



Concentration in Seed Markets

POTENTIAL EFFECTS AND POLICY RESPONSES



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Foreword

In recent years, mergers and acquisitions involving large multinational firms have reshaped the seed and biotechnology sector and have reduced the number of players in the industry. This consolidation process has prompted concerns about whether market concentration leads to reduced competition, higher prices, and lower innovation, which could hurt both farmers and consumers. However, so far little information has been available in the public domain about market concentration and its effects.

This OECD report provides an in-depth assessment of structural changes in global markets for seed and biotechnology based on new data on market concentration across a broad range of countries and crops, and considers potential policy responses.

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Acronyms and abbreviations

Acronym	Description
ABS	Access and benefit sharing
AMS	Agricultural Marketing Service (USDA)
APHIS	Animal and Plant Health Inspection Service (USDA)
BSPB	British Society of Plant Breeders
C4	Four-firm concentration ratio
CADE	Administrative Council for Economic Defense (Brazil)
CBD	Convention on Biodiversity
CCI	Competition Commission of India
CEO	Chief executive officer
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Centre for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CPCSD	California Planting Cotton Seed Distributors
CRD	Crop reporting district (United States)
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats (gene editing technique)
DNA	Deoxyribonucleic acid
DOJ	US Department of Justice
DSI	Digital sequence information
DUCA	Data Use and Compensation Agreement
DUS	Distinct, uniform and stable
EMEA	Europe, the Middle East and Africa
EPO	European Patent Office
EU	European Union
EUR	Euro
F1	First filial generation of offspring
FAO	United Nations Food and Agriculture Organization
FTC	US Federal Trade Commission
GAIN	Global Agricultural Information Network (USDA)
GDP	Gross domestic product
GEMAA	Generic Event Marketability and Access Agreement
GM	Genetically modified
GRDC	Grains Research and Development Corporation
HHI	Hirschman-Herfindahl Index
ICARDA	International Centre for Agricultural Research in Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics

IITA	International Institute for Tropical Agriculture
ILP	International Licensing Platform - Vegetables
IP	Intellectual property
IPC	International Patent Classification
IRRI	International Rice Research Institute
ISAAA	International Service for the Acquisition of Agri-biotech Applications
ISF	International Seed Federation
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
MIT	Massachusetts Institute of Technology
NAFTA	North American Free Trade Agreement
NIAB	National Institute of Agricultural Botany (United Kingdom)
NLI	National List
NPBT	New Plant Breeding Techniques
NUTS2	Nomenclature of Territorial Units for Statistics, second level
ODM	Oligonucleotide-directed mutagenesis
OLS	Ordinary least squares
OSSI	Open Source Seed Initiative
PBI	Plant Breeding Institute (United Kingdom)
PBR	Plant breeders' rights
PLUTO	Plant variety database (maintained by UPOV)
PPP	Purchasing power parity
PVP	Plant variety protection
PVR	Plant variety rights
Q2	Second quarter
R&D	Research and development
RdDM	RNA-dependent DNA methylation
RNA	Ribonucleic acid
SAES	State Agricultural Experiment Stations (United States)
SDN	Site-directed nuclease
SPG	Saskatchewan Pulse Growers
TALENs	Transcription activator-like effector nucleases
TRIPS	Agreement on Trade-Related Aspects of Intellectual Property Rights
UK	United Kingdom
UPOV	International Union for the Protection of New Varieties of Plants
US	United States
USD	US dollar
USDA	United States Department of Agriculture
USPTO	United States Patent and Trademark Office
VCU	Value for Cultivation and Use
WARDA	African Rice Centre (formerly West Africa Rice Development Association)
ZFN	Zinc Finger Nuclease

Executive summary

Well-functioning seed markets are essential for agriculture and global food security. The growth in crop production worldwide depends on improved varieties made possible by public and private investments in R&D, and continued investments in these genetic improvements will be necessary for a sustainable increase in agricultural productivity. For this reason, it is important to ensure seed markets remain competitive and innovative.

The merger of Dow and DuPont, the acquisition of Syngenta by ChemChina, and the merger of Bayer and Monsanto have recently reshaped the global seed industry. Various stakeholders and observers have expressed their concern over the increasing consolidation and the impact it may have on prices, innovation and product choice in markets for seed and genetically modified (GM) technology. A related concern is that mergers could create exclusionary “platforms” of complementary GM seeds, crop protection products and digital agriculture services.

However, not much data has been available so far in the public domain on the actual degree of concentration in markets for seed and GM technology. Moreover, the public debate has tended to focus on the role for competition policy, ignoring the potential for other government policies to stimulate competition and innovation in the industry.

This study provides new and detailed empirical evidence on the degree of market concentration in seed and GM technology across a broad range of crops and countries, and analyses the causes and potential effects of increasing concentration in these markets. The study also provides an account of how competition authorities in major markets responded to the mergers, and suggests policy options beyond competition policy to help safeguard and stimulate competition and innovation in plant breeding.

Consolidation in global seed markets has been ongoing for several decades and has two main causes. High fixed costs, in particular for R&D, create pressure for “horizontal” mergers that combine firms with activities in the same domains. In parallel, technological and commercial complementarities between seeds, GM technology, and crop protection chemicals create incentives for “non-horizontal” mergers between companies active in these different domains. A new complementarity may be emerging today with digital technologies and precision agriculture. Major seed and crop protection companies have been investing in digital agriculture in recent years, as big data could enable customised advice to farmers on the best seeds or crop protection products to use and could in turn inform R&D.

Horizontal and non-horizontal mergers have different effects on prices and innovation. The risk of harmful effects is normally smaller for non-horizontal mergers as these do not directly lead to higher market concentration, and have scope for generating more efficiency gains, for instance by enabling more innovation. At the same time, non-horizontal mergers are not necessarily harmless as they could be used to exclude competitors from accessing important markets or resources.

In the past three decades, a series of horizontal and non-horizontal mergers and acquisitions created the “Big Six”: Monsanto, Bayer, BASF, Syngenta, Dow and DuPont. These multinationals were all active in agrochemicals, and (with the exception of BASF) had strong positions in seed and biotechnology. The recent merger wave reduces the number of major firms to four.

The current consolidation shows both horizontal and non-horizontal characteristics, as the mergers combine firms with a complementary geographic focus and complementary product portfolios. In markets where the mergers would have created a large horizontal effect (that is, a large increase in market concentration), competition authorities have typically required substantial divestitures before allowing the merger. Bayer in particular has been required to divest almost its entire seed business, together with several other assets, all of which were sold to BASF, which now emerges as an important player in global seed markets. Because of the remedies imposed by competition authorities, the risk of harmful effects on prices and innovation is limited.

Detailed new data on market concentration in seed shows there is considerable variation across different crops and countries. Seed markets for sugar beet, cotton, sunflower, maize, and rapeseed are typically more concentrated, while seed markets for potato, soybean and wheat and barley are much less concentrated. Some countries appear to have systematically higher degrees of market concentration across different crop seed markets.

Genetically modified plant traits such as herbicide tolerance or insect resistance can be incorporated into seeds. For such GM traits, market concentration is much higher than for seed itself, and the market is dominated almost exclusively by large multinationals. Traits owned by Monsanto are particularly prominent, especially in markets where fewer GM crops have been approved. On the other hand, data on patents for CRISPR-Cas9 suggest this new technology is mostly dominated by academic institutes, with some presence of DowDuPont but without a strong position for the other multinational firms.

A statistical analysis did not find any clear evidence that increases in market concentration raised seed prices or reduced innovation, although the analysis could not take into account many other factors which could influence the results. Prices and innovation rates differ between crops, due perhaps to biological factors. Prices and innovation rates tend to differ between countries, even after controlling for market concentration, suggesting that other policies could also affect the performance of seed markets.

In addition to competition policy, three broad categories of complementary policy options exist to stimulate competition and innovation in the industry. First, while a sound regulatory framework is necessary to ensure markets function properly, regulation may also inadvertently create transaction costs and barriers to entry, which could in turn contribute to higher levels of market concentration. Policy makers should therefore avoid unnecessary regulatory barriers to entry. This is of particular importance given the emergence of new plant breeding techniques potentially accessible to smaller enterprises.

Second, successful innovation depends on access to genetic resources as well as intellectual property. Policy makers should ensure that plant breeders have access to these necessary inputs, for instance by supporting efficient procedures for accessing genetic materials and by facilitating efficient licensing of intellectual property.

Third, policy makers can stimulate both public and private R&D. The public sector historically played an important role in plant breeding, and still continues to do so in many countries. However, as private-sector investment is growing, the public sector can evolve towards more fundamental research, where the private sector typically underinvests. Policy makers can also stimulate private R&D through public-private partnerships, for instance by providing matching funds.

This study also underlines the importance of having precise data in order to discuss issues of market concentration. Highly aggregate estimates of market concentration, which have been cited in the public debate, present a misleading picture and are not useful for policy makers in view of the important variations by crop and by country.

1. Introduction

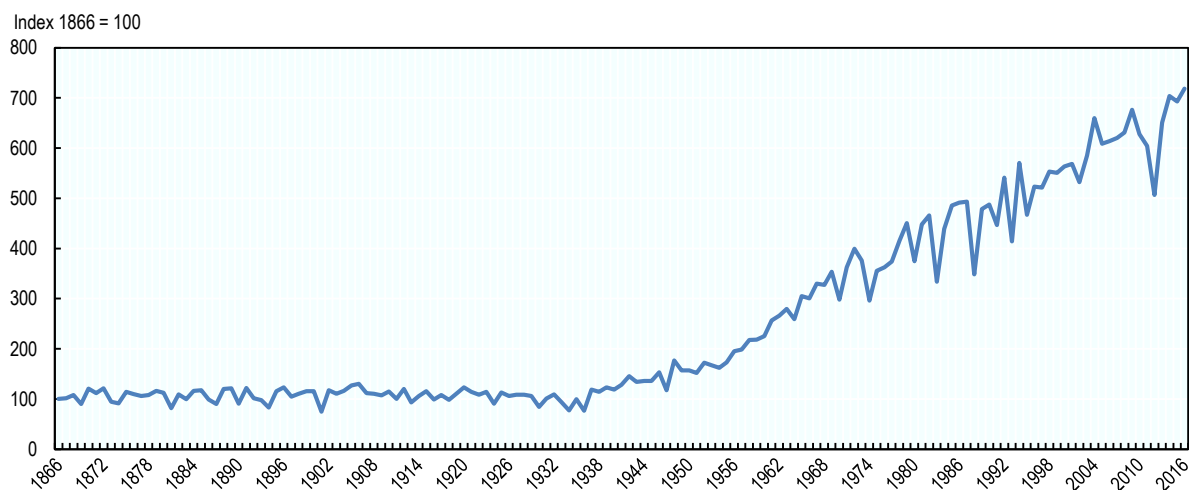
This chapter introduces the main themes of the study. A competitive and innovative seed industry plays an important role in increasing agricultural productivity. In recent years, mergers and acquisitions have led to a further consolidation in an already highly concentrated industry, which raises questions about potential harmful effects on prices, choices, and innovation. At the same time, a wide array of public policies affect seed markets. Yet, not much information has been available so far as to the extent of market concentration and its potential harmful effects. This report provides new data and analysis on concentration in the industry, reviews the theoretical and empirical literature on effects of mergers, and presents several policy options.

Plant breeding has historically played an important role in increasing agricultural productivity. Continued investments in plant breeding will be essential to ensure a productive, sustainable and resilient agricultural system for the future. In recent years, important mergers and acquisitions have reshaped the global seed industry, further consolidating an already highly concentrated industry. This in turn raises questions about potential harmful effects on prices, choices, and innovation. Yet, so far not much information has been available as to the extent of market concentration and its potential harmful effects.

1.1. The importance of plant breeding

Global agriculture faces the triple challenge of raising productivity while ensuring sustainability and improving resilience. To achieve these goals, innovation in the form of high-performing varieties is essential.¹ Historically, improvements in varieties have underpinned large gains in agricultural productivity across the world.² For instance, the introduction of hybrid maize in the 1930s in the United States broke a decades-long pattern of stagnating yields, and enabled a seven-fold increase in the US maize yield over subsequent decades (Figure 1.1). Studies typically place the contribution of better varieties at 50% or more of this total increase in yield (Fernandez-Cornejo, 2004^[1]).³

Figure 1.1. Maize yields in the United States, 1866-2016



Note: Yields for maize (harvested for grain).

Source: USDA (2017^[2])

A study by the National Institute of Agricultural Botany (NIAB) in the United Kingdom showed that increases in UK cereal yields since 1982 were mostly due to better varieties, putting the relative contribution of genetic improvement at 88% for cereal crops and rapeseed (Mackay et al., 2011^[3]).

In developing countries, the strong growth in agricultural output during the Green Revolution similarly depended in large part on the introduction of improved varieties. These were developed through the Consultative Group on International Agricultural Research (CGIAR) and national agricultural research services (Evenson and Gollin, 2003^[4]). In the second phase of the Green Revolution, from 1981 to 2000, better varieties accounted for 40% of total production growth in all developing countries. Simulations suggest that without these

improved varieties, per capita caloric intake in the developing world would have been 13%-14% lower (Evenson and Gollin, 2003^[4]).

Even stagnating yields may hide an important contribution by plant breeding in preventing a further decline. Olmstead and Rhode (2002^[5]) show that stagnating wheat yields in the United States between 1840 and 1940 required considerable efforts by plant breeders to introduce varieties resistant against a wide array of pests and diseases, and to breed varieties which could thrive in regions where wheat breeding previously did not take place. Olmstead and Rhode (2002^[5]) estimate that wheat yields in 1909 would have been 46% lower if no new varieties had been introduced since 1840. Continued investments in improved varieties are thus not only important for productivity growth, but necessary to maintain productivity at current levels.

1.2. Consolidation in the global seed industry

Since 2015, three large mergers and acquisitions have transformed the global seed industry. In December 2015, Dow Chemical and DuPont announced their intention to merge, with the merger officially completed in September 2017. Only a few months earlier, the Chinese state-owned enterprise ChemChina acquired Syngenta, after Syngenta had rejected an earlier bid from Monsanto. In September 2016, Bayer announced a bid to acquire Monsanto. After receiving regulatory approvals, the merger was officially completed in June 2018, creating the world's largest agro-chemical, seed and biotechnology firm.

These mergers consolidate an already highly concentrated industry. In the past few decades, a process of acquisitions and mergers led to the emergence of the Big Six (Monsanto, Syngenta, Bayer, DuPont, BASF, and Dow Chemical), multinationals with a strong position in agricultural chemicals and (with the exception of BASF) seed and biotechnology. The current consolidation wave couples firms with a strong position in the agro-chemical market (Bayer, Dow, ChemChina) to firms with a strong position in the seed and biotechnology industry (Monsanto, DuPont, and Syngenta, respectively). The combination of seed, biotechnology and agro-chemical activities in one firm has been a recurring theme in the past decades. However, the current consolidation brings this to an unprecedented level.⁴

At the same time, the precise level of market concentration is unclear, because detailed data on market shares in different countries and market segments are typically not available in the public domain (Fernandez-Cornejo and Just, 2007^[6]). Some highly aggregate estimates have tried to combine sales data from the Big Six with estimates of the size of the global seed market to calculate measures of global market concentration (e.g. Heisey and Fuglie (2011^[7]), ETC Group (2013^[8])). However, global figures may under- or overstate the degree of market concentration in specific markets. An informed policy debate requires more detailed information.

1.3. Issues raised by increasing market concentration

Increasing concentration in seed markets leads to three potential concerns: Will increased concentration lead to higher seed prices for farmers? Will consolidation reduce innovation and R&D in the seed industry? Will consolidation reduce the number of choices farmers have when choosing varieties?

The answers are not clear *a priori*. In markets where firms are competing head-to-head, a merger could lead to an increase in prices, less innovation and a reduction in the number of varieties. However, mergers may create efficiency gains, especially where firms with

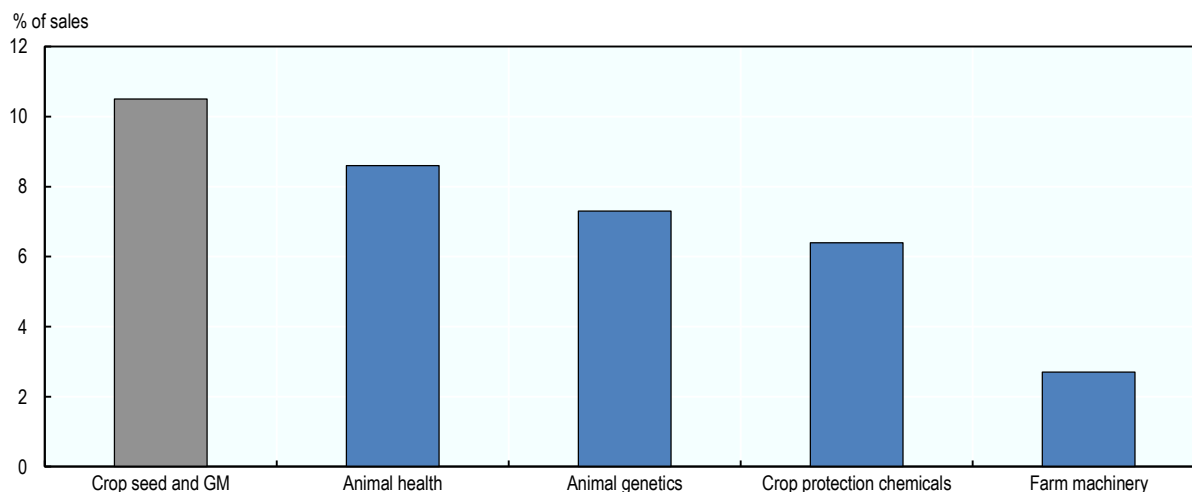
complementary products or technologies are combined.⁵ If competitive pressures remain sufficient, these efficiency gains could in theory lead to lower prices and more innovation.

From the point of view of sustainability and global food security, the possible effects on innovation are particularly important. A reduction in innovation would mean a slower rate of improvement in varieties. Over time, the welfare losses of slower productivity growth in agriculture could easily dwarf any short-run welfare losses caused by higher prices. Hence, understanding the potential effect of mergers and market concentration on innovation is particularly important.

Innovation is a strategic tool in the competitive process as seed firms compete to introduce better-performing varieties. Indeed, the seed industry is exceptionally R&D intensive when compared to other agricultural input industries. As shown in Figure 1.2, the global seed and biotechnology industry invests around 10% of its revenues in R&D. The R&D intensity is typically higher than for smaller firms (Fuglie et al., 2011^[9]).

Many fear that a reduction in the number of competitors could undermine the incentive for these large R&D investments. Several critics of the mergers have also argued that the current mergers are likely to hurt innovation by eliminating “parallel pathways” of R&D and reducing the opportunities and incentives to engage in pro-competitive R&D collaborations (e.g. through cross-licensing of genetic traits). It is also argued that the mergers may create integrated platforms of complementary varieties, traits and chemicals possibly leading to exclusive packages that do not interoperate with products from competitors. In turn, these platforms would raise barriers to entry for smaller firms as they would require new entrants to simultaneously invest in varieties, traits and chemicals. These barriers in turn could result in higher prices, less choice, and less innovation in the long run.⁶

Figure 1.2. R&D intensity of agricultural input industries



Note: Global R&D expenditures as a percentage of global sales, 2009.

Source: Fuglie et al. (2011^[9])

This view is not shared by all observers, however. Proponents of the mergers maintain that the mergers will not necessarily reduce R&D and innovation, and may even encourage it. For instance, removing parallel paths in R&D is not necessarily problematic as it might remove redundancy in research efforts, thus making R&D potentially more efficient. Proponents have

also argued that the feared reduction in R&D collaboration through refusals to cross-license is not likely as firms do not have an incentive to refuse cross-licensing. Moreover, to the extent that mergers lead to complementary platforms of varieties, GM traits, and chemicals, they might improve innovation by allowing better coordination between these different elements (Manne, 2017^[10]).

Much of the discussion focuses on innovation through genetic modification (GM). Only a limited number of OECD countries have adopted GM technology at a large scale. However, similar issues exist for conventional plant breeding, as well as for the new plant breeding techniques (NPBT) which are currently emerging (see Schaart et al. (2015^[11]) for an introduction). Bonny (2017^[12]) provides a useful overview of the link between controversies over market concentration and the broader debate around sustainability and biotechnology.

1.4. Public policies affecting seed markets

Mergers and acquisitions are scrutinised by competition authorities. When a competition authority concludes that a proposed merger may threaten competition in a certain segment, it can block the merger or demand “remedies” such as the divestiture of parts of the merging companies. For instance, in evaluating the merger of Dow Chemical and DuPont, the European Commission (2017^[13]) voiced concerns about competition in several markets for existing pesticides and certain petrochemical products. One concern was that the merger would reduce incentives to engage in innovation. The European Commission ultimately approved the merger, but made it conditional on DuPont divesting a significant part of its existing pesticide business, including its global crop protection R&D organisation.

Most of the public debate has focused on whether competition authorities should allow the mergers in the seed industry. But beyond competition policy, several other public policies affect seed markets. One example is public R&D on varietal improvement by national agricultural research services. Public R&D has historically played an important role in plant breeding, and in several countries continues to do so. Public R&D can also affect private-sector plant breeding through fundamental research, for instance on new plant breeding techniques.

Intellectual property rights for plant varieties and related inventions affect private-sector R&D in plant breeding. Historically, plant varieties did not qualify for intellectual property rights. Over time, a specialised system of intellectual property rights for plant varieties (known as plant breeders’ rights) has emerged. In some jurisdictions, new varieties can nowadays also be protected through the patent system.

Regulations also affect plant breeding. In addition to regulations regarding genetically modified organisms, the marketing of conventional seed varieties may also be subject to regulations; in the European Union, for example, new varieties may only be marketed after passing a test for their value for cultivation and use (VCU). Other examples of public policies affecting seed markets include the maintenance of public seed banks and rules that govern access to international genetic resources.

Given this broad range of policies affecting plant breeding, an important question is whether policy makers can take *complementary* policy actions to ensure a competitive and innovative seed industry, in addition to the decisions made by competition authorities.

