while cutting the time required to do so by almost 20%. These productivity improvements are likely reflective of the same type of efficiency gains in research brought about improvements in sequencing and other enabling technologies.

public sector. Such previous studies have demonstrated the heavy reliance of agricultural biotechnology patenting in the public sector (Graff et al. 2003, 2010); the significant impact of public policies on the growth of agricultural biotechnology patenting (Carew 2005); the university-specific factors, such as quality faculty and infrastructure, which encourage patent production (Foltz et al. 2003); and the complementary relationship between publishing journal articles and patenting in the area of agricultural biotechnology (Kim et al. 2002). It has also been shown that patent quality in agricultural biotechnology, as measured by the number of times a given patent is cited by subsequent patents, has been declining over time (Buccola and Xia 2004). In sum, while our understanding of public sector agricultural biotechnology patenting activities is somewhat well developed, our knowledge of private sector patenting activity in agricultural biotechnology is more limited.

In order to match our measures of R&D investment and patenting activity as closely as possible, we concentrated on the activity of the top six integrated biotech/seed firms, their subsidiaries, and all the firms they acquired over time and examined their US granted patents from 1976 to 2012, effectively from the emergence of the agricultural biotechnology industry on.[4] For this purpose, we procured a database of US granted patents with biotechnology-related International Patent Classification Codes (IPCs) from commercial vendor Thomson Innovation. After consulting with patent experts and practicing patent attorneys, we developed a list of relevant keywords for specific searches in the patent title and claims. The list included both keywords that belonged to agricultural biotechnology patents (e.g., *Solanum*, *Melongena*, aubergine, squash, cabbage, insecticidal, protein, transgenic) and keywords that we used to filter out non-agriculture-related biotechnology patents (e.g., blood, cancer, nervous, cardiovascular, malaria, electronic). To identify the patents belonging to the firms of interest, we employed the assignee information provided in all the patents. Finally, in order to ensure that patents which were not relevant were excluded, we used visual inspection of the individual patents.

These procedures yielded a total of 9441 granted US patents for the period of interest, which are illustrated in Fig. 2. From the illustration we observe four distinct periods of patent production. From 1976 to 1986, as a group the selected biotech/seed firms were producing, on average, 21 patents per year. The corresponding number from 1987 to 1995 increased to 77. From 1996 to 2005, there were significant year-to-year variations, but, on average, the rate of patenting increased to 327 patents per year for the group. Starting in 2006, there was a further increase in the patenting activity with 748 granted patents, on average, procured each year. The exponential trend line in Fig. 2 makes clear the rapid growth in the patenting activity of agricultural biotechnology. It is interesting to note that from 2006 to 2012, the selected firms as a group were granted 5237 patents, which represented 55% of all patents granted to them over the entire 36-year period.

[4] There are more than 100 firms in our focal set, and these firms have been the primary locus of our R&D in the agricultural biotechnology and seed industries for the period of analysis. As such, patent acquisition for this set of firms paints a fairly complete industry-wide picture.

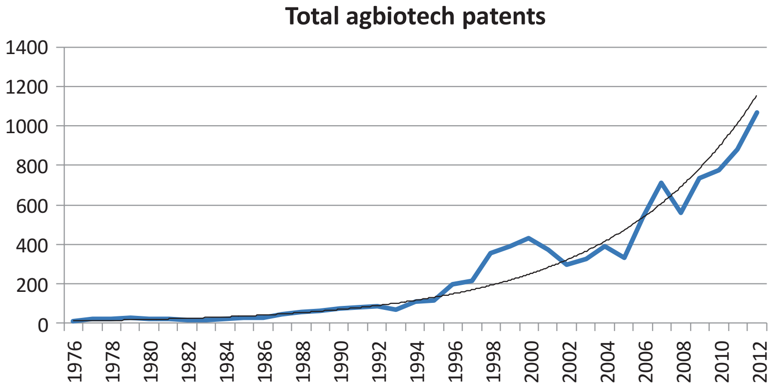

Fig. 2 Agricultural biotechnology patents acquired by selected firms (*Source: Authors' calculations based on data from Thompson Scientific and the USPTO*)

The dramatic increase in the patenting activity of the firms in our sample coincides with a significant growth in the overall patenting activity observed in the USA and elsewhere. The drastic increase in other industries has raised a number of concerns including perhaps the most pertinent one that the patenting system may fail to promote innovation (Shapiro 2003; Jaffe and Lerner 2011). Presumably, the patent system could hinder innovation if patents were increasingly used as strategic tools by firms to block competitors, decrease the odds that patents are disputed, and improve the negotiating position of patent holders (Arundel et al. 1995; Cohen et al. 2002). Often, strategic patenting for blocking competition takes the form of a single invention being protected by a large number of patents owned by the same firm, each covering, in the patent claims, part of the invention's novelty and applicability. Whenever such patent walls are created, competitors are typically discouraged from engaging in legal challenges, since disputing multiple patents can become prohibitively expensive.

In order to assess whether strategic patenting could explain the observed increases in agricultural biotechnology patenting activity illustrated in Fig. 2, we derive the average size of the patent family (the number of patents protecting the same or similar inventions) for all patents in our sample,[5] and we illustrate this average for the period 1976–2012 in Fig. 3.

In general, we observe that the average size of the patent family of the US patents granted to the group of selected firms varies significantly from year to year, but it does not meaningfully increase over time, it remains within the range of 15–30 patents for the period of interest, and, at any rate, it does not explain the exponential growth in the patenting activity observed in Fig. 2. Given our single industry focus, the lack of strategic patenting, and the limited expansion of the granted patents of the firms in new industrial fields, we conclude that increased granted patents in our sample are in fact indicators of increased rates of innovation and discovery over the period of our analysis (Kortum and Lerner 1999).

[5] Patent families include both patents that protect the same invention across different jurisdictions and patents in the same jurisdiction that cover different parts of the same invention.

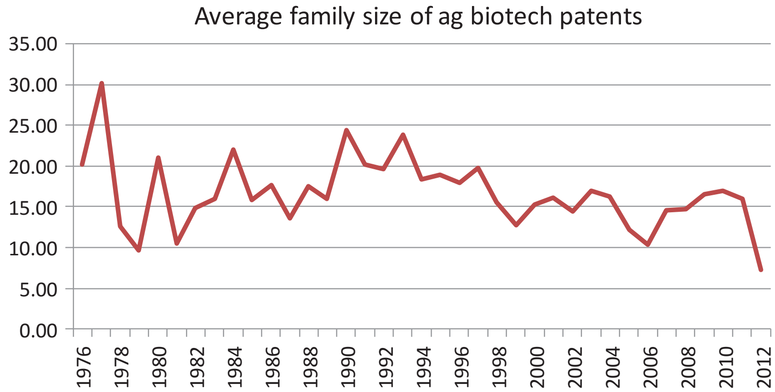

Fig. 3 Average family size of Ag-Biotech patents (*Source: Authors' calculations; data from Thompson Scientific and USPTO*)

Product Licensing

Even though we found no evidence of strategic blocking through patents in the agricultural biotech industry over the period of analysis, issued patents still prevent firms from using other firms' biotech innovations. Broad use of patented discoveries could accelerate commercialization of agricultural biotechnologies. Indeed, in some instances, broad use could be beneficial to the industry as a whole. For instance, the use of different herbicide-tolerant technologies could benefit all firms in the seed and biotech industry. One current problem in agricultural production is growing weed resistance to common herbicides. Plant scientists have been grappling with this issue for nearly as long as herbicides have been in wide use (Retzinger and Mallory-Smith 1997); at last count 443 species of weeds have biotypes that have become resistant to members of 22 different herbicide groups (Heap 2015). Resistance develops most readily when one herbicide, or a group with a common mode of action, is used exclusively and intensively. This can often be the case when a farmer plants one seed line with a single herbicide resistance trait for many years. The key to delaying the development of herbicide resistance in weed populations is using multiple herbicides with different modes of action, either sequentially or in a mixture (Beckie 2011). In order for this strategy to be effective, the crop must be resistant to all herbicides used. Thus the use of resistance traits from various technology suppliers could ensure the longevity of all products. This is true of many other traits as well.