1.5. Aims of this report

The first aim of this report is to present background information regarding the seed industry, including new estimates of concentration levels in different countries and crops, and the structural drivers of observed trends in concentration. A second aim is to shed light on the possible effects of mergers through a review of the theoretical and empirical literature as well as an empirical analysis using the new evidence on market concentration presented here. A third aim is to propose possible policy responses.

Chapter 2 presents an overview of global seed markets, including data on market size, growth, and composition in terms of regions and crops. Trends in technology (in particular genetically modified organisms), prices, and R&D are reviewed.

Chapter 3 examines structural changes in the seed industry. In addition to profiles of the main companies and a review of the recent mergers and divestitures, this chapter examines the causes of increasing industry consolidation. A case study of the US cotton seed market illustrates the structural changes highlighted in this chapter.

Chapter 4 reviews the literature regarding the impact of mergers on prices, innovation, and choices, reviewing both theoretical arguments and empirical evidence from the general economic literature. It also provides specific evidence where available.

Chapter 5 presents new evidence on seed market concentration across countries and crops. This chapter also contains evidence on market concentration in GM traits.

Chapter 6 builds on the new estimates of seed market concentration to explore the effects of higher market concentration on seed prices and innovation.

Chapter 7 turns to policy questions and proposes complementary policy responses for policy makers in light of the information contained in this report.

Seed markets are closely linked to a number of other topics. Some examples include the link between the seed industry and the agrochemical industry; the question of providing access to improved seeds in a developing country context; and broader questions around how plant breeding relates to questions of sustainability and different farming systems. Within the scope of this study, it was not possible to explore all of these questions. Instead, the main focus here is on an economic assessment of market concentration and related policy options. Several other topics are thus left for further research.

Notes

¹ A note on terminology: A *seed* is the physical “carrier” of genetic information of a variety. Farmers choose between different *varieties* when buying seed, and plant breeders aim to develop improved *varieties*. A variety developed or selected through human intervention is also referred to as a *cultivar* (“cultivated variety”). Strictly speaking, the term “seed market” or “seed industry” encompasses both the development of varieties (plant breeding) and the physical production, distribution and sale of seeds. The focus of this study is primarily on plant breeding.

² For historical introductions to plant breeding and seed markets, see Kingsbury (2009_[30]) and Kloppenburg (1988_[14]). For a discussion of the importance of biological innovations, including varietal improvement, in the early development of US agriculture, see Olmstead and Rhode (2008_[246]).

- ³ A recent analysis by crop scientists from DuPont Pioneer estimates the contribution of “genetic gain” (i.e. varietal improvement) in maize yield increases at between 59% and 79% between 1930 and 2011, depending on the production environment (Smith et al., 2014_[231]).
- ⁴ Market concentration has been a topic of debate in other agricultural input industries as well. See Fuglie et al. (2011_[9]) for a global overview and Wesseler et al. (2015_[26]) for the European Union. For industry-specific studies, see Bonanno et al. (2017_[249]) on herbicides in the European Union and Hernandez and Torero (2013_[250]) on the global fertiliser industry.
- ⁵ In addition, mergers may resolve problems of mutually blocking patent claims (“patent thickets”).
- ⁶ See, for example, Moss (2013_[64]), Moss (2016_[210]), Lianos & Katalevsky (2017_[219]), and IPES-Food (2017_[220]).

2. An overview of global seed markets

This chapter presents key figures about global seed markets, including breakdowns of market size by region and crop, data on the importance of genetically modified (GM) seed across countries and crops, and information on trade, prices, and R&D spending in the industry.

2.1. Sources of seed

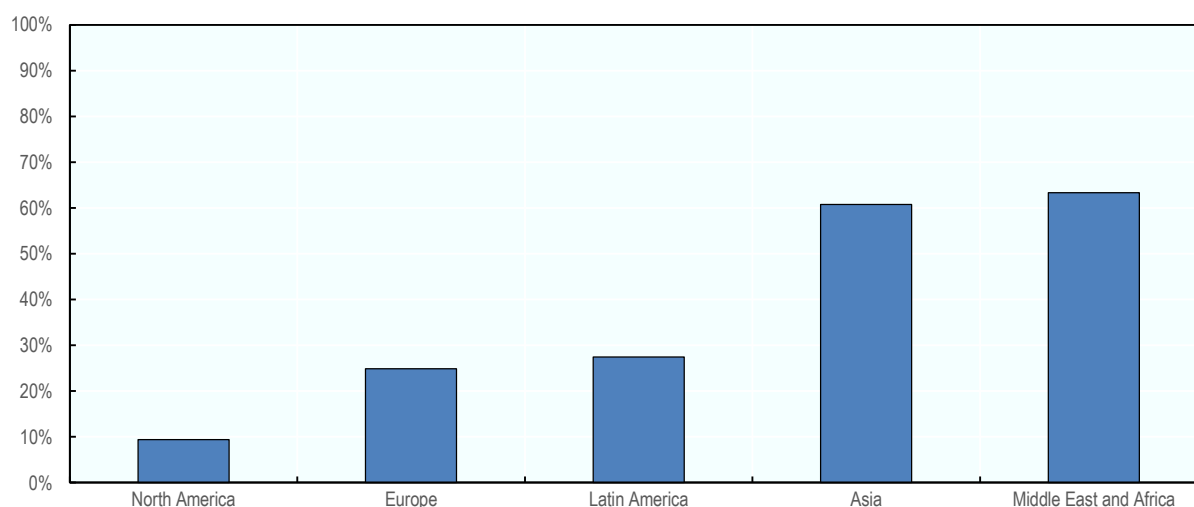
Seed used by farmers can come from three sources: farm-saved seed; purchased seed derived from public plant breeding, or purchased seed from the private sector (Heisey and Fuglie, 2011^[7]).¹ Originally, all seed was farmer-saved. Over the past century and a half, seed originating in the public sector has played an important role in many countries, including the United States (Kloppenborg, 1988^[14]), Australia and Canada. Over time, the importance of the private sector has grown and private-sector seed now dominates global markets, especially in high-income countries (Heisey and Fuglie, 2011^[7]).

The share of farm-saved seed varies across regions and crops.² Figure 2.1 shows how estimated rates of farm-saved seed vary from less than 10% of the total volume of seed used in North America to more than 60% in the developing regions of Asia and the Middle East and Africa.

Similarly, Figure 2.2 shows how the estimated rate of farm-saved seed varies from close to zero for sugarbeet to more than 60% for wheat and barley, rice, and potato.

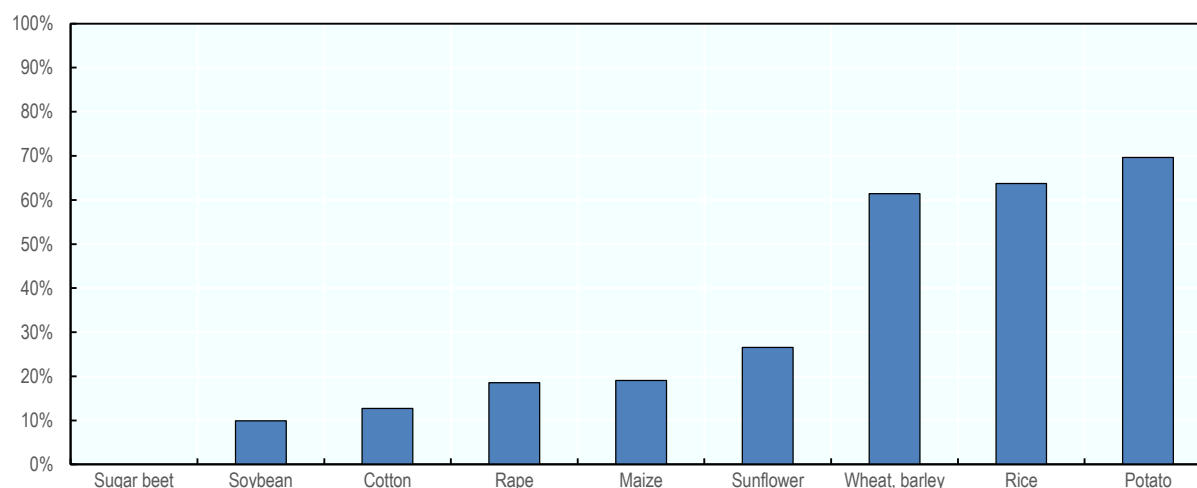
For some crops, farm-saved seed (as well as public seed varieties) continue to play an important role even in developed economies.³

Figure 2.1. Farm-saved seed as share of total, 2016



Note: The estimated share of farm-saved seed here is the ratio of the estimated market value of farm-saved seed (valued at average prices by country) to the total estimated value of seed markets including farm-saved seed.

Source: OECD analysis using the Kleffmann Agriglobe database

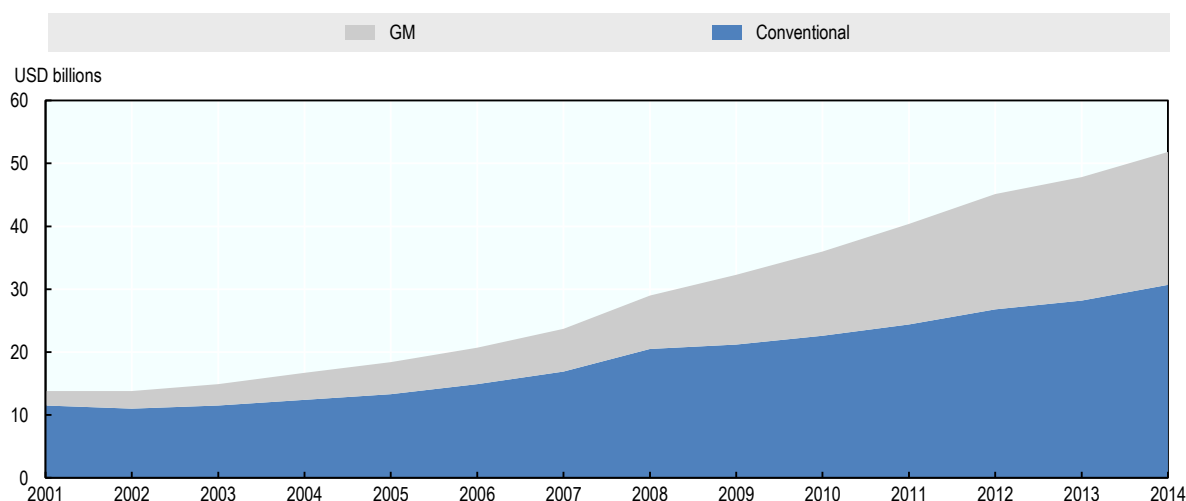
Figure 2.2. Farm-saved seed as share of total, 2016

Note: Data refers to the global seed market. The estimated share of farm-saved seed here is the ratio of the estimated market value of farm-saved seed (valued at average prices by country) to the total estimated value of seed markets including farm-saved seed.

Source: OECD analysis using the Kleffmann Agriglobe database.

2.2. Size and growth of the global commercial seed market

The size of the global commercial seed market (i.e. excluding farm-saved seed but including public commercial varieties) was estimated at around USD 52 billion in 2014 (Figure 2.3).⁴ In the past years, global seed markets have grown strongly in (nominal) value, driven by the expansion of GM in particular, although conventional seeds also registered growth.

Figure 2.3. Evolution of the global commercial seed market, 2001-2014

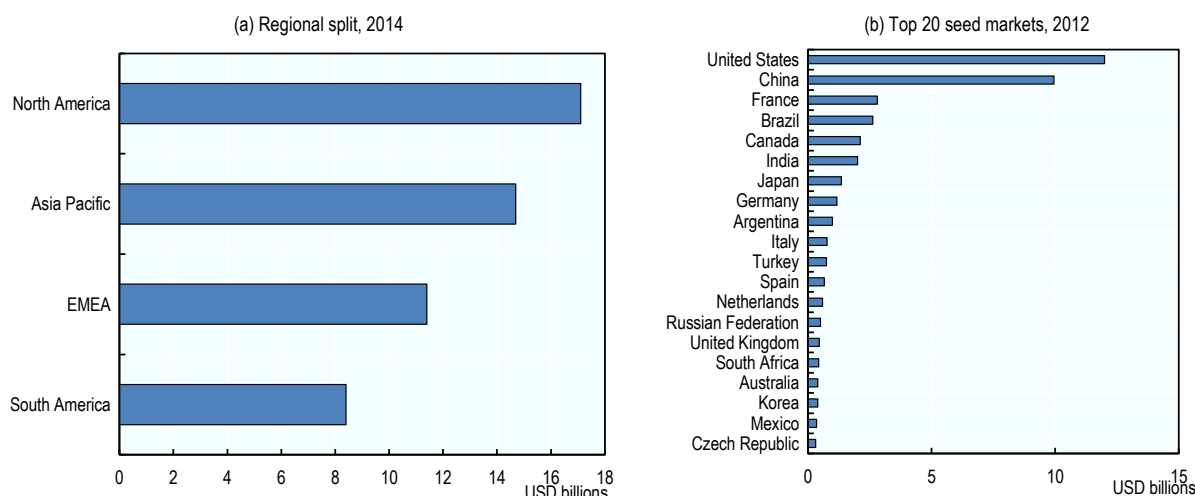
Note: Not adjusted for inflation. Includes public and commercial seeds; excludes flower seeds and farm-saved seed.

Source: Syngenta (2016^[15])

2.3. Seed markets by region

Estimates of the regional split of seed markets are presented in Figure 2.4. The United States is globally the largest seed market, followed by the People's Republic of China (hereafter "China"). The next most important national seed markets, led by France, Brazil and Canada, are considerably smaller. Regionally, North America is the largest market with an estimated one-third of the global market by value.

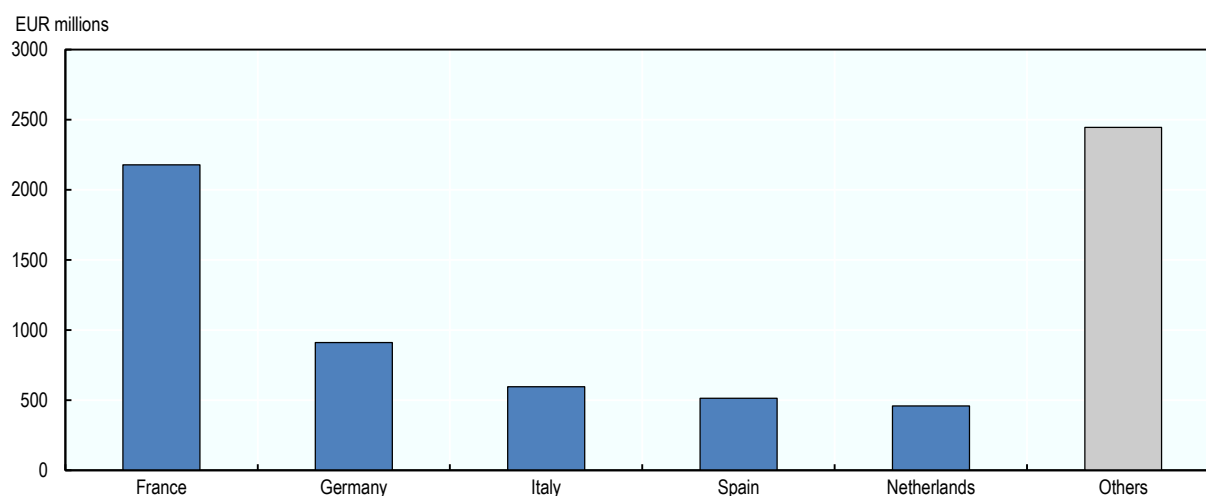
Figure 2.4. Regional split of global seed markets



Note: EMEA stands for Europe, Middle East and Africa. North America refers to the NAFTA countries (Canada, United States and Mexico).

Source: Panel (a): same scope and source as Figure 2.3. Panel (b): based on International Seed Federation data cited in ISAAA (2016^[16]).

Figure 2.5. Domestic seed markets in the European Union, 2012



Source: Ragonnaud (2013^[17]), using data from the International Seed Federation. Data includes field crops, vegetable and flower seed. These numbers exclude the value of seed potatoes (estimated at around EUR 350 million) and vegetative planting materials of ornamentals (around EUR 500 million) (Marien Valstar, personal communication).

Taken as a whole, the European Union is the third-largest seed market in the world after the United States and China, accounting for 20% of the global total (Ragonnaud, 2013^[17]). France by itself accounts for nearly one-third of the EU total. France, Germany, Italy, Spain, and the Netherlands combined account for two-thirds of the EU market.⁵

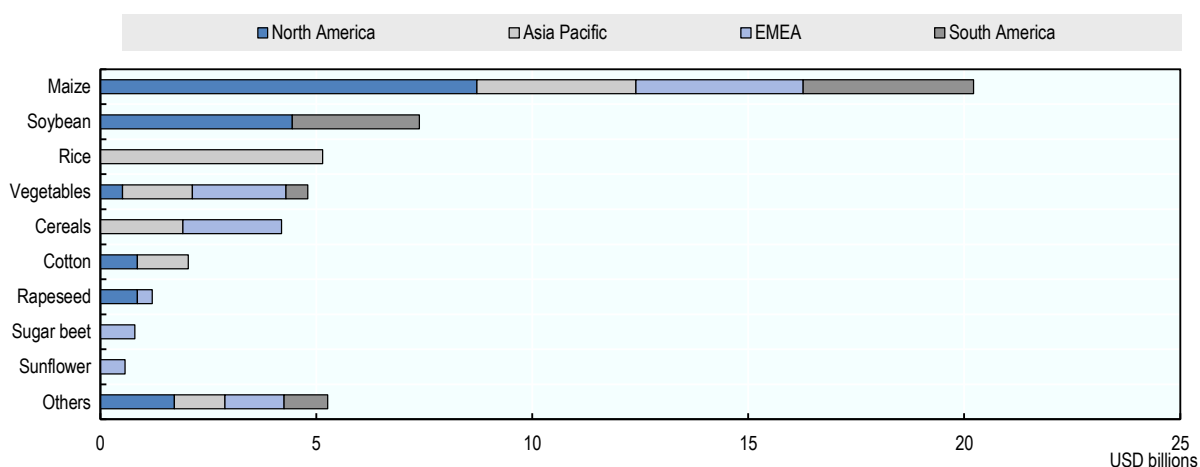
2.4. Seed markets by crop

While the global seed market is diverse, a small number of crops dominate total seed sales (Figure 2.6). Of an estimated USD 52 billion in 2014, almost 40% is made up of maize and an additional 14% of soybeans. The large size of maize and soybeans is driven by the Americas where GM varieties are commonly used. Globally, 78% of the area planted with soybeans uses GM varieties. The typically higher prices for GM seed automatically lead to a larger estimate of market sizes in terms of value.

Rice is estimated to be the third largest seed market by value, driven by demand in Asia Pacific where around 90% of the global area planted with rice can be found.

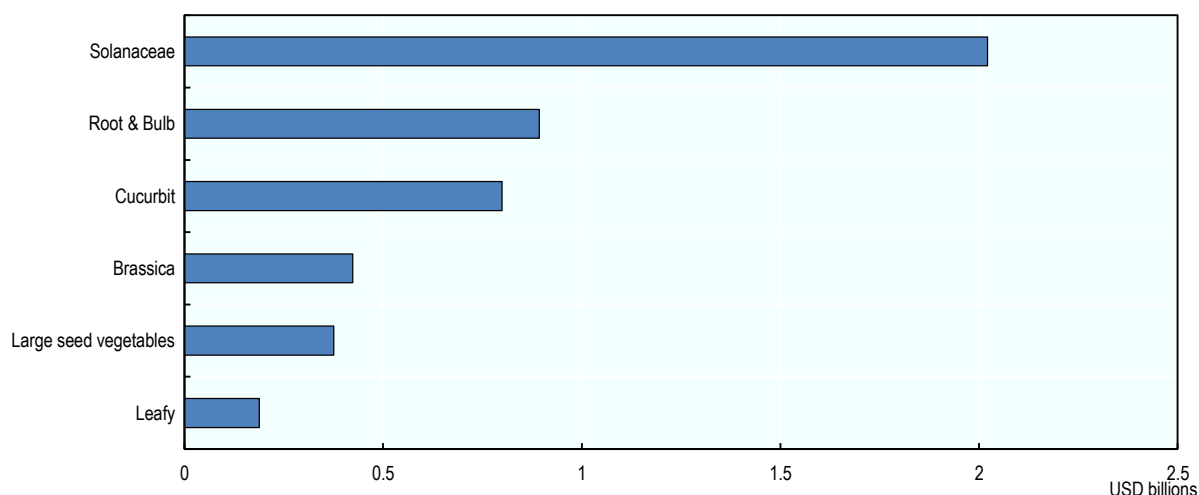
The global market for vegetable seed is estimated to be around USD 4.7 billion (Figure 2.6). Vegetable seeds typically have a high value and account for a much larger share of the global seed market by value than would be expected from their relatively modest volumes. Within vegetable seed, an estimated 43% of the market consists of Solanaceae seeds – a crop category which includes tomatoes, peppers, and eggplants (Figure 2.7).

Figure 2.6. Estimated size of global seed market by crop, 2014



Note: The category “Others” contains seed segments considered of less importance for a specific region, and may therefore include sales of other crops listed here. For instance, the category includes sales in small cereals (wheat and barley) in North America, soybeans in EMEA, etc. Global estimates by crop presented here are likely to be a lower bound.

Source: Syngenta (2016^[15]).

Figure 2.7. The global vegetable seed market by crop, 2014

Note: Solanaceae include tomato, pepper and eggplant; Root & Bulb includes onion and carrot; Cucurbit includes melon, watermelon, cucumber and squash; Brassica includes cabbage, cauliflower and broccoli; Large seed vegetables includes beans, peas and sweet maize; Leafy includes lettuce and spinach.

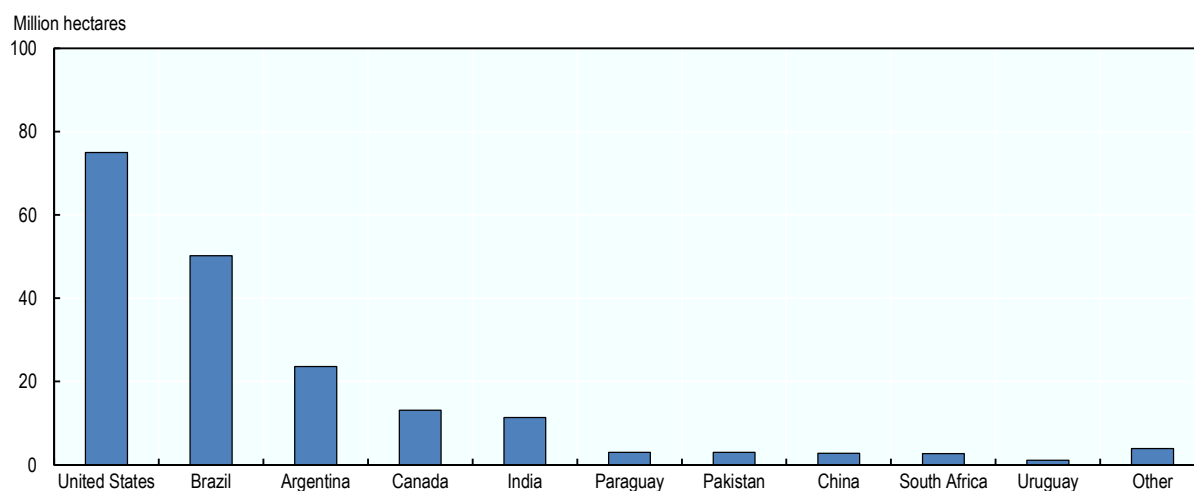
Source: Syngenta (2016^[15])

2.5. Genetically modified (GM) seeds

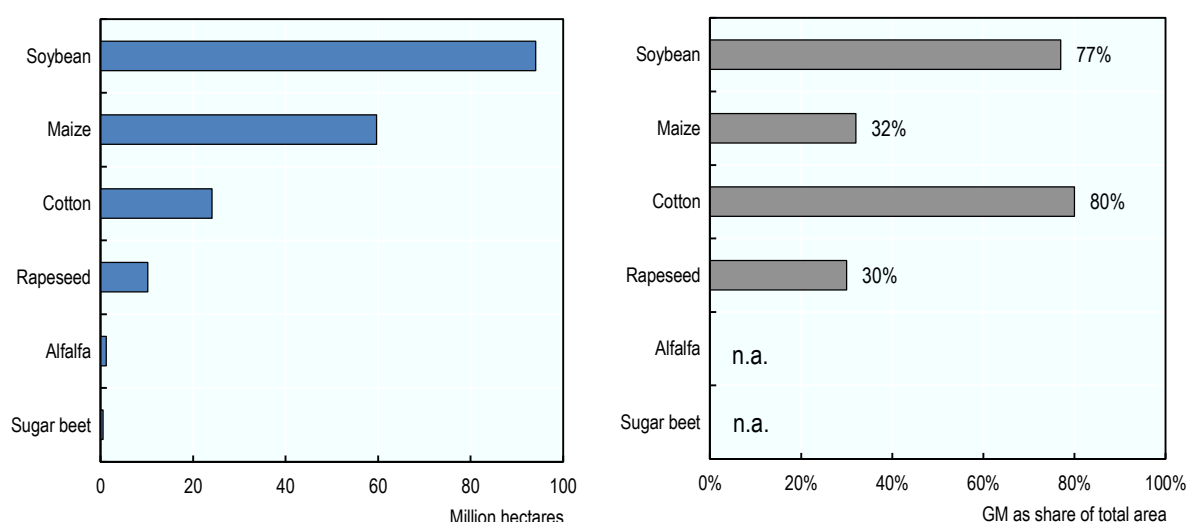
Genetically modified seeds have had a drastic impact on the structure and evolution of global seed markets.⁶ Advances in genetics led to the development of the first genetically modified (GM) plant in 1982, and the first commercialisation of GM plants took place in the early 1990s with the introduction of the Flavr Savr tomato variety (1994). Today, at a global level 190 million hectares are planted with GM crops. Since 2012, the area planted with GM crops in developing countries has exceeded that in developed countries. In 2017, developing countries accounted for 53% of the global area under GM crops, a share which is expected to grow further (ISAAA, 2017^[18]). In 2107, the countries with the largest GM area are the United States (75 million hectares, or 40% of the global total), Brazil (50 million hectares, 26%) and Argentina (24 million hectares, 12%) (Figure 2.8).

In the European Union, only one GM “event” has been approved for cultivation: a type of insect-resistant maize grown on 130 000 hectares in 2017.⁷ Spain (124 000 hectares, representing around 28-30% of the total maize area) and Portugal (7 000 hectares) are the only countries where this GM maize variety is planted (ISAAA, 2017^[18]) (European Seed Association, 2016^[19]). Other EU Member States which used to have GM cultivation are the Czech Republic, Slovakia, and Romania, but none of these countries planted GM crops in 2017.

The main GM crops globally are soybeans (94 million hectares in 2017), maize (60 million hectares) and cotton (24 million hectares) (Figure 2.9). GM adoption rates vary among these commodities. Seventy-seven per cent of hectares planted with soybeans are planted with a GM variety. For cotton, this share is 80%, but for maize only 32%.

Figure 2.8. Global area of GM crops in 2017, by country

Source: ISAAA (2017^[18])

Figure 2.9. Global area of GM crops by crop and GM adoption rates, 2017

Source: ISAAA (2017^[18])

Three types of GM crops can be distinguished: crops with *enhanced input traits* (e.g. herbicide tolerance; resistance to droughts, pests, diseases); crops with *enhanced output traits* (e.g. crops with better micronutrient availabilities); and *crops for non-traditional uses* (e.g. crops that produce pharmaceuticals or bio-based fuels). The adoption of GM crops is mostly limited to the first category (Fernandez-Cornejo, 2004^[1]) and have two main traits: herbicide tolerance and insect resistance.

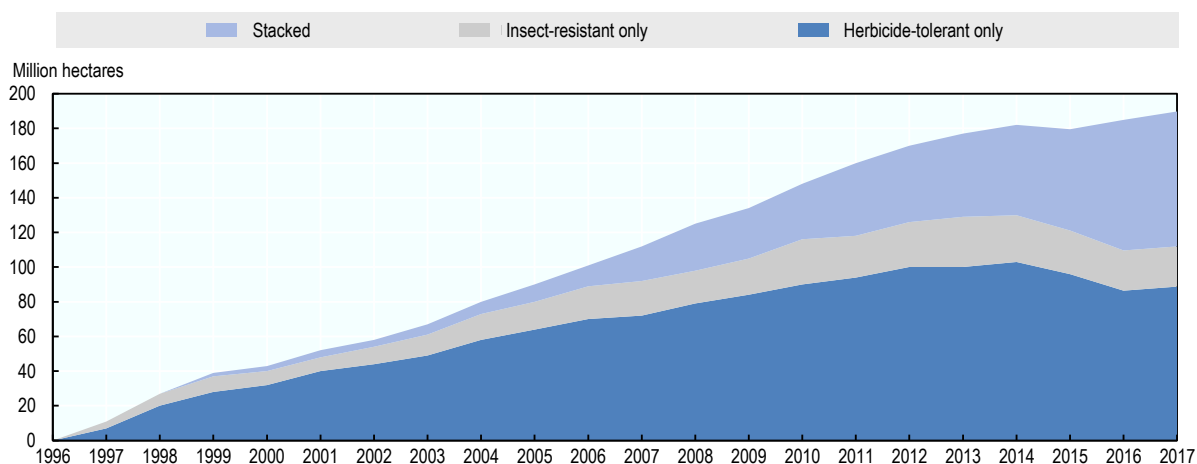
A leading example of organisms with genetically modified *herbicide tolerance traits* are crops with genetic modifications making the plant resistant to the herbicide glyphosate, such as Monsanto's Roundup Ready GM trait.

A leading example of organisms with genetically modified *insect resistance traits* are crops that incorporate a gene of the soil bacterium, *Bacillus thuringiensis* (Bt). Bt produces a

protein which is toxic to certain insects. By incorporating the gene into the genetic material of plants such as maize or cotton, the plant produces the protein in its leaves, thus providing protection against insects such as the European corn borer (for maize) and the bollworm (for cotton).

In the past, most GM crops were either herbicide tolerant or insect resistant, but *stacked traits* (combining different traits) have recently been gaining importance. Stacks can include traits for tolerance to several herbicides and/or traits for resistance against different insects (e.g. corn borer and root worm in maize). Globally, single-trait herbicide-tolerant seed occupied 89 million hectares in 2017, or 47% of the total hectares of GM crops worldwide. Single-trait insect resistant seed was used on 23 million hectares (12% of the total). The area covered with single-trait GM crops has been declining in recent years, but the area covered with stacked traits has registered strong growth and at present occupies 78 million hectares. Stacked traits currently account for 41% of global GM hectares (Figure 2.10).

Figure 2.10. Global area of GM crops by trait, 1996-2017



Source: ISAAA (2017^[18])

2.6. International trade in seeds

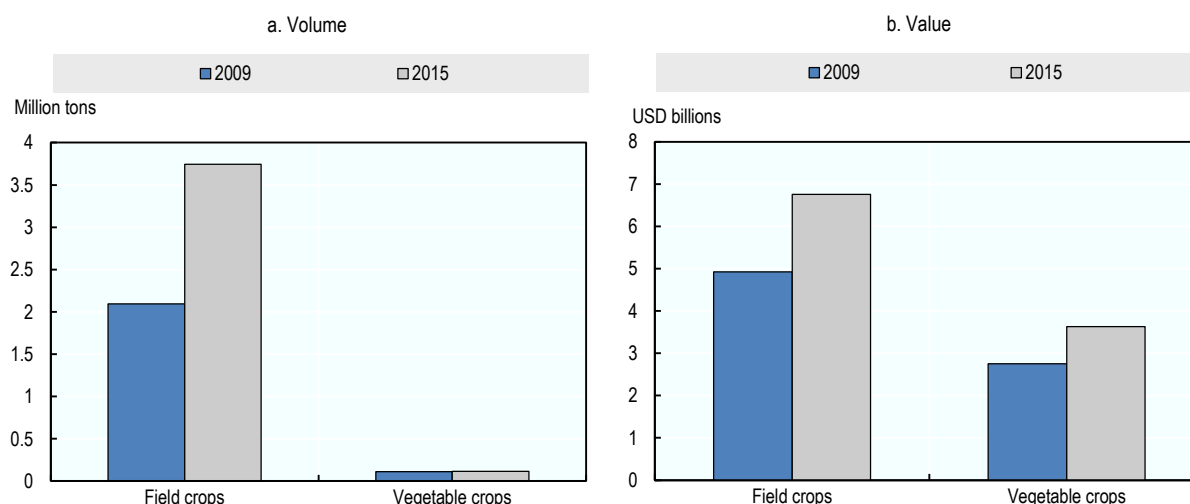
Seeds are widely traded. In 2015, around 3.9 million tonnes of seed were traded, representing a value of more than USD 10 billion according to statistics gathered by the International Seed Federation (ISF). This compares to an estimated value of the global seed market of around USD 50 billion. Although caution is needed in comparing these numbers, trade seems to represent about one-fifth of the value of the global seed market.

Figure 2.11 compares global exports of field and vegetable crops, by volume and by value, in 2009 and 2015. In terms of volume, the majority of trade (>95%) is in seeds of field crops. However, vegetable crop seed has a much higher value per weight. As a result, vegetable crop seed represented 35% of exports in value terms, but less than 5% in volume terms in 2015.

International trade in field crop seeds has been expanding strongly in both volume and value terms. Between 2009 and 2015, volumes grew by almost 80% while the value of exports rose by 37% (indicating a decline in unit values). By contrast, volume growth for vegetable seeds has been almost flat. Nevertheless, the value of exports of vegetable crop seeds grew by 32%, driven by an increase in the unit value of exports.

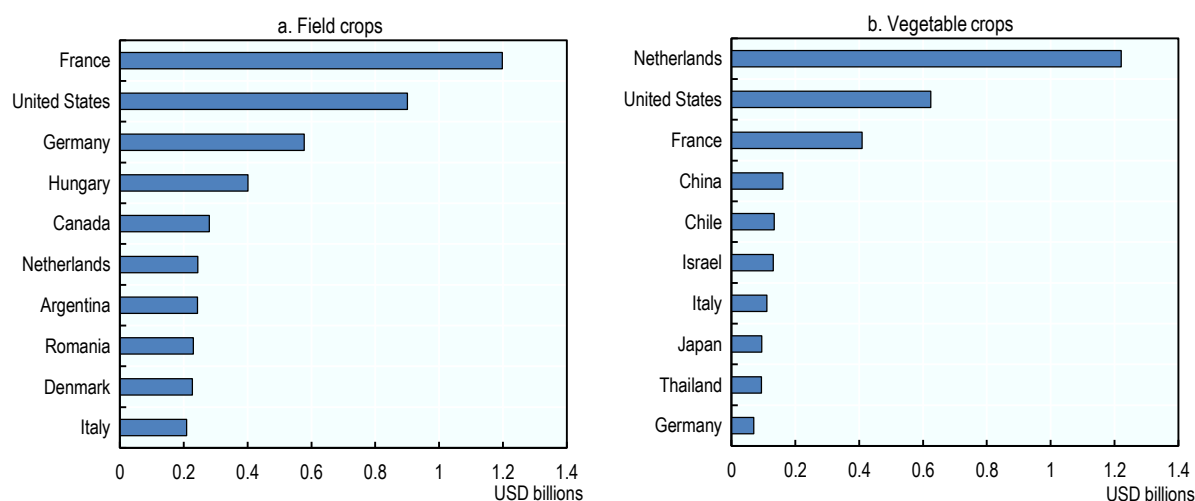
Figure 2.12 shows the main exporting countries (by value) in field crop seed and vegetable crop seed. For field crop seed, France, the United States and Germany are the main exporters, accounting for 40% of global exports by value. For vegetable crop seed, exports are more concentrated; the main exporters are the Netherlands, the United States and France, accounting for more than 60% of exports by value.

Figure 2.11. Global exports of field and vegetable crop seeds, 2009-2015



Source: International Seed Federation.

Figure 2.12. Main exporters, 2015



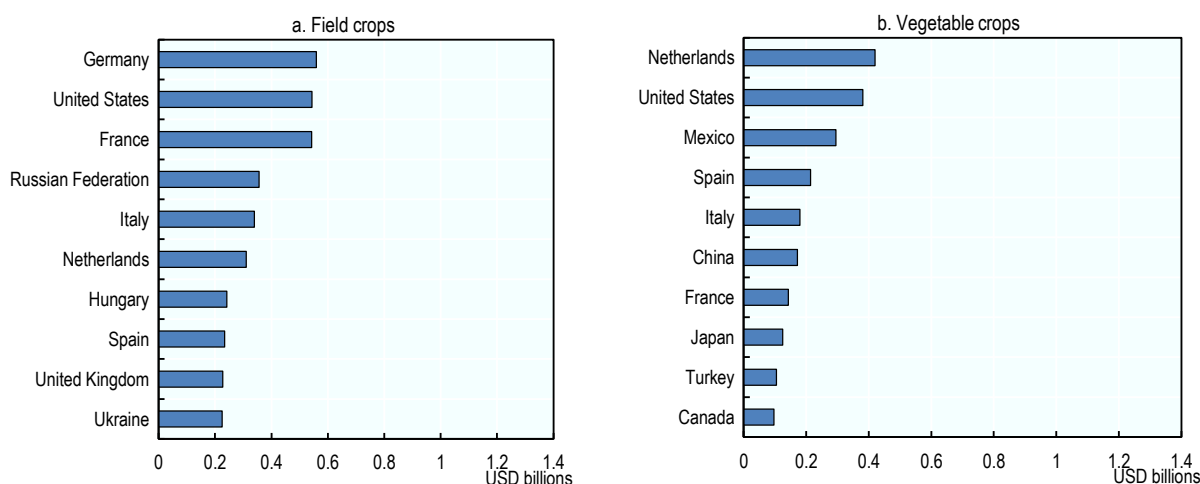
Note: The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Source: International Seed Federation.

Figure 2.13 shows the main importers of seeds for field crops and vegetable crops in 2015. Imports are more dispersed than exports for both categories. Interestingly, there is considerable overlap between the list of main importers and exporters, even within the same

category. For both field and vegetable crops, no less than six of the top-ten exporters are also among the top-ten importers. For field crops, the top importers are France, the United States, Germany, Hungary, the Netherlands, and Italy; for vegetable crops, these are the Netherlands, the United States, France, China, Italy, and Japan. This pattern is explained by a high degree of re-exporting as the seed value chain may cross borders multiple times. For instance, Hungary imports the parent seeds of maize and sunflower, breeds the hybrid crosses, and exports the resulting hybrid seeds back to markets such as France and the United States. The Dutch seed industry tends to outsource vegetable seed multiplication to many countries. Final processing occurs in the Netherlands and seeds are re-exported.⁸

Figure 2.13. Main importers, 2015



Source: International Seed Federation.

International trade in seeds depends on an efficient and reliable system to certify the identity of the varieties traded. This is made possible through international co-operation in the OECD Seed Schemes (Box 2.1).

Box 2.1. The OECD Seed Schemes

The OECD Seed Schemes were established in 1958 and provide an international framework for the varietal certification of agricultural seed in international trade (OECD, 2012^[20]).

Once a country has been accepted, its certification standards for the identity and purity of seeds are considered equivalent to those of other member states in the same Seed Scheme. The goal is to facilitate trade by reducing technical barriers, improving transparency, and lowering transaction costs.

Membership is voluntary and includes many non-OECD states. Currently, 60 countries participate in various Seed Schemes, although with varying participation per Scheme. Participation in the Cereals Seed Scheme, for instance, is nearly universal, while that in the Vegetables or Beet Seed Schemes is limited.

In total, around 50 000 varieties and 200 species are covered under the OECD Seed Schemes. The quantity of seed certified continues to grow and currently exceeds 1 million tonnes out of a total estimated international seed trade volume of around 4 million tonnes (OECD, 2016^[21]) (ISF, 2017^[22]).

Recent work at the OECD in the context of broader research on trade-related international regulatory co-operation has demonstrated the positive effect of the OECD Seed Schemes on international trade in seeds. Results show that the value of seed exports can increase by more than 12% if a country joins the OECD Seed Schemes. If both the exporter and the importer are members of the same Seed Scheme, results show that trade is about 30% higher (OECD, 2017^[23]). This demonstrates the important role the Schemes play in facilitating international trade in seeds.

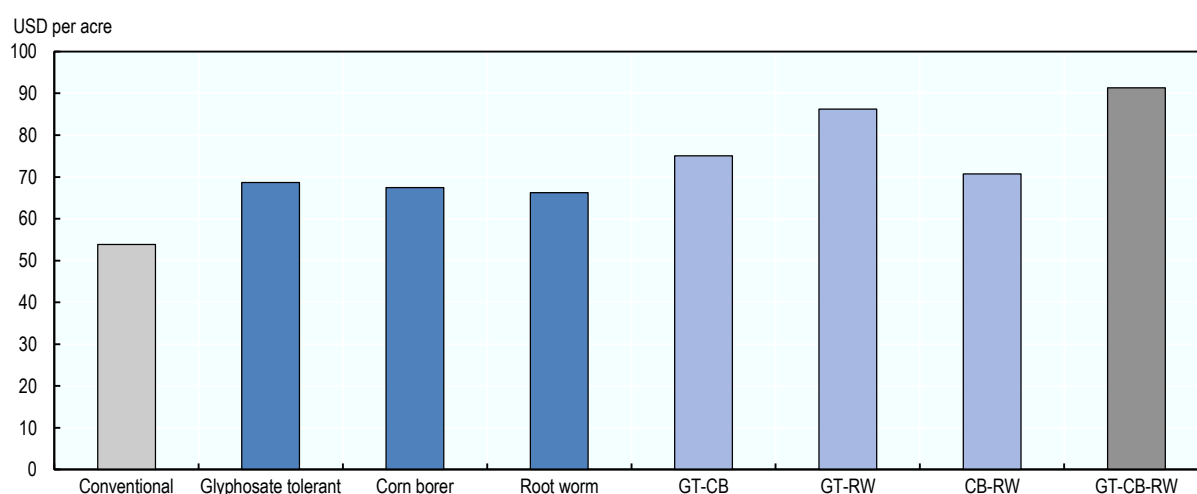
2.7. Prices

Seed for sugar beets, vegetables, maize, and soybeans are typically more expensive while the seed price for wheat is typically lower (Bonny, 2017^[12]). In addition, seed prices vary depending on which GM traits are included (if any), as well as on local market conditions. Giving a full account of seed prices is therefore difficult even if data were easily available. However, some broad findings can be presented.

United States

Figure 2.14 shows estimates of US maize seed prices (in USD per acre) in 2011, highlighting the pricing differentials between conventional seed and different types of GM seed. Conventional maize seed cost around USD 54 per acre (USD 133 per hectare), while different single-trait GM seeds cost around USD 67 per acre (USD 167 per hectare).⁹ Double-stacked traits are more expensive, costing on average around USD 77 per acre (USD 190 per hectare), while triple-stacked traits are more expensive still at around USD 91 per acre (USD 226 per hectare). Unsurprisingly, GM seeds are more expensive than conventional seeds, although the premiums vary from around 25% for single-trait GM seed to around 70% for triple-stacked traits (stacks with more than three traits are also commercially available).¹⁰

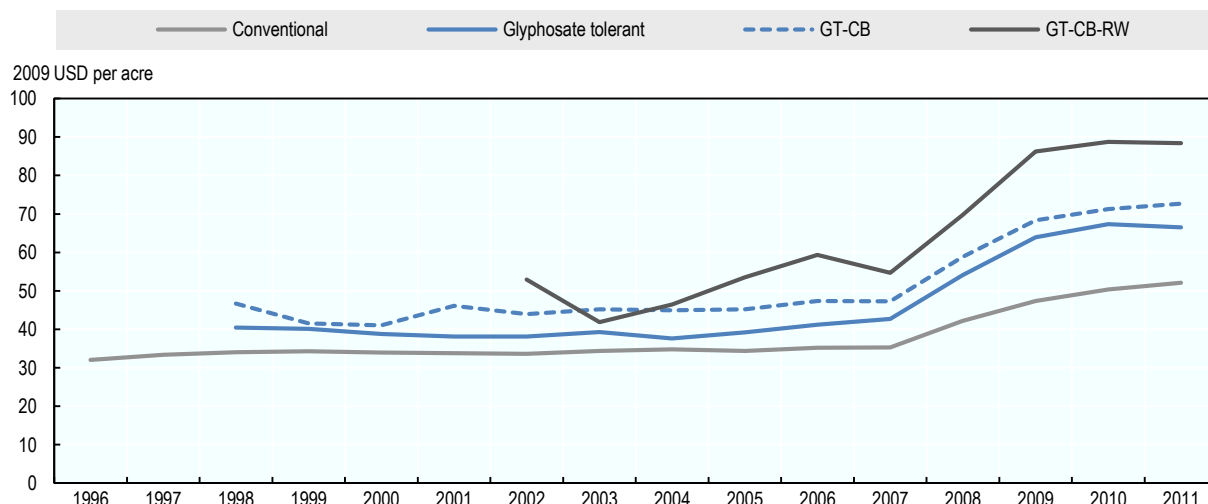
Figure 2.14. Seed prices for US maize in 2011



Note: One acre is around 0.4 hectares, so multiplication by 2.5 gives the approximate value per hectare. Light blue denotes double stacked traits; dark grey denotes triple stacked traits.