Such broad use of patented agricultural biotechnologies could be achieved through licensing and cross-licensing agreements in the industry. Analyzing such agreements can be challenging, however, as data on the existence of such agreements and their terms are typically confidential and not easily accessible. In order to understand how much licensing and cross-licensing of innovations takes place, in this study we use a unique data set that includes all corn hybrids commercialized in the USA over the 1996–2012 period. The data set includes information about the

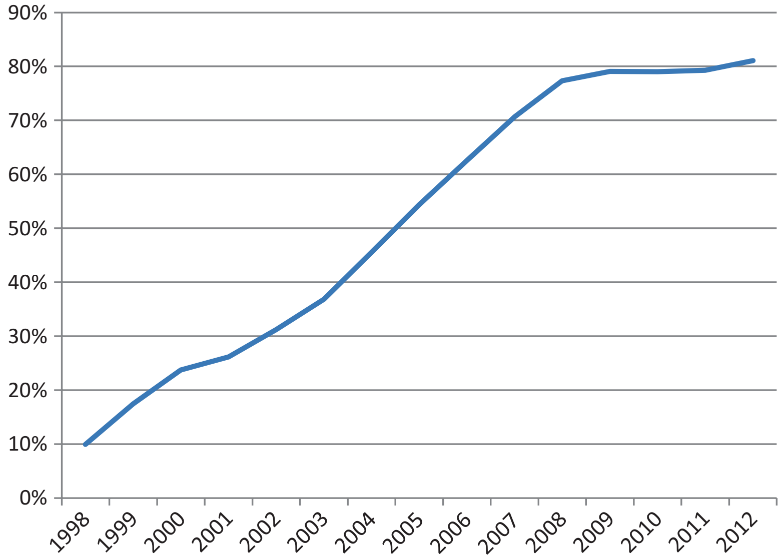

Fig. 4 Percentageof varieties that incorporate at least one trait outsourced from another company (*Source: Authors' calculations*)

individual biotech traits used in each hybrid sold, and as such it provides a complete census of all traits commercialized by each seed firm in the industry.[6] Based on this data, we construct indicators that provide insight on licensing and cross-licensing of biotech innovations in the seed industry.

Figure 4 illustrates the percentage of hybrids sold in a given year in the USA which have been developed through licensing of one or more biotech traits from another company. At the early stages of commercialization of biotechnology traits, only a small share of hybrids was developed with outsourced traits. In contrast, by 2010 more than 70% of hybrids sold included at least one trait developed through a licensing agreement.

As the number of biotech traits and trait providers increased over time, seed firms began incorporating traits licensed from multiple technology suppliers. Figure 5 shows the average number of licensing relationships of firms in the seed industry that used biotech traits in their hybrids over the 1997–2012 period. In the late 1990s and early 2000s, seed firms were licensing traits developed by an average of 1.5 biotech trait suppliers. Since the mid-2000s, this number has grown to over 2.5.

Indeed, over the period of analysis, biotech trait suppliers began to cross-license traits so that their stacks can take advantage of the complementary functionality of their competitors' traits. Figure 6 shows the percentage of firms, relative to the total number of trait providers, which contributed to the development of the various hybrids sold in the market. Initially, most of the biotech hybrids planted in the USA

[6]Agricultural biotech traits were first introduced in 1996, so the data set we use for our analysis provides an almost complete picture of the commercial use of the technology.

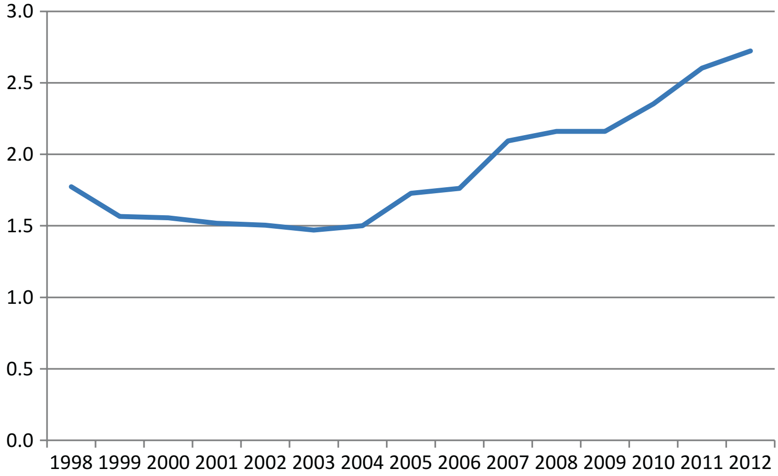

Fig. 5 Average number of licensing relationships of seed companies with biotech providers (*Source: Authors' calculations*)