Source: Ciliberto et al. (2017^[24]), using GfK Kynetec data.

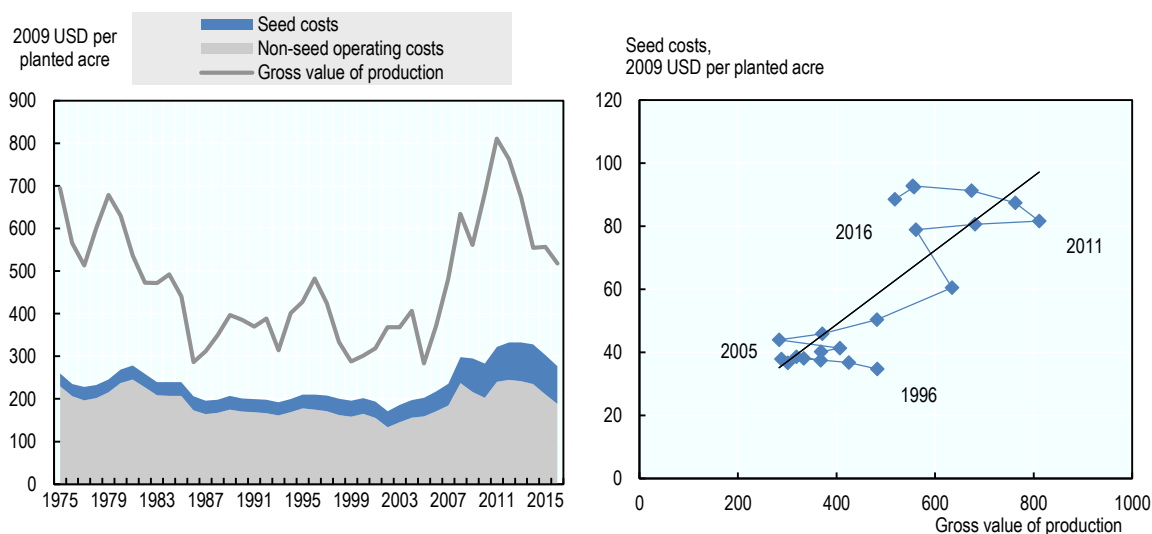
Figure 2.15 shows the evolution of US maize seed prices between 1996 and 2011. In real terms, seed prices have grown considerably during the late 2000s. Conventional seed prices increased by 54% between 2001 and 2011, after correcting for inflation. The price of glyphosate-tolerant maize seed increased by 74% in real terms over the same period. Most of the increase appears to have taken place between 2007 and 2010. The high output prices during this period may be a partial explanation for the observed price evolution as these increased farmers' willingness to pay while simultaneously increasing seed production costs (Ciliberto, Moschini and Perry, 2017^[24]).

Figure 2.15. Evolution of US maize seed prices, 1996-2011

Note: All prices converted to 2009 USD using the US GDP Deflator.

Source: Ciliberto et al. (2017_[24]), using GfK Kynetec data.

To put these developments in context, Figure 2.16 compares seed costs for US maize producers with the gross value of production and other operating costs since 1975. All values are expressed in 2009 USD per planted acre. Panel (a) shows that operating costs in the long run broadly follow the trend of gross value of production: declining between 1975 and the early 2000s, an increase during the 2000s, and a decline in recent years. Panel (b) looks in more detail at the relationship between seed costs and gross value of production since 1996. Seed costs and gross value of production both increased strongly between 2005 and 2011, a period during which the US maize price almost tripled in real terms. After reaching a peak in 2012, the real US maize price had fallen by half by 2016. Panel (b) shows that growth in seed costs slowed down after 2011, and declined between 2015 and 2016.

Figure 2.16. Costs and returns for US maize

Note: All prices converted to 2009 USD using the US GDP Deflator; excluding government subsidies.

Source: OECD analysis using USDA Commodity Costs and Returns reports for maize.

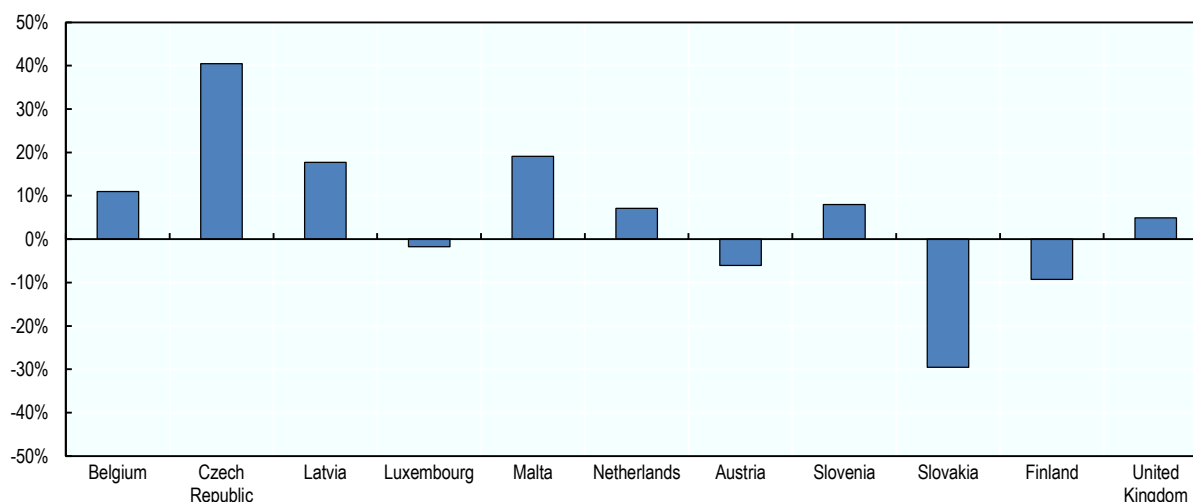
Likewise, Bonny (2014^[25]) shows that the seed cost for soybeans in the United States has remained relatively stable between 2001 and 2013 when measured as a percentage of the gross product per hectare. She points out that prices of both GM and conventional soybeans increased over this period as seed prices are often based on soybean prices at the Chicago Board of Trade. In addition, higher seed costs were generally compensated by lower costs for pesticides.

European Union

A study by Wesseler et al. (2015^[26]) on the agricultural inputs sector in the European Union looks at the evolution of seed costs as a share of total farm costs. Wesseler et al. (2015^[26]) analyse the evolution of the seed cost share across the NUTS2 geographical regions of the European Union and find that the seed cost share increased modestly over time between 1989 and 2009. Estimates indicate that the seed cost share for the average farm increased from around 5.2% of total costs in 1989 to around 6.3% of total costs in 2009 for the EU-15. Moreover, the estimates indicate that since 2004, seed costs in the EU-15 have been declining as a share of total costs (although the change appears modest).

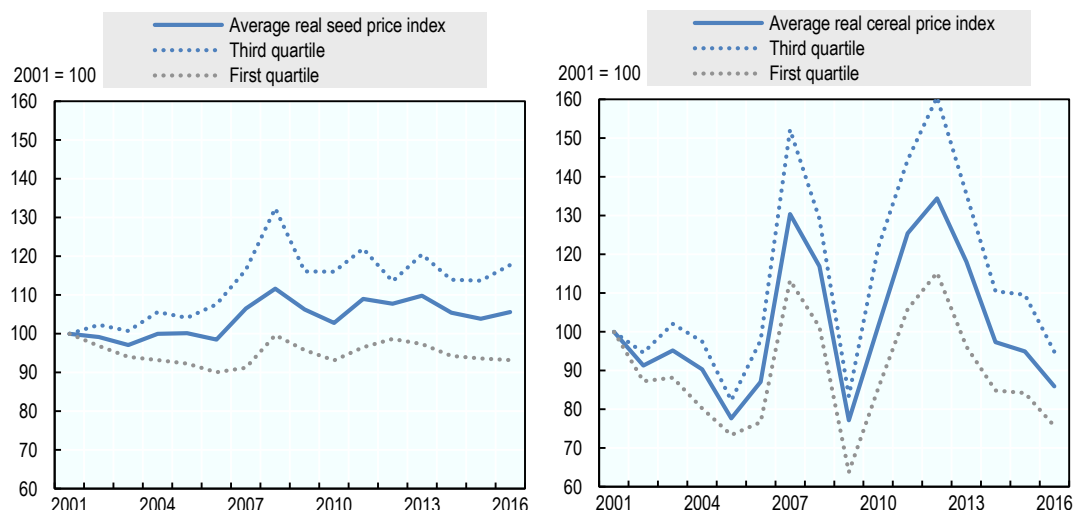
Figure 2.17 presents additional data on the evolution of seed prices in the European Union, using Eurostat data. As data availability differs by country, this figure shows information for 11 countries for which a seed price index is available since 2001. Panel (a) shows the evolution of the real price of seed in these countries between 2001 and 2016. There is no clear trend in seed prices. In some EU Member States seed prices have increased strongly (e.g. Czech Republic, Latvia, Malta), in others there is evidence of a decrease (Slovakia, Finland), and in yet others, changes have been modest (e.g. Luxembourg, United Kingdom).

Figure 2.17. Evolution of seed prices in the European Union



Note: Average real seed price index in Panel (b) is calculated as unweighted average of the 11 countries listed in Panel (a).

Source: Eurostat, *Price indices of the means of agricultural production* (apri_pi10_ina)

Figure 2.18. Evolution of real cereal prices in selected European countries

Note: Average price index calculated as unweighted average of price indices for the 11 countries listed in Figure 2.17 (except Malta, for which data is not available in Eurostat).

Source: Eurostat, *Price indices of agricultural products* (apri_pi10_outa)

Panel (b) shows an unweighted average over time of the price indices for these countries, as well as indications of the “spread” around this average. Over the period as a whole, there is evidence of a modest increase (6% over the 15-year period), but with variations over time. Prices increased in real terms in most countries between 2006 and 2008, declined between 2008 and 2010, and increased in 2011-2013. This development corresponds to the path of cereal prices in the European Union over the same period (Figure 2.18). As in the United States, seed prices in Europe appear to be strongly influenced by price developments in output markets.

2.8. Research and development

The growth of private R&D

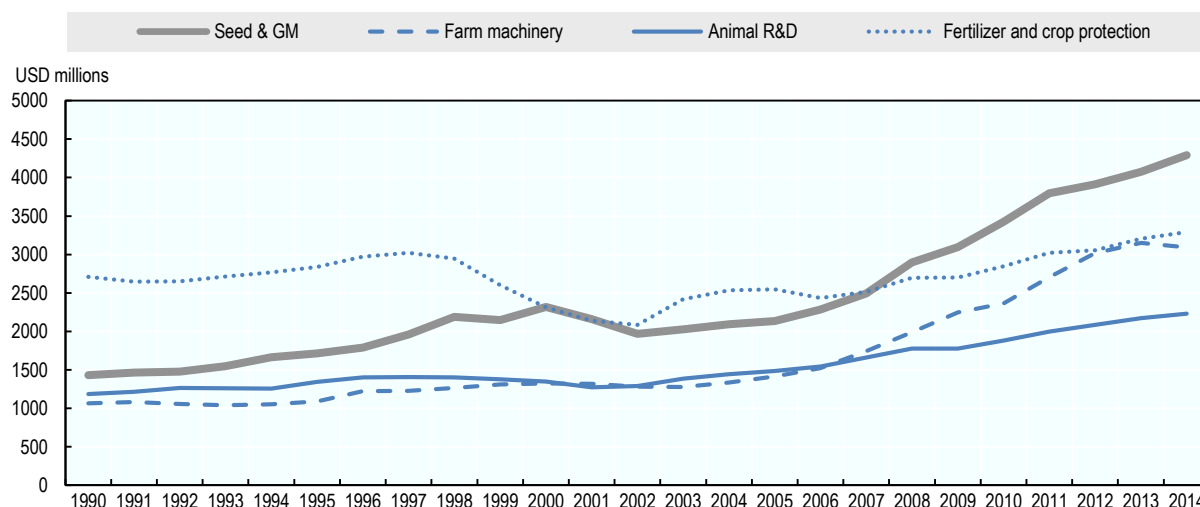
Following the development of hybrid maize in the 1930s and the strengthening of intellectual property rights, plant breeders could expect a greater private return from investments in research and development (R&D). As a result, private R&D in plant breeding has been growing significantly over time. In real terms, private R&D expenditures on plant breeding in the United States increased almost fourteen-fold between 1960 and 1996 (Fernandez-Cornejo, 2004^[11]), and private R&D spending has continued to increase in recent years (Fuglie, Clancy and Heisey, 2017^[27]).

The growth in private R&D for crop improvement is also seen at a global level. Figure 2.19 presents estimates of global private sector R&D in agricultural input industries between 1990 and 2014, using data from Fuglie (2016^[28]). In real terms, private sector R&D for seed and biotech has grown by a factor of three over this period, with most of the increase occurring after 2004.

The growth in private R&D for seeds and biotech is remarkable in comparison with other agricultural input sectors. In 1990, private R&D for seeds and biotech, farm machinery, and animal R&D (including animal health and animal genetics) was considerably lower than

R&D for fertilizer and crop protection. In the past quarter-century, private R&D grew faster for seeds and biotech than for any other agricultural input industry. Real R&D spending grew 200% for seed and biotech compared to 190% for farm machinery, 88% for animal R&D, and 22% for crop protection and fertilizers.

Figure 2.19. Private R&D by input sector worldwide, 1990-2014



Note: In millions of constant 2005 PPP dollars.

Source: Based on Fuglie (2016^[28]), Tables 3 and 4.

Seeds and biotech also have a higher research intensity than other agricultural input industries (Figure 1.2). R&D for crop seed and traits represented more than 10% of sales in 2009, considerably higher than the R&D intensity in, for example, crop protection or farm machinery (although these numbers predate the increase in farm machinery R&D visible in Figure 2.19, which may be tied to the development of precision agriculture).

The large increase in R&D is driven to an important degree by traits for genetically modified crops, but indirect evidence suggests that R&D intensity is also high for conventional (non-GM) plant breeding. For instance, the German seed company KWS obtains about half of its revenues from the European market where the share of GM is negligible, yet spent EUR 190 million on R&D in 2016-2017. This corresponds to an R&D intensity of 14%. Similarly, 44% of the revenues of the French seed company Limagrain/Vilmorin originate in the European market; Vilmorin invested EUR 240 million on research in 2016-2017, corresponding to an R&D intensity of 15%.¹¹ These data are only suggestive, as most of this expenditure may be on traits research for those markets where GM seeds are in wide use. Nevertheless, qualitative information offered by both firms in their annual reports confirms sustained efforts using conventional breeding for both firms. Similarly, in the Dutch vegetable plant breeding industry, R&D expenditures are estimated to be 15%-30% of sales in the absence of GM technology (Schenkelaars, de Vriend and Kalaitzandonakes, 2011^[29]).

The evolving roles of private and public R&D

The development of plant breeding has been shaped by the interplay of public and private efforts. While the relative contribution of private and public plant breeding differs by country, in general the public sector has played an important role in improving plant varieties.

In some countries, efforts originated in the private sector and were subsequently supplemented by research in the public sector (Kingsbury, 2009_[30]). This was the case, for instance, in Sweden, the United Kingdom, and the Netherlands. In Sweden, private efforts led to the creation of the Svalöf Institute at the end of the 19th century, which became part of a state system by the early 20th century. In the United Kingdom, despite the establishment of public plant breeding institutions, only 40% of the funds for plant breeding came from public sources between 1910 and 1921. However, following World War II, public plant breeding received a major boost, and wheat varieties bred by the public Plant Breeding Institute (PBI) dominated agriculture by the 1970s, as did potato varieties originating in the Scottish PBI.

In the Netherlands, small seed firms, hobby breeders and farmer cooperatives have played an important role in plant breeding, possibly because there was a form of legal variety protection at an early stage. The Netherlands set up a public institute for plant breeding in Wageningen in 1912, the Foundation for Agricultural Plant Breeding (*Stichting voor Plantenveredeling*) in 1948, as well as the Institute for Horticultural Plant Breeding (*Instituut voor de Veredeling van Tuinbouwgewassen*). Nevertheless, private plant breeders remained important as public institutes concentrated on research rather than breeding and were not allowed to release commercial varieties of crops where private breeding companies existed.

In other countries, the role of the public sector was even more prominent. This was particularly the case for the United States. Already in 1819, naval and consular personnel were encouraged to collect plants which could be useful to US agriculture, and the US Patent Office played an important role in collecting and distributing plant material throughout the 19th century. Since the establishment of the United States Department of Agriculture (USDA) and land grant universities in 1862, and State Agricultural Experiment Stations (SAES) in 1887, these institutions have devoted considerable efforts to plant breeding and distribution of improved varieties (Kingsbury, 2009_[30]) (Kloppenburg, 1988_[14]).

The strong growth in private R&D has led to a change over time in the relative importance of private and public R&D (Fernandez-Cornejo, 2004_[11]). In 1960, public spending accounted for 60% of total R&D on crop improvement for maize in the United States. By 1984, this share had fallen below 40%. For soybeans, practically all crop improvement research in the United States was conducted by the public sector in 1960; by 1984, the share of the public sector had fallen to about three-quarters of the total. Comparable data for recent years is not available, but given the emergence of genetically modified seeds during the 1990s the private share of crop improvement R&D for maize and soybeans has almost certainly continued to increase.

R&D expenditures by large private companies now dwarf the R&D budgets of the largest public sector agricultural research agencies. In 2007, the R&D budgets of Bayer (USD 978 million), Syngenta (USD 830 million), Monsanto (USD 770 million), BASF (USD 655 million), and DuPont (USD 633 million) exceeded the crop science research budget of the USDA's Agricultural Research Service (USD 456 million) and that of CGIAR (USD 178 million) (Fuglie et al., 2011_[9]).

Given the rising importance of private R&D, public and private R&D tend to play complementary roles. A detailed analysis for the United States in the 1990s found that private sector R&D consisted more of short-term applied work focused on varietal development. In contrast, the USDA Agricultural Research Service focused more on long-term basic research, e.g. developing new breeding techniques, with the State Agricultural Experiment Stations falling somewhere in-between (Frey (1996_[31]), Fuglie et al. (2017_[27])).¹²

International agencies continue to play an important role in plant breeding for developing countries. The International Rice Research Institute (IRRI, founded in 1960) and the International Maize and Wheat Improvement Center (CIMMYT, founded in 1966) were key actors during the Green Revolution. They were later joined by the International Institute for Tropical Agriculture (IITA, 1967), the International Centre for Tropical Agriculture (CIAT, 1967), the African Rice Centre (WARDA, 1971), the International Centre for Agricultural Research in Dry Areas (ICARDA, 1977), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, 1977). To coordinate the research efforts of these agencies, the Consultative Group for International Agricultural Research (CGIAR) was established in 1971. Several of these centres have significant public-private partnerships with leading international seed companies, although with limited effects on food security, poverty reduction or agricultural development (Spielman and von Grebmer, 2006^[32]).

In addition to specific agricultural science research, plant breeding benefits from research within the broader scientific community. This link has become stronger over time with the emergence of genetic modification and New Plant Breeding Techniques (NPBT), including genome editing techniques, such as CRISPR/Cas (Scheben and Edwards, 2017^[33]).¹³

Notes

- ¹ The focus in this study is on seed markets relevant to food and agriculture. Most of the data and discussion relates to field crops and (to a lesser extent) vegetables, excluding, for example, ornamental crops, grasses, or forestry.
- ² Data on farm-saved seed needs to be interpreted with caution, as this number is likely to be underestimated (Heisey and Fuglie, 2011^[7]). On a global level, farm-saved seed is most common in those countries where data is the least available. On the importance of farm-saved seed in developing countries, see van Etten et al. (2017^[120]) and Spielman and Kennedy (2016^[154]).
- ³ Bonny (2014^[25]) calculates that farm-saved seed accounted for 45% of the total wheat crop planted in France between 1981 and 2012, without a clear downward trend.
- ⁴ As pointed out by Bonny ((2014^[25]), (2017^[12])), different sources and methods lead to different estimates of market sizes, and figures provided by some market research agencies tend to give lower estimates as they may underestimate sales by small and medium-size enterprises. In particular, often-cited market estimates by Phillips McDougall (of USD 35 billion in 2015) only account for two-thirds of global crops. If the four-firm concentration ratio is calculated using such low estimates, the degree of market concentration is automatically overstated. This is particularly the case for the widely-used estimates of ETC Group (2013^[8]). The Syngenta estimates used here are in line with estimates of the International Seed Federation and the bulk of the market research estimates surveyed in Bonny (2017^[12]).
- ⁵ The European Union forms a single market for seeds as it has a harmonised regulatory environment across all Member States. However, agro-ecological differences across countries imply that the relevant market for farmers may have a narrower geographic scope, depending on the crop.
- ⁶ See Bonny (2014^[25]) for an introduction to the genetically modified seed sector.

- ⁷ A note on terminology: a GM *trait* refers to a (phenotypic) characteristic such as herbicide tolerance (see further). A GM *event* refers to the underlying genetics and is defined by the DNA sequence that has been inserted into the host genome and the site(s) where this DNA has been inserted (Mumm, 2013^[248]). The terms GM and biotechnology/biotech are used interchangeably in this report.
- ⁸ Personal communication with Szabolcs Ruthner and Marien Valstar.
- ⁹ One acre is around 0.4 hectares, so multiplication by 2.5 gives the approximate equivalent in USD per hectare.
- ¹⁰ The higher cost of GM seed may partly reflect market power and the need to recover high R&D investments, but production and post-harvest processing costs may also be higher. To prevent low-level pollen contamination, GM seed production may use greater isolation distances or other isolation mechanisms, which raise the cost of producing seed. Another factor influencing seed prices is the degree of post-harvest processing, conditioning, and seed treatment.
- ¹¹ These R&D intensities are calculated using revenues for KWS and Vilmorin including their share of the AgReliant joint venture, following Vilmorin's own presentation of its R&D numbers. The Vilmorin R&D number of EUR 240 million represents the total investment in R&D; for accounting reasons, only EUR 192 million are included in Vilmorin's profit-and-loss statement. For KWS, the EUR 190 million represent the R&D outlays included in the profit-and-loss statement. Both companies are discussed in more detail in the next chapter.
- ¹² The complementary roles of public and private agricultural R&D spending are explored in greater detail in Chapter 7.
- ¹³ The precise impact of broader scientific research on plant breeding is difficult to assess, as scientific research in one field may find unexpected applications in another field, often with long lags. For instance, CRISPR was first identified in research on the genome of *E. coli* in 1987 (Bortesi and Fischer, 2015^[169]). Recent research on the impact of public funding of science through the National Institutes of Health in the United States shows that public funding positively affects private-sector patenting activity, although lags are long (up to twenty years after the initial NIH grant approval) and roughly half of the ultimate impact takes place in different research areas (Azoulay et al., 2015^[254]).

Annex 2.A. Selected data tables

Annex Table 2.A.1. Evolution of the global commercial seed market, 2001-2014

Year	Conventional	GM	Total
2001	11.5	2.3	13.8
2002	11.0	2.8	13.8
2003	11.5	3.4	14.9
2004	12.4	4.3	16.7
2005	13.3	5.1	18.4
2006	14.9	5.8	20.7
2007	16.9	6.8	23.7
2008	20.5	8.5	29.0
2009	21.2	11.1	32.3
2010	22.6	13.4	36.0
2011	24.4	16.0	40.4
2012	26.8	18.3	45.1
2013	28.2	19.6	47.8
2014	30.7	21.1	51.8

Note: In billions of USD, not adjusted for inflation. Includes public and commercial seeds; excludes flower seeds and farm-saved seed.

Source: Syngenta (2016^[15]).

Annex Table 2.A.2. The global seed market by crop and by region, 2014

Billion USD	North America	Asia Pacific	EMEA	South America	Total
Maize	8.7	3.7	3.9	3.9	20.2
Soybean	4.4	n.a.	n.a.	2.9	7.4
Rice	n.a.	5.1	n.a.	n.a.	5.1
Vegetables	0.5	1.6	2.2	0.5	4.8
Cereals	n.a.	1.9	2.3	n.a.	4.2
Cotton	0.9	1.2	n.a.	n.a.	2.0
Rapeseed	0.9	n.a.	0.3	n.a.	1.2
Sugar beet	n.a.	n.a.	0.8	n.a.	0.8
Sunflower	n.a.	n.a.	0.6	n.a.	0.6
Others	1.7	1.2	1.4	1.0	5.3
Total	17.1	14.7	11.4	8.4	51.6

Note: EMEA stands for Europe, Middle East and Africa. North America refers to Canada, United States, and Mexico.

Source: Estimates based on Syngenta (2016^[15]).

Annex Table 2.A.3. Top 20 domestic seed markets in 2012

Rank	Country	Value (USD billions)	Share of global market (%)
1	United States	12.0	27%
2	China	10.0	22%
3	France	2.8	6%
4	Brazil	2.6	6%
5	Canada	2.1	5%
6	India	2.0	4%
7	Japan	1.4	3%
8	Germany	1.2	3%
9	Argentina	1.0	2%
10	Italy	0.8	2%
11	Turkey	0.8	2%
12	Spain	0.7	1%
13	Netherlands	0.6	1%
14	Russian Federation	0.5	1%
15	United Kingdom	0.5	1%
16	South Africa	0.4	1%
17	Australia	0.4	1%
18	Korea	0.4	1%
19	Mexico	0.4	1%
20	Czech Republic	0.3	1%
	Rest of world	4.3	10%
	Total	44.9	100%

Source: Based on International Seed Federation data cited in ISAAA (2016^[16]).

Annex Table 2.A.4. Global area of GM crops in 2017, by country

Country	Area under GM crops (million hectares)	Share of global GM area
United States	75.0	40%
Brazil	50.2	26%
Argentina	23.6	12%
Canada	13.1	7%
India	11.4	6%
Paraguay	3.0	2%
Pakistan	3.0	2%
China	2.8	1%
South Africa	2.7	1%
Uruguay	1.1	1%
Other	3.9	2%
Total	189.8	100%

Source: ISAAA (2017).

Annex Table 2.A.5. Global area of GM crops in 2017, by crop

Crop	Area under GM crops (million hectares)	GM as % of total area
Soybean	94.1	77%
Maize	59.7	32%
Cotton	24.1	80%
Rapeseed	10.2	30%
Alfalfa	1.2	n.a.
Sugar beet	0.5	n.a.
Papaya	<1	n.a.
Other	<1	n.a.
Total	189.8	n.a.

Source: ISAAA (2017).

Annex Table 2.A.6. Global exports of field and vegetable crop seeds, 2009-2015

	Volume (Million tons)		Value (USD billions)	
	2009	2015	2009	2015
Field crops	2.10	3.74	4.92	6.75
Vegetable crops	0.11	0.12	2.75	3.63
Total	2.21	3.86	7.67	10.38

Source: International Seed Federation.

Annex Table 2.A.7. Main seed exporters, 2015

Field crops, 2015		Vegetable crops, 2015	
Country	Exports (USD billions)	Country	Exports (USD billions)
France	1.20	Netherlands	1.22
United States	0.90	United States	0.62
Germany	0.58	France	0.41
Hungary	0.40	China	0.16
Canada	0.28	Chile	0.13
Netherlands	0.24	Israel	0.13
Argentina	0.24	Italy	0.11
Romania	0.23	Japan	0.10
Denmark	0.23	Thailand	0.09
Italy	0.21	Germany	0.07
Rest of world	2.24	Rest of world	0.58
Total	6.75	Total	3.63
Top 10 share	67%	Top 10 share	84%

Note: Statistical discrepancies exist between global export and import data.

Source: International Seed Federation.

Annex Table 2.A.8. Main seed importers, 2015

Field crops, 2015		Vegetable crops, 2015	
Country	Imports (USD billions)	Country	Imports (USD billions)
Germany	0.56	Netherlands	0.42
United States	0.54	United States	0.38
France	0.54	Mexico	0.30
Russian Federation	0.36	Spain	0.21
Italy	0.34	Italy	0.18
Netherlands	0.31	China	0.17
Hungary	0.24	France	0.14
Spain	0.23	Japan	0.13
United Kingdom	0.23	Turkey	0.11
Ukraine	0.23	Canada	0.10
Rest of world	2.95	Rest of world	1.39
Total	6.53	Total	3.52
Top 10 share	55%	Top 10 share	61%

Note: Statistical discrepancies exist between global export and import data.

Source: International Seed Federation.

Annex Table 2.A.9. Costs and returns for US maize, 1975-2016

Year	Gross value of production (USD per acre)	Seed costs (USD per acre)	Total operating costs (USD per acre)	Output price (USD per bushel)
1975	694.3	29.7	259.4	8.1
1976	566.1	28.7	234.8	6.5
1977	513.2	31.5	228.0	5.8
1978	601.6	30.9	232.6	6.0
1979	678.6	30.5	245.5	6.2
1980	629.7	32.1	269.0	7.0
1981	536.0	33.3	278.4	4.9
1982	472.4	31.9	259.1	4.2
1983	472.1	31.1	239.6	6.0
1984	492.1	32.5	239.4	4.7
1985	440.6	32.3	239.0	3.8
1986	286.0	33.0	206.2	2.4
1987	311.6	31.5	196.0	2.6
1988	350.5	30.5	197.8	4.2
1989	396.6	32.6	207.2	3.4
1990	385.4	30.7	201.0	3.3
1991	369.6	31.3	199.8	3.3
1992	388.8	31.3	197.7	2.9
1993	314.3	31.1	192.3	3.2
1994	401.6	30.7	199.3	2.8
1995	427.5	31.8	209.9	3.7
1996	482.3	34.7	209.9	3.7
1997	424.8	36.8	208.0	3.2
1998	333.4	38.1	200.0	2.4
1999	288.2	37.8	196.0	2.1
2000	301.2	36.7	201.5	2.2
2001	318.7	38.6	193.8	2.2
2002	367.9	37.4	171.1	2.7
2003	368.5	40.2	185.8	2.5
2004	406.6	41.3	197.4	2.4
2005	283.1	44.0	202.6	1.9
2006	371.1	45.9	217.3	2.7
2007	481.8	50.4	235.3	3.4
2008	634.1	60.5	297.9	4.4
2009	561.2	78.9	295.0	3.6
2010	681.1	80.6	283.0	4.3
2011	811.0	81.7	321.7	5.5
2012	762.8	87.5	332.3	6.5
2013	673.9	91.3	332.6	4.3
2014	554.3	92.8	328.0	3.3
2015	556.9	92.4	303.4	3.3
2016	517.9	88.5	277.1	3.0

Note: All prices converted to 2009 USD using the US GDP Deflator; excluding government subsidies.

Source: OECD analysis using USDA Commodity Costs and Returns reports for maize.

Annex Table 2.A.10. Global private R&D spending by agricultural input sector, 1990-2014

Year	Seed & biotech	Animal R&D	Fertilizer and crop protection	Farm machinery
1990	1,431	1,188	2,708	1,065
1991	1,466	1,217	2,649	1,080
1992	1,479	1,265	2,650	1,058
1993	1,550	1,261	2,713	1,041
1994	1,664	1,256	2,767	1,053
1995	1,716	1,344	2,840	1,090
1996	1,789	1,401	2,970	1,224
1997	1,960	1,407	3,021	1,227
1998	2,189	1,404	2,948	1,264
1999	2,146	1,379	2,600	1,312
2000	2,317	1,348	2,314	1,325
2001	2,160	1,275	2,139	1,321
2002	1,969	1,288	2,083	1,282
2003	2,026	1,384	2,417	1,276
2004	2,095	1,444	2,534	1,337
2005	2,133	1,484	2,547	1,416
2006	2,286	1,543	2,435	1,525
2007	2,493	1,659	2,514	1,742
2008	2,897	1,778	2,695	1,990
2009	3,096	1,775	2,701	2,247
2010	3,426	1,880	2,848	2,363
2011	3,796	1,999	3,020	2,705
2012	3,911	2,087	3,053	3,017
2013	4,074	2,172	3,203	3,152
2014	4,290	2,229	3,291	3,091
<i>Annual real growth</i>	4.7%	2.7%	0.8%	4.5%

Note: In millions of constant 2005 PPP dollars.

Source: Based on Fuglie (2016[23]), Tables 3 and 4.

3. Structural changes in the seed industry

The seed industry has witnessed several phases of consolidation in the past three decades. This chapter presents profiles of the main firms in the global seed industry, with particular attention to recent changes. The drivers behind the observed pattern of change and consolidation are discussed in-depth and illustrated with a case study of the US cotton seed industry. Implications for the current merger wave are also examined.

3.1. The organisation of the seed industry

To understand structural changes in seed markets, it is useful to distinguish four stages in the seed supply chain (Fernandez-Cornejo, 2004^[1]):

- *Plant breeding*, where R&D leads to new, improved varieties. This sector is highly concentrated. An even smaller set of firms is active in the development of GM traits.
- *Seed production*, which is typically outsourced by plant breeding firms to contract farmers.
- *Seed conditioning*, which is the stage where seeds are dried, cleaned, sorted, treated with insecticides and fungicides, and packaged for distribution and sale. Like seed production, this stage contains many smaller firms, often linked by contracts to large seed firms.
- *Seed distribution*, where seeds are sold to end users. Wholesale distribution is often controlled directly by large seed firms, sometimes through licensing agreements. At the local level, retail distribution of seeds often takes place through local intermediaries such as farmer-dealers or agricultural supply stores. The precise structure of the distribution stage differs from region to region. In some countries, agricultural cooperatives play an important role in distribution of agricultural inputs, including seeds (Syngenta, 2016^[15]).

By way of illustration, the maize seed sector in France comprises 12 plant breeding enterprises, 40 seed production firms (which in turn contract with 4 615 farmers), and 4 842 sales outlets (Gnis, 2017^[34]). For the European Union as a whole, an estimated 7 000 firms are active in the seed industry across the various stages of the supply chain. Poland, Romania and Hungary together account for 2 800 such firms, most of which are small and medium enterprises (Ragonnaud, 2013^[17]).

Research and development can be undertaken by the public sector (e.g. at universities) as well as by private firms, and is typically costly and time-consuming. Traditional plant breeding in particular takes several years, as it most often requires repeated crossing and selection. On average, it takes more than ten years after the first crossing before any actual sales are made (KWS, 2017^[35]). Recent breakthroughs using the so-called New Plant Breeding Techniques (NPBTs) could potentially lead to significant reductions in the time needed to develop new varieties (Schaart et al., 2015^[11]) (Scheben and Edwards, 2017^[33]). For research on genetically modified organisms, significant additional costs are incurred for safety assessments and other tests required by regulatory bodies (Kalaitzandonakes, Alston and Bradford, 2007^[36]).

The category of plant breeders includes large, well-known companies such as Monsanto, as well as a range of smaller niche players. There are also many smaller seed companies that do not engage in R&D, but produce and sell seed under licensing or other commercial arrangements, and (at the other end of the spectrum) there are small- and medium-size agricultural biotechnology companies which engage in R&D but often have little or no sales yet (Heisey and Fuglie, 2011^[7]).

3.2. Leading firms in the global seed industry

This section provides background on the leading firms in the industry. Firms involved in recent mergers and acquisitions are discussed first (in chronological order according to the date when the initial bid or proposal was announced); two other important players (Limagrain/Vilmorin and KWS) are then discussed.

DowDuPont

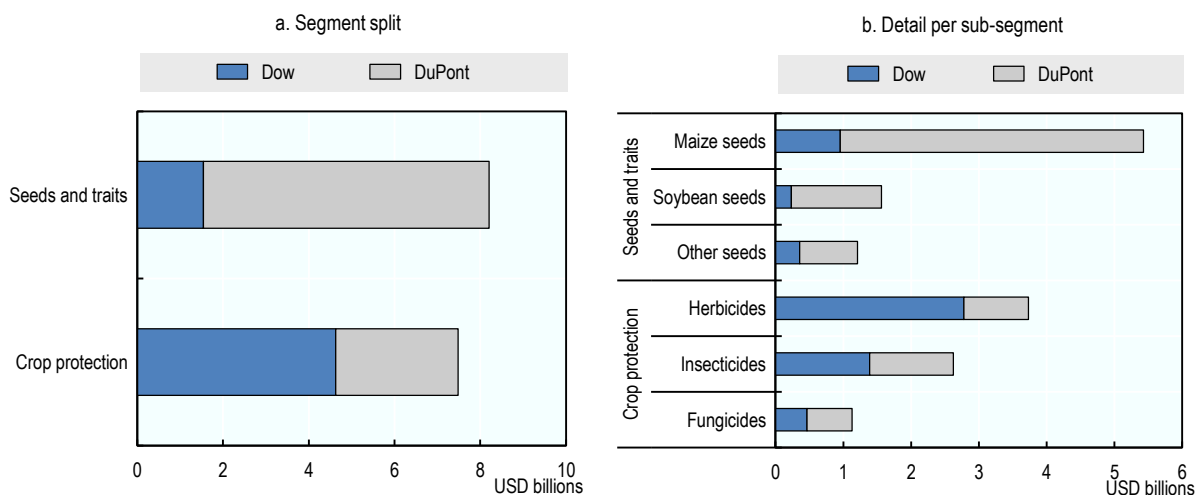
The merger of Dow and DuPont was initially announced in December 2015, and officially concluded on 1 September 2017. The new company, DowDuPont, consists of three main divisions which will eventually become separate and independent companies. Its agriculture division, under the name of Corteva Agriscience, corresponds to the activities of DuPont Pioneer, DuPont Crop Protection and Dow AgroSciences. Two other divisions focus on materials science and specialty products (DowDuPont, 2018^[37]).¹

Before merging, Dow's agricultural sales were mostly centred on crop protection chemicals while DuPont's agricultural sales were dominated by seeds (notably through its Pioneer brand). Figure 3.1 shows a pro forma representation of combined sales of Dow and DuPont based on 2016 sales data, not taking into account any divestitures. Before divestitures, the combined agricultural sales of Dow and DuPont were around USD 16 billion. As shown in Panel (a), Dow and DuPont have complementary profiles and the joint company has a more balanced segment split as a result. As shown in Panel (b), within seeds and traits, maize seeds are by far the most important source of revenues, with soybean seeds a distant second. Within crop protection, most revenues come from herbicides (where Dow is traditionally strongest) and insecticides (where both Dow and DuPont historically had important sales).

In terms of geographic split (Figure 3.2), DuPont's agricultural sales before the merger were mostly concentrated in North America, which accounted for 54% of 2016 sales. North America was also the centre of gravity for Dow Agricultural Sciences (41% of 2016 sales), but compared to DuPont, a larger share of revenues came from Latin America.

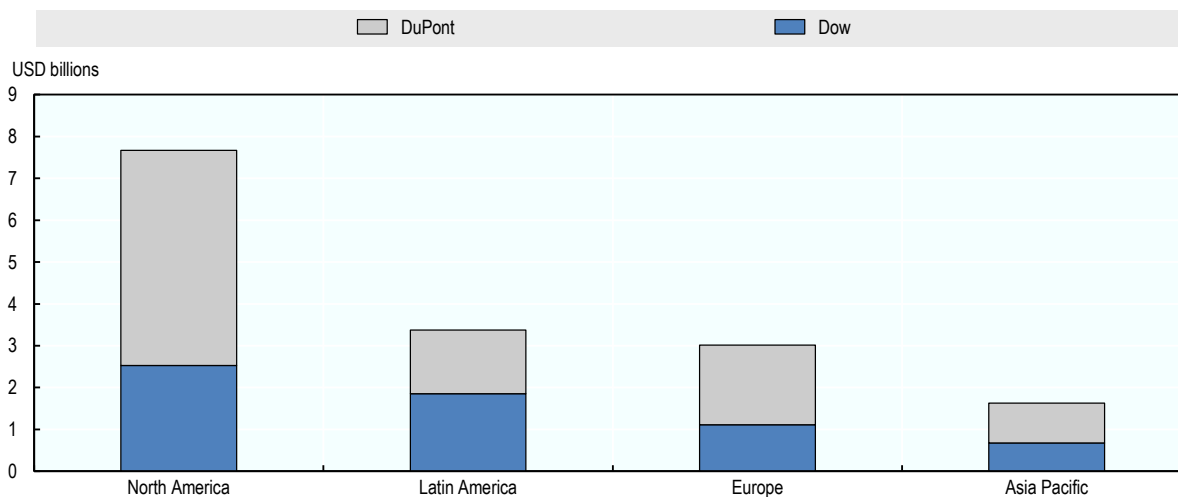
Before taking into account the divestitures, the combined Dow and DuPont agricultural operation is therefore geographically concentrated in the Americas, with almost half of sales in North America and 22% in Latin America. Europe (including India for Dow) accounts for 19% and Asia Pacific for 10%.

The merger of Dow and DuPont was scrutinised by competition authorities. The European Commission conditionally approved the merger in March 2017 subject to significant divestitures. DuPont agreed to divest a large part of its crop protection business, including its global crop protection R&D organisation. In May 2017, Dow and DuPont received approval in Brazil conditional on divesting assets related to maize seeds in the Brazilian market. In June 2017, the United States Department of Justice announced the conclusions of its own investigation, and required divestitures similar to those required by the European Commission. Following the divestitures, total sales in DowDuPont's agriculture division are estimated at around USD 14 billion (compared to around USD 16 billion in the pro forma calculation shown in the charts). Data presented in the 2017 Annual Report of DowDuPont do not allow for a more detailed analysis.

Figure 3.1. Pro forma 2016 sales per segment for Dow and DuPont (agriculture)

Note: Pro forma estimates based on the 2016 sales figures for the companies, not taking into account divestitures. Data is approximate and based on company materials.

Source: Company annual reports; Dow presentation at Bank of America Merrill Lynch Global Agriculture Conference, March 2017.

Figure 3.2. Pro forma 2016 sales per region for Dow and DuPont (agriculture)

Note: Pro forma estimates based on the 2016 sales figures for the companies, not taking into account divestitures. Europe for Dow refers to Europe, Middle East, Africa and India. Data is approximate and based on highly aggregate numbers in company materials.

Source: Company annual reports; Dow presentation at Bank of America Merrill Lynch Global Agriculture Conference, March 2017.