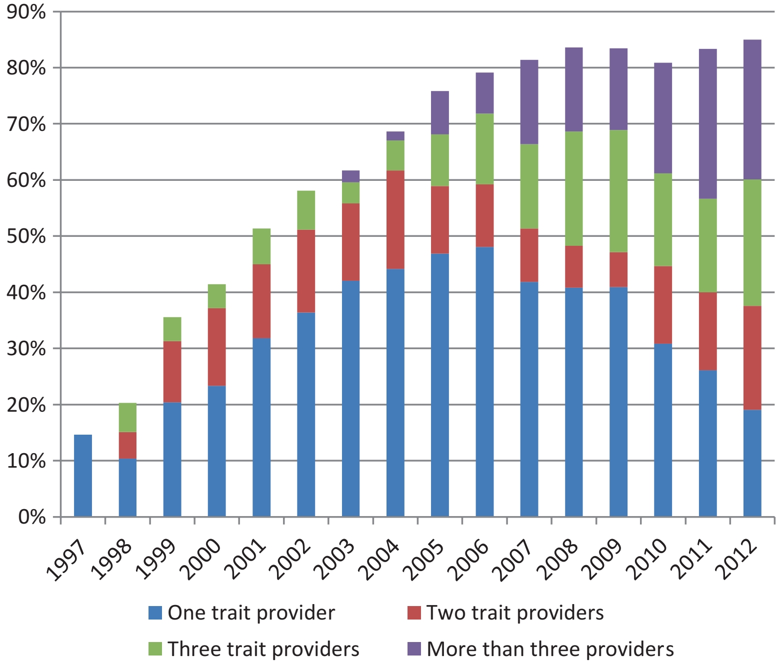

Fig. 6 Percentage of seed companies using multiple trait providers for the development of their hybrids (*Source: Authors' calculations*)

were developed by a single trait provider containing one or two biotech traits. As early as 1998, a few biotech hybrids were developed through the contribution of two trait providers, which mainly combined the European corn borer resistance trait developed by Monsanto and a herbicide tolerance trait developed by either Bayer or BASF. Starting in 2006, the number of hybrids developed with traits from two or more providers began to increase, while single supplier hybrids started to lose market share. During this time period, significant cross-licensing broadened access to new biotechnology traits across the seed industry.

It is worth noting that the increasingly broad licensing activity in the US seed corn industry is somewhat unexpected because such activity tends to occur less in industries that are concentrated (Lieberman 1989; Arora and Gambardella 2010). Since licensing activities are related to the underlying market structure, understanding the causes of the recent licensing trends in agricultural biotechnology traits and germplasm could provide useful insights.

The framework most typically used to analyze the incentives to license is that of transaction costs (Williamson 1991) which posits that technology suppliers will tend to rely on arm's-length contracts to transfer their technology when such costs are low. When transaction costs are high due to incomplete contracts, both the technology supplier and the licensee may be exposed to opportunistic behavior, especially if transaction-specific investments must be made during the transfer. Anderson and Sheldon (2011) proposed that licensing agreements in the biotech/seed industry may have recently increased because of a strengthening of property rights, which implies that transaction costs may be declining. Shi (2009) on the other hand argued that in some situations, vertical integration was preferable; broad licensing of biotech traits in markets where seeds are perfect substitutes would reduce the profits of seed firms to the point where they would not be able to recover negotiation and introgression costs of biotech traits.

The transaction cost framework may nevertheless be too narrow and may not be able to address the broader strategic intent of firms because it abstracts from firm activities that may be important in influencing their licensing decisions. Indeed, Fosfuri (2006) has argued that the effect of licensing decisions on the revenues generated in the product market may take precedence over transaction cost considerations when the technology providers also operate in downstream markets. In such a situation, licensing strategies may have important competitive repercussions since, essentially, technology providers create their own competition when they enable firms in the product market to compete more effectively by granting them access to their own technology.

Fosfuri (2006) has identified the revenue trade-offs that technology providers need to balance when devising their licensing strategies. Holding transaction costs constant, technology providers may on one hand benefit from royalty revenues (or any other forms of compensation for the transfer of the technology), while on the other hand they may lose through indirect dissipation of profits through increased competition in downstream markets. Because of this balance, the structural characteristics of the markets that technology suppliers operate in can influence their licensing decisions.

With respect to such structural considerations, Fosfuri (2006) has made two propositions that are relevant to agricultural biotechnology and seed industries: First, technology suppliers with small market shares in the product market are more likely to resort to licensing than if they were controlling a large share of the downstream product market. Second, when one technology supplier licenses its technology, significant competition in the technology market generally compels other technology providers to license their technology as well (Arora and Fosfuri 2003).[7] These propositions are generally consistent with early developments in the agricultural biotech/seed industries and may explain the broad licensing activities observed in recent years. Specifically, all technology suppliers in the biotech industry (Monsanto, Bayer, and BASF in the early years and Dow and Syngenta more recently) have had small market shares in downstream seed markets and hence an incentive to make their technology available broadly available.[8] The increasing availability of biotech traits and the diminishing differentiation among them may have also encouraged such firms to adopt similar broad licensing strategies.