ChemChina-Syngenta

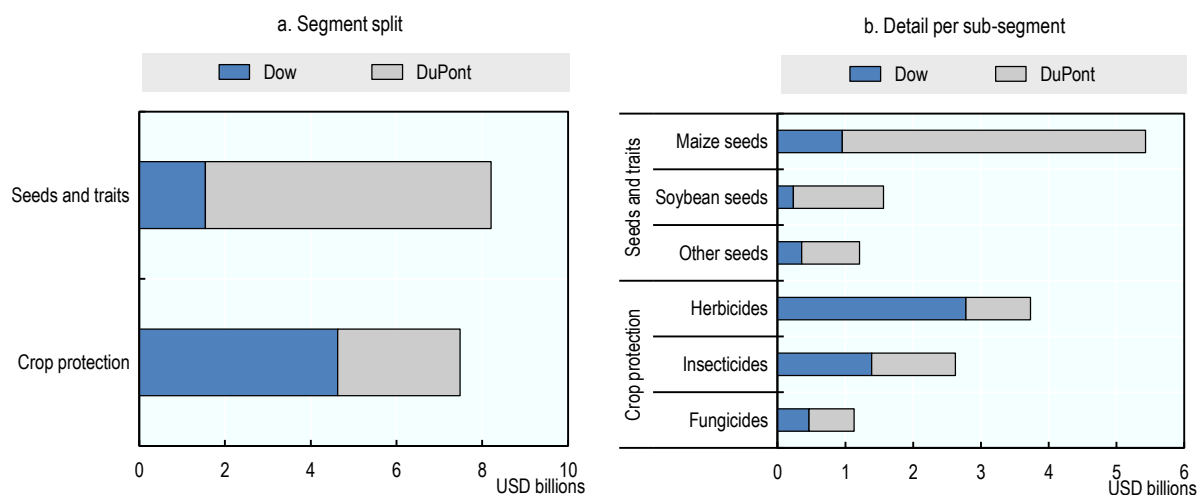
After a failed bid by Monsanto on Syngenta in 2014-15, ChemChina (China National Chemical Corporation) launched a bid for Syngenta in February 2016, offering USD 43 billion for the company. Regulatory approval was obtained in April 2017 from EU and US regulators, but under the condition of divesting certain parts of the ChemChina and Syngenta pesticide businesses.

ChemChina is the largest chemical firm in the People's Republic of China (hereafter "China") and operates a wide range of businesses from basic chemicals to high-end manufacturing.² Although it is a state-owned company, ChemChina has been described as "functioning as an aggressive private business" and a "state enterprise in name only" (Weinland and Hornby, 2017^[38]). The Syngenta acquisition is the largest overseas acquisition by a Chinese firm to date. In June 2018, ChemChina announced a merger with Sinochem, another large state-owned chemical conglomerate (Reuters, 2018^[39]). The merger will create the world's largest industrial chemicals group. One reason for the merger is reportedly the need to ensure that ChemChina has sufficient financial strength to absorb Syngenta (Weinland and Hornby, 2017^[38]).

Syngenta's CEO, Erik Fyrwald, has described ChemChina's acquisition of Syngenta as a strategic step to ensure food security for China through a two-pronged strategy. The goal, according to Fyrwald, is not only to acquire leading technology to improve productivity in China, but also to ensure continuous development of technology to improve productivity elsewhere in order to maintain potential sources of food imports for China (Colvin, 2017^[40]) (Tsang, 2017^[41]).³ Historically, ChemChina has invested little in agricultural R&D; before the Syngenta acquisition, its core activity in agriculture was in the generic pesticide market through its Adama subsidiary. This makes the ChemChina-Syngenta acquisition different from the DowDuPont and Bayer-Monsanto transactions, which combined two R&D-intensive firms.

Syngenta's sales are mostly concentrated in Europe, the Middle East and Africa (EMEA), Latin America, and North America (Figure 3.3); Asia is currently less well-served. Seeds account for about 23% of Syngenta's global revenues, but this share is smaller in Asia Pacific (15%). From Syngenta's point of view, the acquisition by ChemChina could open opportunities for sales growth in Asia, in particular in the seeds segment.

Figure 3.3. Syngenta 2017 sales by region and segment



Note: EMEA is Europe, Middle East and Africa.

Source: Company annual reports.

ChemChina's subsidiary Adama sells generic pesticides in the European Union and the United States (among other markets). Both in the United States and the European Union, there was an overlap between Adama's generic portfolio and Syngenta's portfolio of pesticides; in the European Union there was additional concern around Adama's plant growth regulator business. In the United States, competition authorities required ChemChina to divest three pesticide products. In the European Union, ChemChina has divested a significant part of the Adama pesticide business, as well as some Syngenta pesticides, several generic pesticides which were under development, and part of Adama's plant growth regulator business (European Commission, 2017^[42]) (Bartz, 2017^[43]). As ChemChina has no seed sales, there was no competition conflict with Syngenta's seed businesses.

Bayer-Monsanto

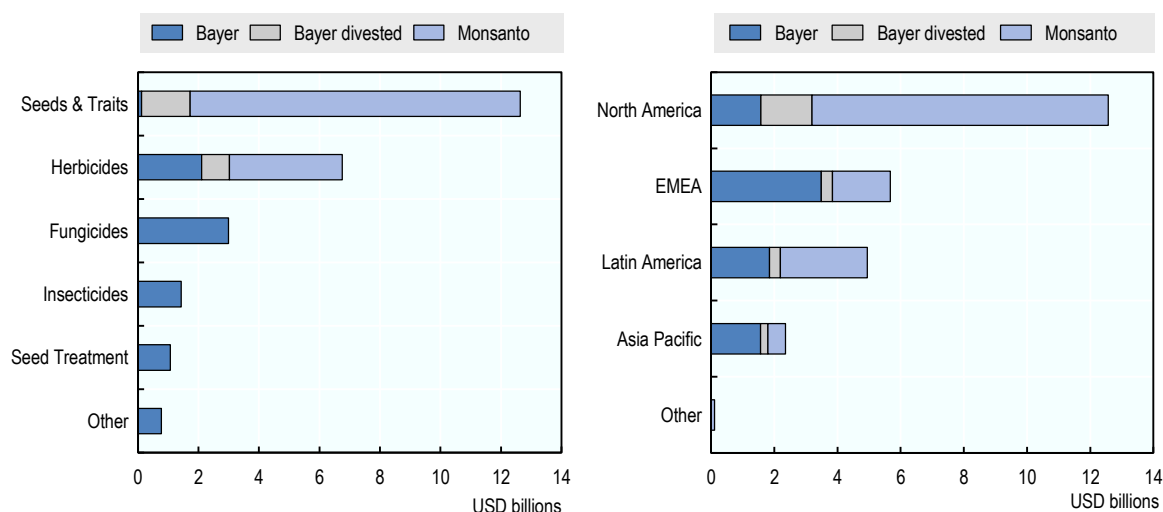
In September 2016, Bayer and Monsanto announced a merger agreement whereby Bayer would pay USD 57 billion to acquire Monsanto. Materials made available to investors describe the merger as bringing together “two different, but highly complementary businesses” and notes that “[t]he combined business will benefit from Monsanto's leadership in Seeds & Traits and Climate Corporation platform along with Bayer's broad Crop Protection product line across a comprehensive range of indications and crops in all key geographies” (Bayer and Monsanto, 2016^[44]). To obtain regulatory approvals, Bayer had to divest most of its seeds and traits activities and important parts of its herbicide business, which altogether accounted for around USD 2.5 billion in sales. After BASF acquired these activities from Bayer, the merger of Bayer and Monsanto was officially completed in June 2018.

The Monsanto acquisition transforms Bayer from a firm mostly focused on pharmaceuticals and consumer health to a firm with a roughly equal share of sales in healthcare and in crop science and seeds. The new Bayer Crop Science, including Monsanto, has combined sales of around USD 23 billion (using pro forma 2017 sales after divestitures). This makes Bayer the largest firm in the industry.

Before the divestitures, Bayer's CropScience division derived most of its revenues from agricultural chemicals (notably herbicides and fungicides), with a smaller contribution of seeds and GM traits (Figure 3.4). Monsanto's profile was complementary, as it derived most of its revenues from the sales of seeds and GM traits and, to a lesser extent, herbicides. Monsanto had little or no revenues from fungicides, insecticides, or seed treatment.

In terms of geographic split, the firms also had different profiles. While the sales of Bayer CropScience were diversified across different regions, Monsanto's sales were heavily concentrated within North America. This region accounted for about two-thirds of Monsanto's revenues, with sales in the United States alone accounting for 56% of the firm's revenues. Latin America was the second most important region, with 13% of global revenues coming from Brazil and 6% from Argentina. However, sales in Europe, the Middle East and Africa (EMEA) and Asia Pacific were considerably smaller than Bayer's.

As a first approximation, Monsanto could be characterised as a company selling GM seeds and herbicides in the Americas, whereas Bayer could be characterised as a company selling mostly agricultural chemicals across a broad range of regions, but with relatively less presence in the United States. At this high level of aggregation, Bayer and Monsanto appear complementary in terms of product offering and regions, although overlap existed in several markets.

Figure 3.4. Pro forma 2017 sales of Bayer-Monsanto after divestitures

Note: Pro forma estimates based on the 2017 sales figures for the companies. The segment and region split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed segment split of the divested businesses: EUR 800 million in herbicides and EUR 1.4 billion in seeds and traits. Assumed split by regions: EUR 1.4 billion in North America; EUR 300 million in South America; EUR 300 million in EMEA; EUR 200 million in Asia Pacific. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts. Financial data converted using an average exchange rate of USD/EUR 1.15. EMEA stands for Europe, Middle East and Africa. North America includes Mexico.

Source: OECD estimates based on company annual reports, Bayer (2016^[45]) and BASF Q2 2018 Analyst Conference Call handout.

The divestiture of several Bayer businesses to BASF (Table 3.1) does not fundamentally change this picture. Bayer sold its non-selective herbicide (Liberty), the LibertyLink herbicide tolerance technology, nearly all of its global soybean and rapeseed/canola seed business, its cotton seed business (except in India and South Africa), its global vegetable seeds business, and several related R&D assets.⁴ An estimate of the corresponding sales divested by Bayer are shown in Figure 3.4. According to these estimates, the divested businesses correspond to nearly the entire seeds and traits business of Bayer and a considerable share of its herbicide business, and around half of Bayer's sales in North America. Despite these significant divestitures, Bayer and Monsanto continue to have complementary profiles, both in terms of regions and in terms of products.

In the future, the firms expect to move beyond simply a combined offering of current products towards developing “integrated solutions” to include seeds and traits, crop protection, and digital farming (Bayer and Monsanto, 2016^[46]). The combined firm would have a pro forma R&D budget of USD 2.8 billion (12% of sales) compared with estimated budgets of USD 1.8 billion for DowDuPont (11% of sales, not taking into account potential R&D reductions underway now) and USD 1.4 billion for ChemChina-Syngenta (8.5% of sales). The combined R&D capabilities would include more than 35 R&D sites and around 175 breeding stations.

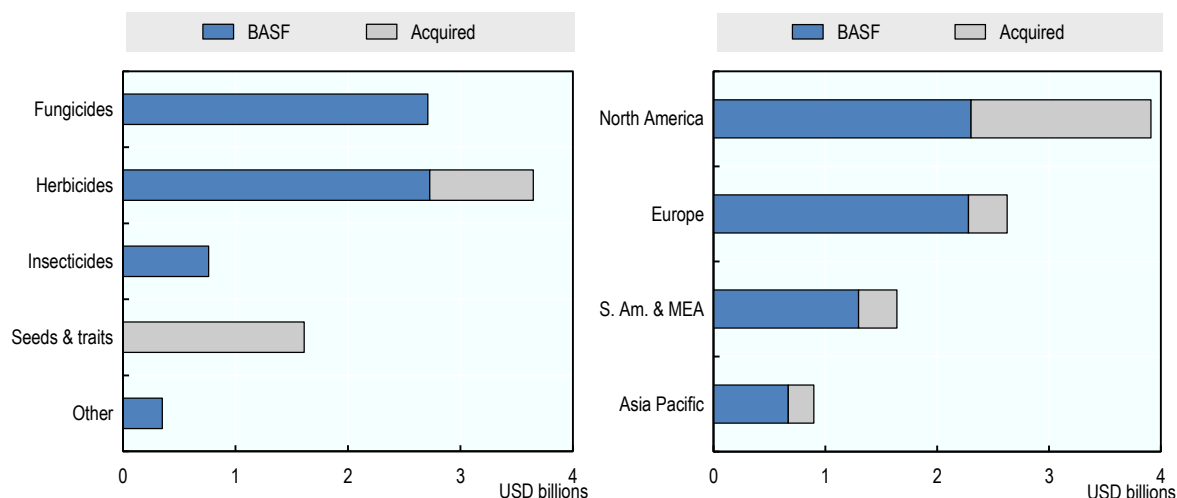
Table 3.1. Bayer assets divested to BASF

Crop protection	Seeds and traits	Digital farming
- Global glufosinate-ammonium herbicide business (Liberty, Basta, Finale) - Selected glyphosate-based herbicides in Europe 3 non-selective herbicides under development - Selected seed treatment products	- Essentially the entire soybean business - Essentially the entire canola/rapeseed business - Cotton business (except India, South Africa) - Global vegetable seeds business - LibertyLink technology - R&D capabilities for divested crops - R&D platform for hybrid wheat	Digital Farming business (Bayer receives a non-exclusive license for certain applications outside North America)

Source: Bayer investor presentation: “Monsanto Acquisition Update,” June 2018.

BASF

BASF was traditionally the sixth member of the Big Six of seed and agrochemical suppliers. In contrast to the other players, which combined seeds and chemicals sales, BASF’s agricultural sales have historically focused almost exclusively on agricultural chemicals (Figure 3.5). Not including the recently acquired Bayer business, the 2017 sales of BASF’s Agricultural Solutions division amounted to USD 6.6 billion, with most of the revenues coming from fungicides and herbicides. Europe and North America were the main markets for its agricultural sales, accounting for more than two-thirds of revenues.

Figure 3.5. BASF pro forma agricultural sales, 2017

Note: Using an average exchange rate of USD/EUR 1.15. “S. Am & MEA” is South America, the Middle East, and Africa. Segment and region split of EUR 2.2 billion of acquired Bayer sales is approximate. Assumed segment split: EUR 800 million in herbicides and EUR 1.4 billion in seeds and traits. Assumed region split: EUR 1.4 billion in North America; EUR 300 million in South America, the Middle East and Africa; EUR 300 million in Europe; EUR 200 million in Asia Pacific. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts.

Source: Company reports and BASF Q2 2018 Analyst Conference Call handout.

BASF did not participate in the earlier rounds of mergers and acquisitions that created integrated seeds-and-pesticides firms, preferring instead to focus on crop protection chemicals. The transfer of several Bayer businesses changes the picture. BASF not only acquires Bayer's non-selective herbicide (Liberty), but also most of Bayer's seeds and traits business. The seeds and traits segment has become a significant part of BASF's agricultural sales, accounting for some 18% of sales (Figure 3.5). While this transaction increases BASF's portfolio, the firm will nevertheless remain a small player compared to Bayer-Monsanto, DowDuPont and ChemChina-Syngenta.

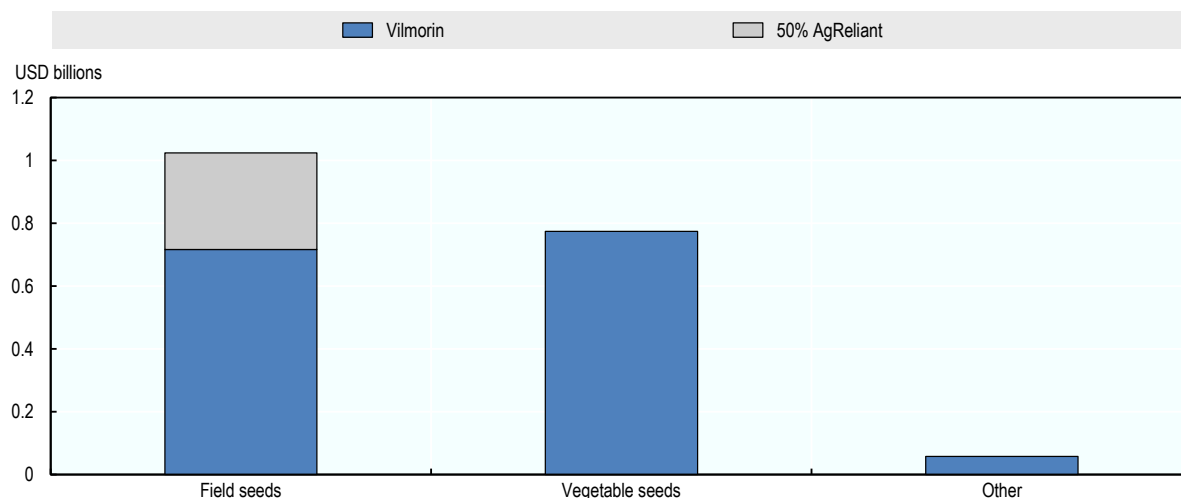
Limagrain/Vilmorin

While less well known than the Big Six, the French cooperative Limagrain is a major international player in seeds due to its ownership of Vilmorin, a leading plant breeding firm initially founded in the 18th century by the botanist to the French King Louis XV (Kingsbury, 2009^[30]). Total sales of Vilmorin were around USD 1.6 billion in 2017-18. In addition, Vilmorin owns 50% of AgReliant, a joint-venture with KWS (discussed in more detail below). Adding its share of AgReliant sales, total sales reach USD 1.9 billion. Field seeds account for 55% of this total, while vegetable seeds contribute 42%. The remainder is accounted for by sales of gardening seeds and other activities (Figure 3.6).

Reflecting its origins in France, 50% of total sales occur in Europe. Vilmorin also has considerable sales in the Americas (34%), notably through AgReliant, but the firm's footprint in Africa, the Middle East, and Asia Pacific is limited (Figure 3.7). The geographic split for field seeds is different from that of vegetable seeds. While field seeds sales are heavily concentrated in Europe and the Americas (accounting for 90% of field seeds sales), the sales of vegetable seeds are more evenly spread out across regions. Europe and the Americas each contribute about one-third of total vegetable seeds sales, with the remainder split between Africa and Middle East, and Asia and Pacific.⁵

Within field seeds, two-thirds of sales are for cereals (maize, wheat and barley) and 15% for sunflower. AgReliant's field seeds sales in North America (half of which are included in Vilmorin's sales figures in this report) are heavily concentrated in maize (78%) and soybeans (21%).

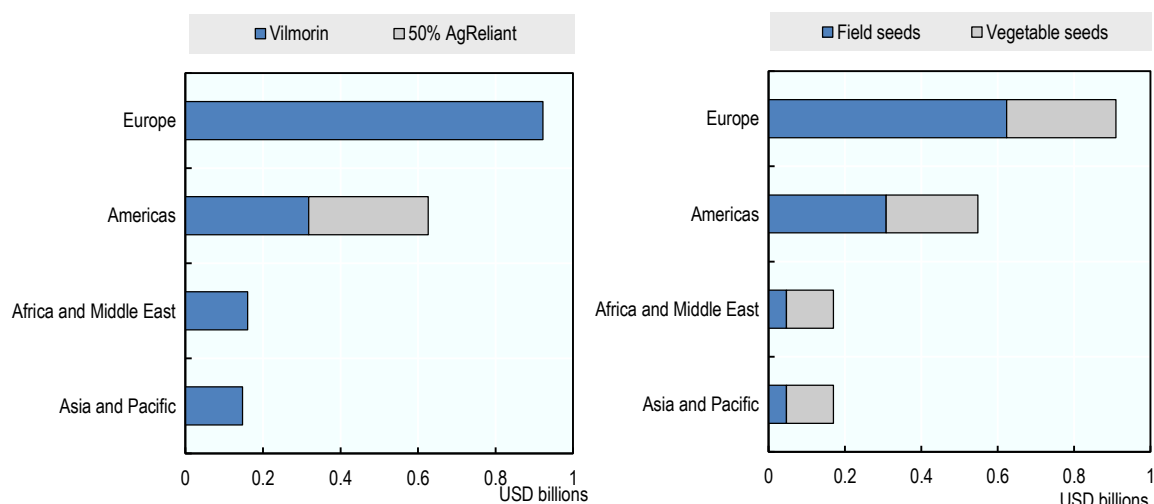
Figure 3.6. Vilmorin sales per segment, 2017-18



Note: Using an average exchange rate of USD/EUR 1.15. AgReliant is a 50/50 joint venture with KWS.

Source: OECD estimates based on company annual report.

Figure 3.7. Vilmorin sales per region, 2017-18



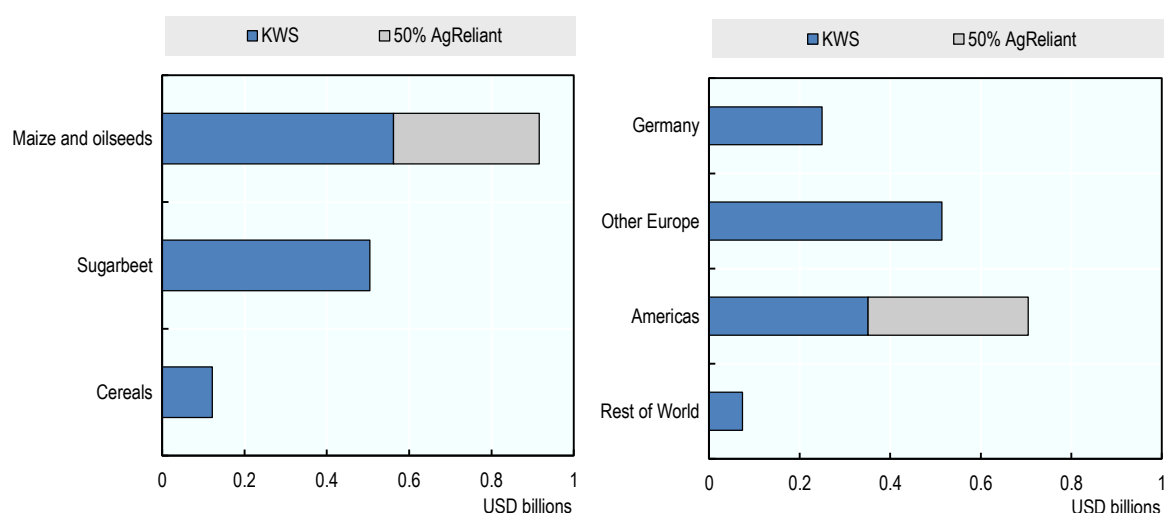
Note: Using an average exchange rate of USD/EUR 1.15. Data refer to 2017-18. Totals may differ due to rounding.

Source: OECD estimates based on company annual report. Data include 50% of sales of AgReliant (a 50/50 joint venture with KWS).

KWS

The German-based seed firm KWS, founded in 1856, focuses on three major segments: maize and oilseeds, sugar beet, and (non-maize) cereals (Figure 3.8). Nearly half of the USD 1.2 billion in KWS sales come from maize and oilseeds, while sugar beet accounts for 42% of sales. In addition, KWS is 50% owner of AgReliant (jointly owned with Vilmorin). Adding a proportionate share of AgReliant sales to KWS sales figures raises total sales to USD 1.6 billion, of which 59% are in maize and oilseeds.

Figure 3.8. KWS sales per segment, 2016-17



Note: Using an average exchange rate of USD/EUR 1.11. Data refer to 2016-17. AgReliant is a 50/50 joint venture with Limagrain/Vilmorin.

Source: OECD estimates based on company annual report.

Germany is a major market for KWS, accounting for 21% of the firm's sales. Other European countries represent 43% of the total, while the Americas account for 30%. After adding the KWS share of AgReliant sales, the importance of the Americas grows to 46%.

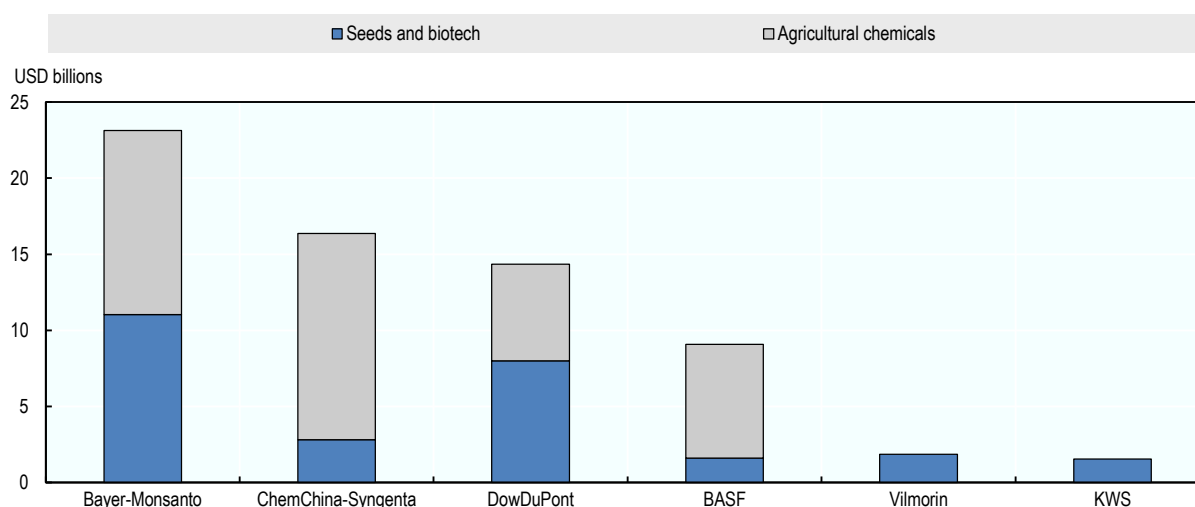
KWS has a remarkably strong position in sugar beet, where it estimates it has a 55% global market share. In the EU-28, KWS estimates its market share to be around 44%, while this share in North America is estimated to be well over 80% (KWS, 2017^[35]).

In 2018, KWS attempted to purchase Bayer's vegetable seeds business, which was being sold as part of Bayer's preparation for its merger with Monsanto. This acquisition would have diversified KWS's activities away from field crops and would have led to a significant increase in size for KWS (Burger and Weiss, 2018^[47]). Its bid, however, was not successful.

Leading firms after the mergers

Figure 3.9 shows the new Big Six in the seeds industry after the mergers, using pro forma estimates of 2017 sales after taking into account the estimated impact of mergers and divestitures. Bayer-Monsanto is the largest player, with roughly equal shares of sales coming from seeds and biotech versus agricultural chemicals. ChemChina-Syngenta is second, at about a third smaller than Bayer-Monsanto, but mostly focused on agricultural chemicals. DowDuPont is the third major player, with a roughly equal split between seeds and biotech. Following the acquisition of Bayer assets, BASF has become the fourth player in the sector, although its total sales are less than half of those of Bayer-Monsanto. Finally, both Limagrain/Vilmorin and KWS, while important players, are small in comparison with the market leaders. Each firm has less than one-tenth the sales of Bayer-Monsanto.⁶

Figure 3.9. Pro forma 2017 sales of leading firms after mergers and divestitures



Note: Pro forma estimates based on the 2017 sales figures for the companies (or most recent data available). Bayer-Monsanto includes estimated effect of divestitures (about USD 2.5 billion). ChemChina-Syngenta includes an estimated USD 4.3 billion in agro-chemical sales of ChemChina. DowDuPont based on pro forma 2017 data reported by DowDuPont (accounting for divestitures). BASF includes estimated effect of acquired Bayer business. Data for Vilmorin and KWS include sales of AgReliant.

Source: OECD estimates based on company annual reports; Colvin (2017^[40]) for ChemChina.

3.3. Drivers of structural change and consolidation

Schenkelaars et al. (2011^[29]) describe the evolution of the global seed industry in three waves.

- A first wave occurred in the 1930s, when hybrid seed was introduced. New commercial seed firms emerged (including Pioneer Hi-Bred, now part of DowDuPont), which adapted and improved varieties developed through public research.
- A second wave occurred in the 1970s, around the same time as the intellectual property regime for plant breeding was strengthened via plant breeders rights (PBRs) and patents. Several pharmaceutical, petrochemical and agrochemical companies in the United States and Europe started a process of mergers and acquisitions. However, many seed firms remained independent and maintained their market position. Over time, several multinationals divested their seed assets.⁷
- A third wave of structural change started in the 1980s and was driven by biotechnology. A small number of large agrochemical multinationals invested heavily in these new technologies, both through in-house R&D and by acquiring smaller players. This third wave was characterised by strategic mergers and acquisitions to obtain access to varieties, traits, and tools, leading to the current constellation of integrated firms.

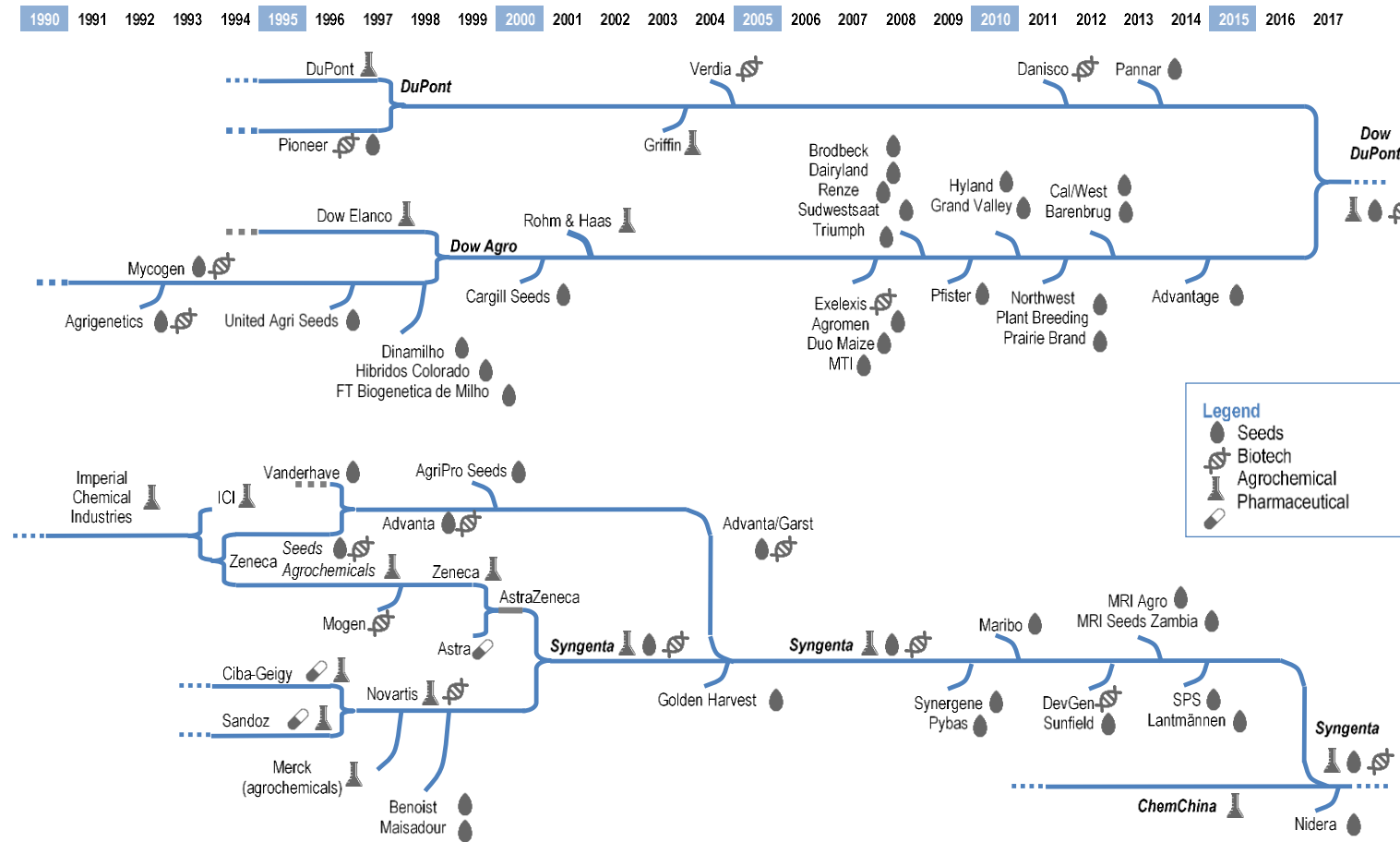
Figure 3.10 presents the “family tree” of the main players in the seed industry today, including recent mergers. An open question is whether the industry is witnessing a fourth wave of consolidation caused by data-driven precision agriculture.

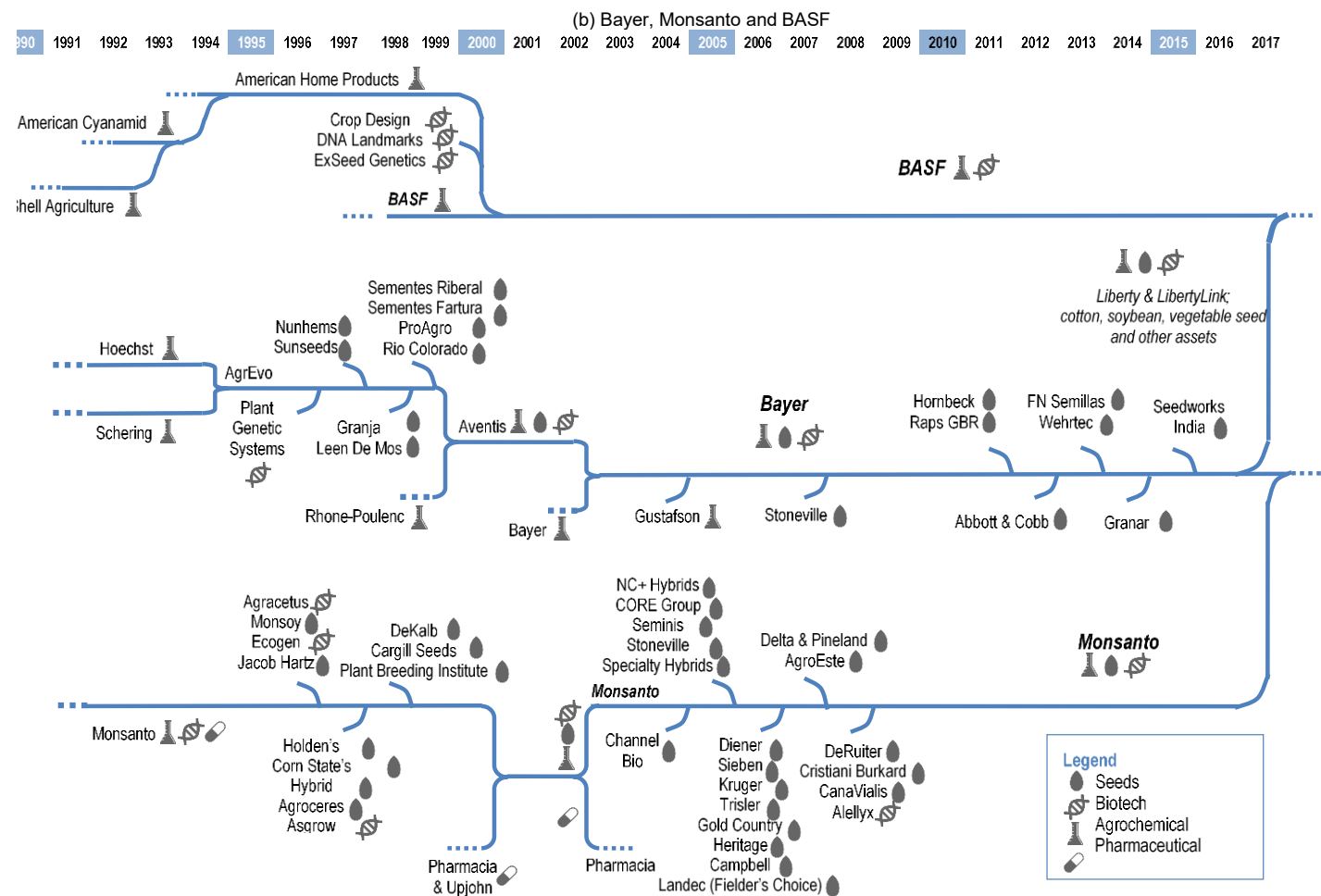
Fulton and Giannakas (2001^[48]) argue that structural changes in the seed and biotech industry are best understood as a mix of horizontal and non-horizontal combinations, which each have their own set of drivers. A *horizontal* merger combines firms active in the same or similar markets, and aims to achieve economies of scale (when costs can be spread over a larger production volume of the same product) and economies of scope (when costs can be spread over different types of products). In the seed and biotech industry these economies of scale and scope exist according to Fulton and Giannakas (2001^[48]) because of the presence of large sunk costs related to R&D and regulatory costs of GM. In contrast, *non-horizontal* mergers combine firms active in different markets – for example, between a supplier and a customer (a *vertical* merger) or between firms producing complementary products. In the seed and biotech industry, non-horizontal mergers and acquisitions are driven by various complementarities.

The family tree of modern seed firms shows both horizontal and non-horizontal combinations. Although each of the major players has followed a distinct trajectory, paths typically show a clear link between plant breeding, biotech, chemicals, and pharmaceuticals. Syngenta, for instance, can be traced back to a chemical company (Imperial Chemical Industries), a pharmaceutical company (Novartis), and a seed company (Vanderhave). At the same time, Syngenta’s 2004 acquisition of Adventa/Garst can be seen as a horizontal move to expand the scale and scope of its seed business.

Figure 3.10. Mergers and acquisitions in the global seed industry, 1990-2017

(a) DowDuPont and ChemChina-Syngenta



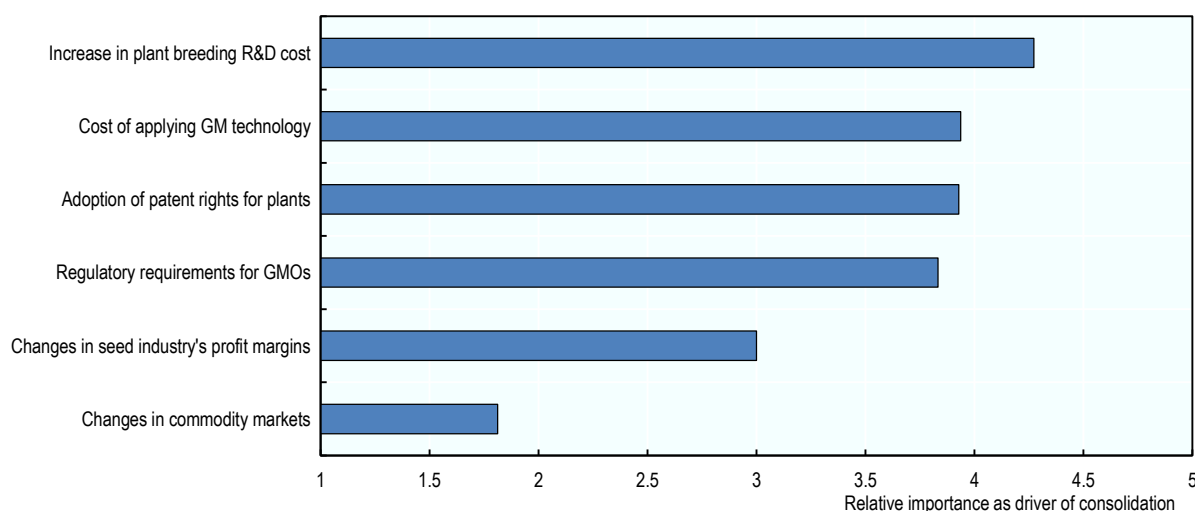


Note: Only major acquisitions in seeds, agrochemicals and biotech are shown.
Source: OECD based on Fernandez-Cornejo (2004^[11]), Heisey and Fuglie (2011^[77]), Howard (2009^[49]), Crunchbase (2017^[50]), Wesseler et al. (2015^[26]), company websites.

These drivers of consolidation are also cited by industry participants. Schenkelaars et al. (2011^[29]) asked executives of nine seed firms to rank the different causes of recent industry consolidation. Their seed firms included Monsanto, DuPont-Pioneer, Syngenta, KWS, and Limagrain, as well as smaller firms such as Rijk Zwaan (which specialises in vegetable seed). Most respondents agreed that an increase in plant breeding R&D costs was a key driver (Figure 3.11). This was true even for vegetable seed firms where GM was not relevant at the time of the survey. In addition to continuing efforts in GM, other seed firms were investing in advanced non-GM technologies. Other causes which were ranked as relevant include the high costs of applying GM technology, the extension of the patent system to cover plants (see Box 3.1), and regulatory requirements for GM technology. One firm mentioned the cost of access to genetics (finished lines) and germplasm for breeding uses, as well as legal costs as drivers of industry consolidation.

In terms of the distinction made by Fulton and Giannakas (2001^[48]), the increasing costs for plant breeding and GM technology, and costs related to regulatory requirements for GMOs are drivers of horizontal mergers and acquisitions. Patent rights, access to genetics and germplasm, and the associated legal costs of navigating intellectual property claims can be seen as drivers of non-horizontal mergers and acquisitions (although they may play a role in horizontal mergers and acquisitions).

Figure 3.11. Causes of industry consolidation



Note: Based on interviews with executives of seed firms (DuPont-Pioneer, Bayer-Nunhems, Illinois Foundation Seed, KWS, Limagrain, Monsanto, Rasi Seeds, Syngenta, Rijk Zwaan). Possible causes ranked from 1 (low) to 5 (high). One firm added *Costs of access to genetics (finished lines) and germplasm for breeding uses* and *Legal costs* as drivers, both with a score of 4 (not included in the above chart).

Source: Schenkelaars et al. (2011^[29])

Sunk fixed costs as driver of horizontal mergers and acquisitions

The existence of sunk fixed costs implies that firms can lower their average costs by increasing the scale or the scope of their operations.⁸ Two types of sunk fixed costs often cited in the context of the seed industry are regulatory costs and R&D costs.

Regulatory costs for GM technology

Regulatory costs associated with the approval of a genetically modified organism are high both in the United States and the European Union. A detailed analysis of the duration of the regulatory process by Smart et al. (2017^[51]) shows the process takes an average of almost 2 500 days in the United States and 1 800 days in the European Union. These different durations are not directly comparable, but they do show that the approval process is long.⁹

The financial costs of compliance have been estimated at between USD 6 and USD 15 million for genetically modified maize traits (Kalaitzandonakes, Alston and Bradford, 2007^[36]). Industry-commissioned studies have put the regulatory cost as high as USD 35 million, or 26% of the total cost of introducing a new GM crop (Phillips McDougall, 2011^[52]). Some industry executives interviewed by Schenkelaars et al. (2011^[29]) placed regulatory costs at USD 100 million, while others mentioned USD 15 to USD 30 million. Some caution is required in interpreting these numbers as it can be difficult to allocate the costs of various activities and processes to “regulatory” as opposed to “non-regulatory” factors. Moreover, costs for a single-country approval will differ from those needed for global regulatory approval. Despite difficulties in measuring regulatory costs precisely, there is little doubt that compliance requires considerable investment, which adds to the sunk fixed costs of developing and introducing a GM trait. It has been argued that high regulatory costs discourage investment in genetic modification for crops with small markets; this phenomenon has been documented for specialty crops (Miller and Bradford, 2010^[53]).¹⁰

Regulatory costs could contribute to horizontal mergers and acquisitions through several channels. First, larger firms may be more efficient in dealing with regulatory procedures, for instance because larger firms can employ full-time specialists. Second, a larger firm can expect greater sales for a given product introduction, all else equal, which means a given regulatory cost burden can be spread over a greater sales volume. Third, mergers could allow firms to reduce the rate of innovation, thereby avoiding the sunk costs of product innovations, including regulatory costs.

It is doubtful, however, whether regulatory costs by themselves can explain ongoing consolidation, and in particular whether they can explain the current mergers. Even without regulatory costs, firms would face high R&D costs to develop and introduce GM traits. Moreover, over time the total market for genetically modified seeds has grown strongly, as documented above. In theory, this growth in market size should enable *more* firms to recover the regulatory costs associated with GM technology, all else equal. Regulatory costs may act as a barrier to entry and may reduce innovation in products with small markets, but it is not clear whether they are an important driver of current consolidation. Put differently, regulatory costs may contribute to a higher level of market concentration than would otherwise be the case, but they do not necessarily explain increases in the level of market concentration in recent years.

Increasing R&D costs

By definition, a fixed cost is a cost incurred by firms independent of how much they produce. This does not mean that all fixed costs are outside of the firm’s control. Some fixed costs (e.g. equipment and infrastructure) may be related to the minimum efficient scale of operations, leaving the firm with little choice on how much to spend on these items. But other fixed costs depend on strategic decisions of firms, as is the case for advertising budgets or R&D efforts. Such *endogenous fixed costs* have different implications for market structure compared with exogenous fixed costs (Sutton, 2007^[54]).