Motives aside, our analysis shows that biotech innovations have been broadly licensed to seed firms and cross-licensed among agricultural biotechnology developers. Such licensing and cross-licensing activity has, in fact, grown through the commercialization period of agricultural biotechnology. The combined effect of increased R&D spending, lack of strategic patenting, and broad licensing and cross-licensing in the agricultural biotech and seed industries should therefore lead to accelerated product innovation in the marketplace. As a final step in our analysis, we evaluate this last proposition by examining the number of new product introductions and product life cycles in the US seed corn industry over the period of analysis.

Product Introductions and Product Life Cycles

A number of indicators can be used to measure effectiveness at different stages of the innovation process. The one that is most directly experienced by farmers is the rate of new product introductions. We examine here how past R&D expenditures and effort have translated in later years into new seed corn hybrids and new biotech traits marketed in the USA over the 1996–2012 period. Because innovative firms may not always be effective in translating R&D into products or they may not have adequate access to complementary assets, the flow of new products may not be perfectly correlated with firm R&D spending (Gambardella and McGahan 2010).

[7] When this domino effect occurs in industries where the technologies offered by the different suppliers are similar, the value of the industry will typically move downward since technology suppliers cannot act strategically upon the technology they possess (Dierickx and Cool 1989; Arora and Gambardella 2010; Gambardella and McGahan 2010). Such distributional effects could continue to encourage biotech firms to vertically integrate through the ownership of seed assets and could encourage entry of new firms into the seed industry.

[8] Monsanto's market share of proprietary seeds was initially limited. It has increased over the years through acquisitions and organic growth.

Still, since technical innovations are embodied in products of newer vintage, the rate of new product introduction can be an effective indicator of the rate of innovation in an industry (Hagedoorn and Cloodt 2003).

To construct appropriate indicators of new product introductions in the agricultural biotechnology and seed industry, we use data collected by a commercial market research company, GFK Kynetecs.[9] Our constructed data set includes all corn hybrids planted in the USA between the years 1998 and 2012 and contains observations at the hybrid level with the corresponding name of the seed firm marketing each hybrid, the type of biotech trait incorporated in the seed (e.g., insect-resistant, herbicide-tolerant hybrid and the name of the technology supplier), and the acres planted to a hybrid in any given year. Using this data set, we develop measures of the rates of new hybrid and new biotech trait introductions, product removals, as well as measures of product life cycles in the industry.

Figure 7 illustrates new hybrid introductions and old hybrid removals in the US seed corn market over the 1998–2012 period and shows that both have increased drastically in the last decade. On average, approximately 1100 new hybrids were introduced each year from 1998 to 2004. After 2005, however, the number of new product introductions increased to 1800 hybrids per year, an increase of more than

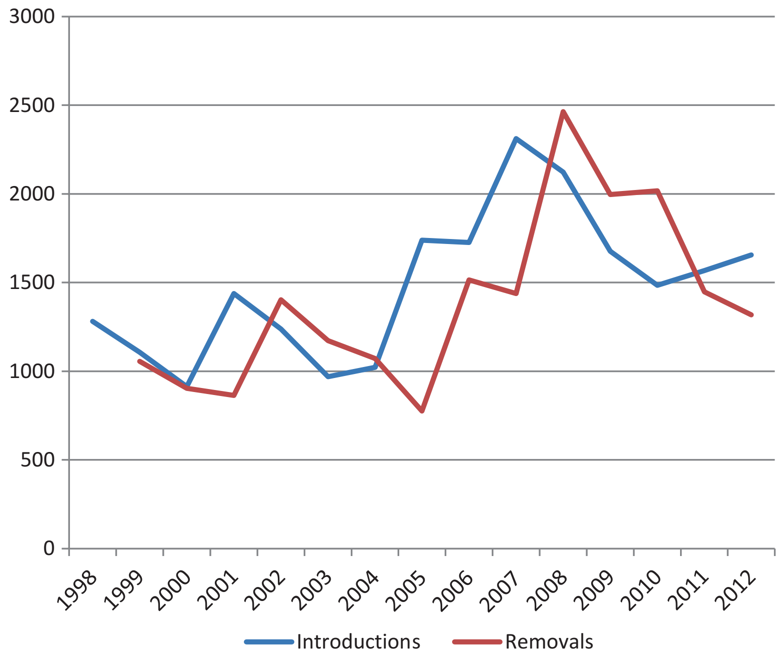

Fig. 7 New hybrid seed introductions and removals in the US corn market (*Source: Authors' calculations based on* GFK Kynetec *data*).

[9]The data is collected through annual surveys of corn producers in the USA. There are almost 250,000 farmer responses about annual purchases of seed corn for the period of interest.

60% relative to the first part of the decade, and reached a maximum of 2300 new hybrid introductions in 2007. The number of product removals shared a similar pattern with new product introductions, which is expected since space in the product lines of firms must be made for the new hybrids; otherwise product inventories would become unmanageable. Still, product removals have followed new product introductions with some lag suggesting that firms tend to decide on such removals after the newly introduced products have been assessed for their market fit.

The total number of hybrids sold in the US seed market follows a similar temporal pattern as that observed in the new product introductions (Fig. 8). The total number of hybrids marketed to US corn growers increased by 23%, from about 2700 in 1998 to 3350 in 2001 and stabilized around 3000 hybrids in 2003. The total number of hybrid seeds in the market increased by more than 66% in the next 4 years, however, climbing from 3000 hybrids in 2003 to 5000 hybrids in 2007. After the peak of 2007, the number of hybrids decreased to 3800 by 2010, and since that time it has again grown to more than 4200 hybrids in the subsequent 2 years, indicating a possible third period of product increase in the marketplace.

A somewhat inverse pattern is observed in the duration of the product life cycles of hybrids marketed in the USA, i.e., in the length of time, they remain in the market once introduced. We use the accelerated failure time model proposed by Magnier

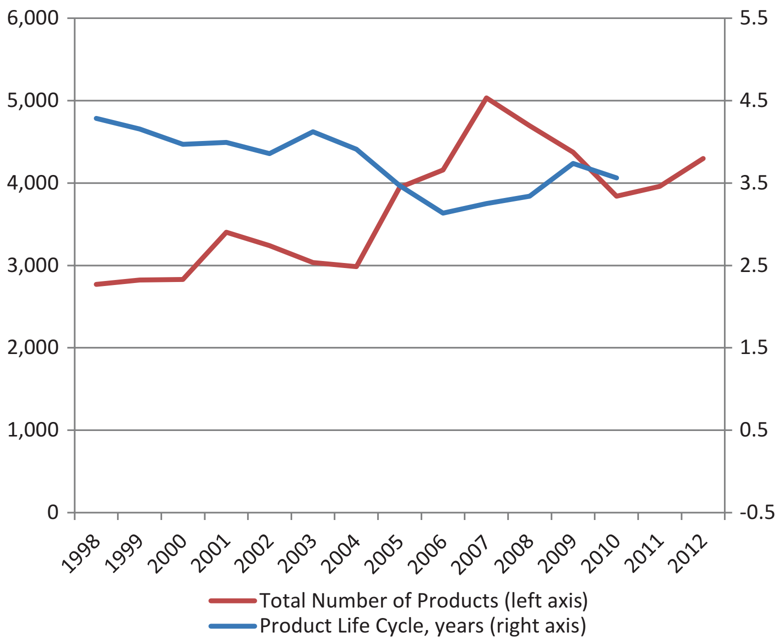

Fig. 8 Total number of products and product life cycle length in the US corn seed market (*Source: Authors' calculations based on* GFK Kynetec *data*)

et al. (2010)[10] to measure the average product life cycle in the US seed corn industry, and we illustrate its values for the 1998–2012 period in Fig. 8. From the illustration it can be readily observed that the life cycle of hybrid seeds in the USA decreased during periods when the number of product introductions and the total number of products in the market increased. Overall, the average product life cycle of hybrids declined from 4.5 years in 1998 to an average of 3.5 years in the last part of the period, which represents a marked decrease of about 20%.

Magnier et al. (2010) observed that new product introductions increased and product life cycles declined in the US seed market during cycles of new biotech trait introductions. As Fig. 9 indicates, there have been three separate waves of new biotech trait introductions between 1997 and 2012, and they seem to coincide with changes in the number of hybrids in the market and the duration of the life cycles. From 1997 to 1999, a period when the number of new hybrid introductions and total number of hybrids increased modestly, a total of ten new biotech traits were introduced, mainly single traits and double stacks (bundles of two biotech traits). From 2003 to 2007, a total of 30 new individual traits and stacks were introduced in the US market, mainly triple stacks and a few quadruple stacks. This period corresponds to the period with the most hybrid introductions and the total number of hybrids in the market. Finally, as more new traits were introduced from 2010 to 2012, the total number of hybrids in the market started to increase again.

The different types of biotech traits and stacks made available to farmers have followed the typical life cycle of adoption, maturity, and decline that are observed for most new technologies and are illustrated in Fig. 10. The single biotech traits that were first introduced in 1996 were quickly adopted and were planted on about one third of all US corn acres by 2004. After that time, their market share started to decline as stacked traits bundling a larger number of biotech traits were placed on the market. Despite their gradual decline in market share, single traits still accounted for about 20% of the market in 2012. Stacks with two biotech traits were introduced

[10] Accelerated failure time models are one of the two main types of models used for survival analysis, the branch of statistics dealing with the duration of an event; the other being proportional hazard models. The proportional hazard model is simpler to specify because it is nonparametric model, while a distribution needs to be chosen in the case of the accelerated failure time model. However, the results of accelerated failure time models are often easier to interpret because partial effects represent expected change in duration, while proportional hazard models produce hazard ratios whose partial effects are relative and therefore more difficult to translate into expected life time. Overall, the two types of models produce very similar results.

The accelerated failure time model we use takes the form $\ln(T) = X\beta + \sigma\varepsilon$, where β represents the set of parameters to be estimated, X is a vector of covariates, σ is scale parameter, and ε is a random disturbance term which is normally distributed. The explanatory variables include the average acreage across the lifetime of hybrid, a categorical variable to account for the size of the seed firm marketing the hybrid, trait-specific dummy variables (e.g., insect resistant, herbicide tolerant), and a set of variables which indicate the first year of commercialization of the hybrid. All parameter estimates except a few of the year of introduction dummies were statically significant at the 99% level, and all estimates had the expected sign. While we do not report the statistical results here to keep the manuscript at a manageable size, the results are available from the authors.

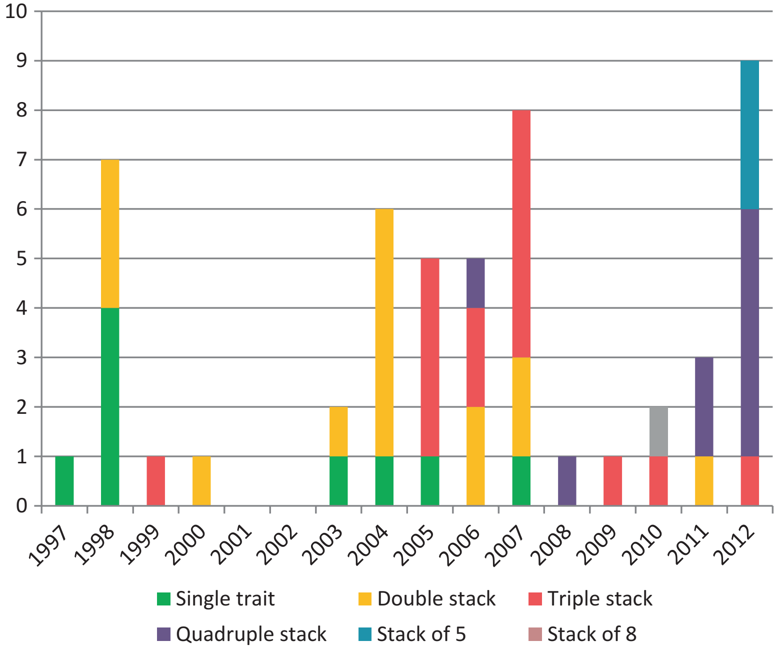

Fig. 9 Number of annual new biotech trait introductions (*Source: Authors' calculations*)

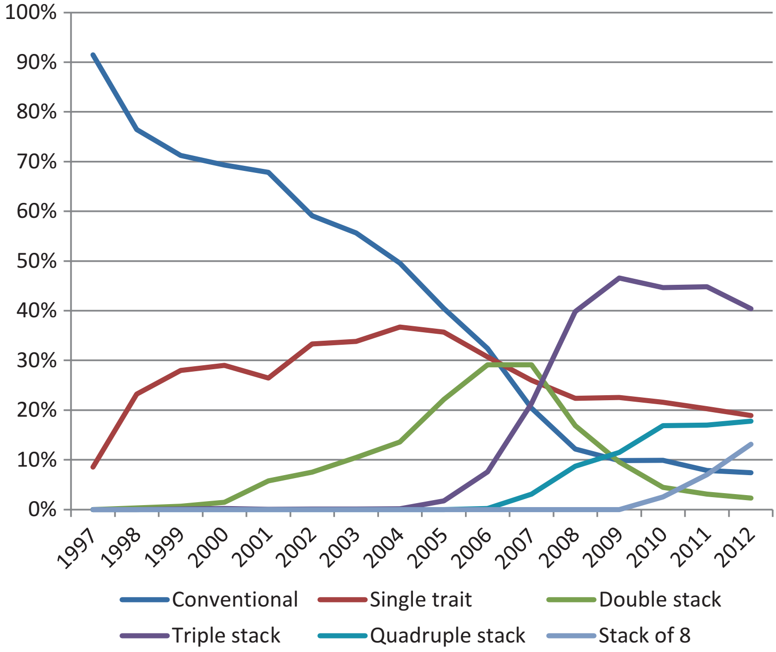

Fig. 10 Market share of different trait combinations (*Source: Authors' calculations based on* GFK Kynetec *data*)

almost in concert with the single traits and reached a maximum penetration by 2006/2007 of roughly 30% of the US corn acres. Nevertheless, their share has quickly declined as "triple stacks" quickly supplanted them to become the most adopted biotech trait bundle in the market. Stacks of four to eight different biotech traits then entered the market and gained market share.

These trends are generally consistent with the characteristics of R&D-driven industries (Bayus and Agarwal 2007), where new products are introduced at a fast rate and older products may still coexist with new ones to satisfy the demand of heterogeneous buyers with different needs (Giannakas 2002). As such, the patterns of new product (hybrids and traits) introductions illustrated in Figs. 7, 8, 9 and 10 are also informative about the ongoing expansion of product variety in the US seed corn market and indicate an increasing pace of innovation over the period of analysis.

Summary and Conclusions

In this chapter we discussed the antecedents to and results of private firm technology transfer in the agricultural biotechnology and seed industry. We examined the innovation process from R&D through product commercialization in order to discern the incentives for technology transfer and its market effects. We focused our analysis on the activities of all major integrated biotech and seed firms, all their subsidiaries, and all the firms they acquired over time. The set, therefore, includes more than 150 firms; collectively, these firms represent the suppliers of a large share of proprietary seeds, all of the commercialized biotech traits, and almost all of the R&D expenditures in these sectors. As we illustrate here, these firms increased their R&D spending at an exponential rate over the 1985–2012 period. Furthermore, since certain R&D costs have declined during this period, their effective R&D spending was likely even higher.

We then examined patterns in patent acquisition by this group of firms over the 1976–2012 period, essentially over the lifetime of the agricultural biotechnology industry. We have found that the number of granted patents secured by the firms in our sample increased exponentially over this period, much like their R&D spending. Since we have found no evidence of strategic patenting to explain the increase in volume, we have concluded that the increased number of granted patents is an indicator of accelerating product innovation in the industry.

We went on to examine the licensing patterns of new biotech traits, once again using the US seed corn/biotech market as a case study, over the 1996–2012 period. In this context, we demonstrated that licensing of biotech traits across technology suppliers and seed marketers expanded over time and represented the dominant strategy in the industry; the number of biotech trait suppliers increased; and the number of hybrid seeds bundling biotech traits from different technology suppliers grew quickly. Taken together, these indicators point to a growing availability of agricultural biotechnologies, increased technology transfer within the industry, and intensified contestability in this technology market.

Finally, we examined the patterns of new product introductions over the period 1996–2012, almost the entire period during which biotech traits have been commercialized. We used the US biotech/seed corn market as a case study due to its leading position in market value and technology development. We found that over the period of the analysis, the rate at which new biotech traits and new hybrids were introduced in the market increased, the total number of hybrids marketed expanded, the total number of biotech traits offered grew while their variety expanded, and the average product life cycle of hybrid seeds declined. All such indicators point to accelerating product innovation and augmented product choices for buyers over the period of the analysis.

Seed and biotech markets are generally fragmented by geography and crop, making it difficult to generalize across such boundaries. Still, information similar to that presented here from seed markets of other crops (e.g., cotton) as well as information from product pipelines (products already in research or development which are expected to be commercialized in the future) suggests accelerating innovation and increased market contestability for new biotech traits and varieties across different crops (e.g., soybeans, cotton, canola) and geographies. As such, we expect that the conclusions we have drawn here are broadly applicable.

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