If a fixed cost is exogenously given to the firm, then an increase in market size makes it possible for new firms to enter the market. Hence, a growing market would then be associated with an increase in the number of firms or, equivalently, a decrease in market concentration.

In a setting with endogenous fixed costs, firms use their investments in advertising or R&D as strategic tools to increase consumers' willingness to pay, improve the quality and range of their product offering, and/or reduce their costs. When the size of the market increases, so does the potential payoff to the firm of capturing a greater market share through higher advertising spending or by offering an improved product. A greater market size is then associated with increased spending on endogenous fixed costs by existing firms. This creates a barrier to entry for new firms, and consequently the number of firms in the industry does not increase when the market grows. In fact, as the market grows and firms escalate their spending on endogenous fixed costs, market concentration may increase.

Anderson and Sheldon (2017^[55]), analysing the US market for GM maize seed, find empirical evidence that these markets are indeed characterised by endogenous fixed investments in R&D. They conclude that the concentration of R&D activity and of sales are probably driven by endogenous investments to introduce better GM traits. In this case, a certain level of concentration is to be expected as a by-product of the same dynamic that ensures high R&D spending on improved GM traits. The increasing market concentration could come about as some firms are driven out of the market and/or as some firms acquire or merge with competitors to reduce the burden of R&D spending. Hence, the observed increase in market concentration in the seed market could indeed be consistent with endogenous R&D spending – an explanation which matches the views of industry participants as reported in Figure 3.11.

Complementarities as a driver of non-horizontal mergers and acquisitions

The seed industry has seen considerable non-horizontal activity, where seed, biotech, and chemical firms combine in various ways. The global seed industry is characterised by several complementarities which help to explain these non-horizontal mergers and acquisitions in the past decades (Heisey and Fuglie, 2011^[7]). These complementarities are also important in evaluating the potential effects of mergers, and can be grouped into two general sets.

Tools, traits and germplasm

A first set of complementarities arises from the process of creating genetically modified seeds. The development of modern biotechnology created a new market for genes conferring valuable traits, and for platform technologies or research tools to create such traits. However, valuable traits need to be inserted in high-quality varieties to be useful to farmers. As a result, there is a strong complementarity between *tools, traits, and varieties (germplasm)* (Heisey and Fuglie, 2011^[7]).

Graff, Rausser and Small (2003^[56]) demonstrated empirically that mergers and acquisitions in the seed and biotech industry in the 1990s reflect complementarities between intellectual property assets in tools, traits and germplasm. Using patent data, they show that firms seek diversified portfolios (combinations of tools, traits and germplasm) through both in-house R&D as well as through mergers and acquisitions to achieve coordination between complementary intellectual assets.

Seeds and chemicals

A second set of complementarities is between *seeds and chemicals*. There are several explanations for this link. First, there is the possibility of creating complementary products,

such as herbicide-tolerant seeds and herbicides. Secondly, there are potential economies of scope in marketing. A third reason is that chemical companies invested in seed as a defensive move when it became clear that genetically modified seeds could compete with crop protection chemicals (Heisey and Fuglie, 2011^[7]).

The current consolidation wave demonstrates these complementarities. Monsanto, which has a relatively stronger position in seeds and biotech, is combining with Bayer, which has a stronger position in agricultural chemicals. Likewise, DuPont's strong position in seeds and biotech is now combined with Dow Chemical's relatively stronger position in agricultural chemicals. ChemChina was only active in agricultural chemicals but has acquired Syngenta which has a strong position in seeds and biotech. Finally, the seeds and biotech business divested by Bayer were acquired by BASF, which was previously active in agricultural chemicals only.

A further example is found in the historical evolution of Monsanto. Founded in 1901 as a chemical company, Monsanto focused on chemicals and pharmaceuticals for most of its history. In the early 1980s, it started to invest in genetic modification. The need to combine traits with germplasm and a distribution network led to an ambitious acquisition strategy in the 1990s to build Monsanto into a seed company. In the span of only two years (1996-1998), Monsanto acquired a range of seed companies that included the international seed businesses of DeKalb and Cargill, building a strong position in seed markets while continuing to invest in the acquisition of other biotechnology firms (Figure 3.10). In 1996, genetic modification by Monsanto led to the introduction of Roundup Ready soybeans, resistant to Monsanto's glyphosate-based herbicide Roundup, first introduced in 1974.

The role of potential complementarities (and substitution effects) between biotechnology and agricultural chemicals was first highlighted by Just and Hueth (1993^[57]). Certain developments in biotechnology are complementary with sales of agricultural chemicals, as in the case of herbicide-tolerant seeds and herbicides. In contrast, other developments in biotechnology are substitutes for agricultural chemicals, as in the case of insect-resistant seeds which are a substitute for insecticides.

Firms selling agricultural chemicals will tend to invest in biotechnology complementary to their existing products. As the integrated firm internalises the spillover effects of the complementary products, it can generate greater chemical sales by selling more biotechnology and vice versa. For such products, mergers between chemical and biotech firms would increase investment in R&D and total output, which would have a positive effect on social welfare.

If, however, a firm sells chemicals and biotechnology which are substitutes (e.g. traditional insecticides and insect-resistant seed), it may try to keep the supply of biotechnology low to avoid "cannibalising" its sales of chemicals. In such a scenario, the potential welfare effects of a merger between a chemicals firm and a biotech firm are less clear; the merger could be an attempt to reduce competitive pressure. The relative importance of these complementarity and substitution effects is therefore essential in order to evaluate the welfare effect of a merger.

Other possible complementarities

In the 1990s, industry observers speculated there might be complementarities between biotechnology and pharmaceuticals, which could give rise to integrated life science companies. However, this trend did not materialize. Instead, firms such as Dow, BASF and DuPont divested their pharmaceutical activities (Heisey and Fuglie, 2011^[7]). Again,

Monsanto is a representative example. The firm, which previously had some pharmaceutical activity, merged in 1999 with Pharmacia & Upjohn to create the chemical-pharmaceutical giant Pharmacia. By 2002, however, the agricultural business was spun off as the “new” Monsanto, severing the link with the pharmaceutical side of the business (Figure 3.10).¹¹

A potential new type of complementarity may be emerging in the form of “digital farming”, a technological trend to use big data techniques to allow precision farming (Kempenaar et al., 2016^[58]). The promise of digital farming is that it could combine detailed data from thousands or millions of individual farmers, together with detailed weather data to uncover through algorithms which seeds, agrochemicals or other agronomic practices are optimal in which setting. This could also deliver precise advice to farmers, tailored to the specific characteristics of their plots and crops.¹²

While many smaller firms appear to be active in this field, there is a clear trend for large players in agricultural input industries to enter the market (Philpott, 2016^[59]). For instance, Syngenta offers digital farming solutions through its AgriEdge Excelsior product. DuPont expanded its own precision farming offering in 2014 through an agreement with the weather and market data provider DTN, while in 2016 Dow AgroSciences launched a “precision agronomy program” based on big data.

Monsanto in particular has invested heavily in precision agriculture, first through the acquisition of Precision Planting in 2012 and then through the USD 930 million acquisition of The Climate Corporation, a Silicon Valley firm specializing in weather prediction. It also entered into an agreement with the leading agricultural equipment manufacturer John Deere in 2015 whereby John Deere would acquire the equipment business of Precision Planting from Monsanto, while providing Monsanto with real-time data from certain John Deere farm equipment. However, this agreement was challenged by the US Department of Justice and subsequently terminated in May 2017.

Monsanto’s leading position in digital farming is cited by Bayer as an important reason for its bid. To some industry observers, the Bayer-Monsanto merger indicates that digital farming may be a transformative technology similar in its impact to GM technology two decades ago (Gullickson, 2016^[60]).

Complementarities between digital farming and the seed and agro-chemical industry can arise from several mechanisms. First, digital farming solutions are sold to the same group of customers as seed and agro-chemicals, creating possibilities for joint marketing. Second, data from thousands of farmers can provide an unprecedented dataset of the performance of crops as a function of soils, weather conditions, farming practices, and types of seeds and agro-chemicals used. This could allow for more tailored marketing efforts (e.g. by selecting the best varieties for a given farm plot) and more efficient product development efforts (e.g. by developing varieties for a specific farm or soil type). It can also provide timely and detailed advice to farmers on agronomic practices to improve their yields, using proprietary insights of the seed firm. Third, by incorporating digital farming into their portfolios, seed and agro-chemical firms can influence farmer choices by suggesting their own products to the detriment of competitors’ products or alternative methods (Philpott, 2016^[59]).¹³

Other developments within digital farming may evolve into substitutes for seed and agro-chemical inputs, for instance if precision farming can become sufficiently precise to reduce the benefits of broad-spectrum herbicides (such as glyphosate). As an illustration, Blue River Technology (acquired by John Deere in 2017 for more than USD 300 million) uses artificial intelligence and machine learning to allow the precise identification of individual weeds in a field. Combined with specialised machinery, this allows the precise application of herbicide

to weeds only. These and similar technologies, if sufficiently advanced, could reduce the demand for herbicide tolerance traits.

At present, digital farming is still in its early stages and it is difficult to assess the potential complementarities and substitution effects at this point. However, interactions between digital farming and other agricultural input industries are likely to increase in importance in the future.

Intellectual Property Rights and access to genetic material

Complementarities have historically played an important role in stimulating non-horizontal mergers and acquisitions in the seed industry. At the same time, direct ownership by one firm is just one possible way of achieving these complementarities. Another possibility is by licensing the necessary intellectual property from other firms. For instance, a seed firm might license GM technology from a biotech firm, allowing it to include the biotech firm's GM trait in its seed. Conversely, a biotech firm could license the use of proprietary germplasm from a seed firm. Similarly, exploiting the complementarity between herbicide and herbicide tolerance could occur through an ad-hoc collaboration between a chemicals company and a biotech firm. Mergers are not always necessary to exploit complementarity effects.

Major firms indeed cross-license genes, giving rise to GM seeds with genes from different seed firms. In 2007, for instance, Monsanto and Dow announced a collaboration to introduce SmartStax, an eight-gene stacked combination in maize. SmartStax combines several insect resistance and herbicide tolerance traits of both Monsanto and Dow. In terms of herbicide tolerance, SmartStax is compatible with both Monsanto's RoundUp (glyphosate) herbicide as well as Bayer's Liberty (glufosinate) herbicide. In addition to cross-licensing traits, the agreement between Monsanto and Dow also enables cross-licensing of germplasm of maize seed to achieve higher-yielding new hybrid combinations. By themselves, therefore, technological complementarities do not fully explain mergers and acquisitions, as firms seem capable of exploiting these complementarities through other organisational setups.

Other factors could explain why mergers and acquisitions have been one of the dominant ways by which companies exploited technological complementarities. First, given the large number of small seed firms and biotech firms initially active in the market, a strategy of licensing could have led to high transaction costs, especially since scientifically complex technical know-how is difficult to transfer between firms (Kalaitzandonakes and Bjornson, 1997^[61]). Second, firms may also have used acquisitions as a way to ensure exclusive access to germplasm or traits, and to obstruct rivals' access to these resources – or conversely, acquisitions may have been the only way to obtain access to rivals' technological resources.

These potential explanations are intertwined within the complex role of Intellectual Property (IP) rights in the seeds and biotech industry. In parallel with the development of the seeds and biotech industry, IP rights on seeds and biotechnology have been strengthened over time (Box 3.1). The impact of stronger IP rights on mergers and acquisitions is unclear, however.

On the one hand, stricter IP protection may make it more difficult for firms to access each other's technological resources, thereby making mergers and acquisitions more attractive. For instance, the breeder's exemption in Plant Breeders' Rights under the UPOV Convention allows firms to use each other's germplasm for research and breeding purposes. In contrast, patents do not provide the same degree of freedom.¹⁴ From this point of view, it cannot be argued that stronger IP protection makes it more difficult for firms to access each other's genetic material, thus stimulating mergers and acquisitions as the best way to access protected IP. A similar argument holds for IP protection of other technologies, including GM traits and

tools. Strong IP protection could lead to mutually blocking patent portfolios and potentially high transaction costs for cross-licensing technologies.

On the other hand, with stronger IP protection a firm may be more willing to license its IP as it faces a lower risk of IP theft or copycat behaviour by competitors. When intellectual property is not sufficiently protected, mergers and acquisitions may be the only way to safely combine intellectual assets as this removes the risk of theft of intellectual property or high litigation costs. Better protection of IP could therefore reduce the incentive for mergers and acquisitions as it allows firms to cross-license instead.

Box 3.1. Intellectual property rights in seed and biotechnology

Plant breeding to develop a new variety is a costly and time-consuming process. Once a variety is introduced on the market, however, there is a risk that competitors and/or farmers will reproduce these seeds without having to incur the considerable R&D costs of the original breeder. Without a system of intellectual property rights, self-pollinating varieties such as wheat can easily be reproduced by competing seed firms (Fernandez-Cornejo, 2004^[11]). Innovators would not be able to capture the full rewards for their efforts. This spillover problem may in turn reduce the incentives for private investments in R&D to create improved varieties. Two main policy solutions are investment in public R&D and/or the provision of intellectual property rights on new plant varieties to provide financial incentives for private R&D.

Intellectual property rights protection for new plant varieties has only emerged gradually. In most countries, intellectual property law initially did not allow for the protection of plant varieties. In the United States, for instance, the Patent Act of 1790 classified biological innovations such as new plant varieties as “products of nature,” which were excluded from protection (Fernandez-Cornejo, 2004^[11]). Innovations by plant breeders could be freely reproduced by competitors and/or reproduced by farmers, reducing the incentive to invest in R&D.

Not all innovations in plant breeding suffered from this incentive problem to the same extent, however. Hybrid seeds in particular provide a biological protection against reproduction by both competitors and farmers. It is difficult to reproduce hybrid seeds, as this requires the parent lines from which hybrid seed is created. At the same time, offspring of hybrid seed is typically much less productive than the hybrid seed itself. As a result, farmers have less incentive to save seeds. The introduction of hybrid maize in the United States in the 1930s greatly increased the potential revenues to plant breeders of developing new maize varieties, even in the absence of intellectual property rights protection.

Over time, intellectual property rights were extended to cover plant varieties. The system of intellectual property rights for new plant varieties is mostly *sui generis*, that is, a system distinct from the patent system governing most other innovative industries. An international system was established by the International Union for the Protection of New Varieties of Plants (UPOV) through successive versions of its International Convention for the Protection of New Varieties. Countries which have implemented the UPOV Convention into national law protect new varieties using Plant Breeders’ Rights (PBR), also referred to as Plant Variety Protection (PVP) or Plant Variety Rights (PVR).¹

A key characteristic of PBR is the “breeder’s exemption” which allows breeders to develop and commercialise new varieties from existing varieties without permission of the owner of the initial variety (with certain exceptions). The rationale behind this exemption is that “breeding is, by definition, the creation of improved varieties by recombining the characteristics of existing varieties” (ISF, 2012^[62]). The goal of this exemption is to strike a balance between providing incentives for innovation and providing access to materials from which future plant varieties can be created.

In addition to PBR, plant-related inventions may be eligible for patent protection in some countries. In the United States, the Supreme Court ruled in *Diamond v. Chakrabarty* (1980) that genetically modified microorganisms can be patented. Since 1985, patents can also be used to protect new varieties in the United States, and plant breeders can use both a patent and a plant breeders’ right to protect the same variety (Pardey et al., 2013^[63]). These patents do not have breeder’s exemptions. Not all jurisdictions are equally restrictive regarding patents on biological materials, however. In Switzerland, using patented biological material “for the purposes of the production or the discovery and development of a plant variety” does not constitute patent infringement.² In the European Union, the “biotech directive” (Directive 98/44/EC) stipulates that a breeder in this situation could apply for a compulsory licence.³

The International Seed Federation, which represents plant breeders, is of the opinion that both PBR and patents are useful, but that PBR is the preferred form given the breeder’s exemption (ISF, 2012^[62]). However, in the United States, seed companies often favour patents (Lence et al., 2016^[64]).

While patents without breeder’s exemption may in theory slow the pace of innovation by making access to genetic material more difficult, they may provide stronger incentives for innovation. These two factors may need to be traded off against each other to decide on the optimal protection of intellectual property rights in plant breeding. Recent theoretical work suggests that patents may be more effective at stimulating innovation when research is expensive and long-lasting, while PBR may be more effective when improvements are expected to have a short life and research technology is easily transferable. Moreover, the same analysis indicates that a system of patents with effective and

easy licensing might offer the best of both worlds in terms of offering incentives while maintaining access (Lence et al., 2016^[64]).

An important policy issue regarding intellectual property rights for seed is the practice of farm-saved seed. Allowing farmers to save seed potentially reduces plant breeders' revenues from developing a new variety, which would in turn reduce their incentives for innovation. The first UPOV Convention (1961) and the 1978 Act allowed governments to permit seed saving by farmers of varieties covered under PBR as long as it was not done for the production of seed for marketing.

These policy options were eventually clarified in the 1991 Act, which provides two exemptions. A first exemption allows for private and non-commercial uses by the farmer (e.g. subsistence farming). A second exemption allows countries adhering to the UPOV Convention to permit seed saving by farmers "within reasonable limits and subject to the safeguarding of the legitimate interests of the breeder" (ISF, 2012^[62]). In the United Kingdom, for instance, farm-saved seed is allowed but an industry-wide system exists for the collection of royalty payments on farm-saved seed. Royalty levels for farm-saved seed are lower than royalty rates on certified ("new") seed. The system applies only to newer varieties (BSPB, 2014^[65]).

1. In addition to plant breeders' rights and patents, the United States also has a system of so-called plant patents, which cover only asexually reproduced plants (excluding potatoes and other tubers). Given their narrow scope, plant patents are not covered in this report; the term "patents" therefore always refers to the "regular" patent system (also known as utility patents in the United States).
2. Similar rules exist in France, Germany, and the Netherlands. Moreover, these rules are part of the Unified Patent Court agreement which will govern most European patents in the near future. At the time of writing, the agreement has been signed by all EU Member States except Spain and Poland. The OECD wishes to thank Marien Valstar for this information.
3. For a global overview, see WIPO (2014^[66]) and <http://www.wipo.int/scp/en/exceptions>.

Some critics allege that cross-licensing creates "non-transparent oligopolies" (Mammana, 2014^[66]) or that these collaborations create "non-merger mergers" and raise questions about cartel behaviour (ETC Group (2008^[67]), Howard (2009^[49])). While it is possible that close collaboration facilitates explicit or implicit coordination, by itself cross-licensing is a pro-competitive practice as it allows competitors to access proprietary technology. In fact, a *refusal* to cross-license by a firm with a large portfolio of traits or germplasm would be more harmful for competition as this would force competitors to invest considerable amounts of money to develop their own traits or germplasm. To the extent that licensing and cross-licensing are possible with modest transaction costs and undertaken in a non-discriminatory way, the practice effectively reduces barriers to entry by eliminating the need to duplicate costly R&D programs. All else being equal, it reduces the incentive for firms to consolidate in order to obtain access to traits and germplasm, thus allowing more independent firms to remain active in the market.

Cross-licensing agreements, such as the SmartStax example mentioned above, are now common. In 2009, about 60% of the stacks on the US market involved traits from multiple firms (Moss, 2013^[68]). The current IP regime in the United States therefore allows firms to collaborate through cross-licensing of intellectual property, rather than forcing them to engage in mergers or acquisitions to exploit these technological possibilities. At the same time, there are numerous examples of litigation between firms around supposed violations of intellectual property rights and licensing agreements. For instance, Oehmke and Naseem (2016^[69]) argue that Dow's 1998 acquisition of Mycogen may have been facilitated by the fact that Mycogen was embroiled in many costly legal battles over intellectual property rights, while Marco and Rausser (2008^[70]) note that Monsanto's acquisitions of both Calgene and DeKalb occurred in the midst of patent infringement suits. In recent years, leading vegetable seed firms have cooperated to create the *International Licensing Platform – Vegetables* to provide a clearinghouse for intellectual property rights with minimal transaction costs (Chapter 7).

Both theoretically and empirically, then, the impact of stronger IP protection on mergers and acquisitions in the seed and biotech industry is mixed. Similar conclusions were reached by Hall and Ziedonis (2001^[71]), who studied the effects of stronger IP protection in the US semiconductor industry between 1979 and 1995. On the one hand, stronger patent rights appear to have facilitated the entry of specialised design firms focused on securing proprietary rights to technologies in niche product markets. This trend may also have contributed to non-horizontal *disintegration* in the industry. On the other hand, large firms engaged in a patent portfolio race, amassing vast patent portfolios to be used in litigation and negotiation with competitors. It seems plausible that firms with mutually blocking patent portfolios consider mergers and acquisitions as a way to overcome legal costs (Marco and Rausser, 2008^[70]).

3.4. The evolution of markets over time: The case of US cotton

The historical evolution of the US upland cotton seed industry provides a good illustration of the structural changes discussed here. Between 1970 and 2017, the area planted with upland cotton in the United States varied between 4 and 6 million hectares. This market was one of the first to use genetically modified varieties. In contrast with most seed markets, public data is available on the market shares of different varieties (expressed as a share of acreage). These data stretch back several decades and allow for an assessment of long-term structural changes in the market. Moreover, Monsanto's acquisition of a leading cotton seed firm (Delta & Pine Land) in 2007 provides an interesting case study on the impact competition authorities can have on the future evolution of seed and GM markets.

Structural changes in the US cotton seed industry

Figure 3.12 shows the estimated market shares of the main players in the US upland cotton seed industry between 1970 and 2017. In the 1970s, a high share of US upland cotton was provided by public plant breeders. Between 1970 and 1975, 16% on average of cotton planted were varieties from public institutes (with varieties from the University of New Mexico the most popular). Although at the time the market was quite concentrated, with four breeders controlling 74% of the market, this concentration has declined over time as Delta & Pine Land lost market shares; the four-firm concentration ratio reached a low of 52% in 1983. Starting in the 1980s, however, the US cotton seed sector witnessed several important structural changes.

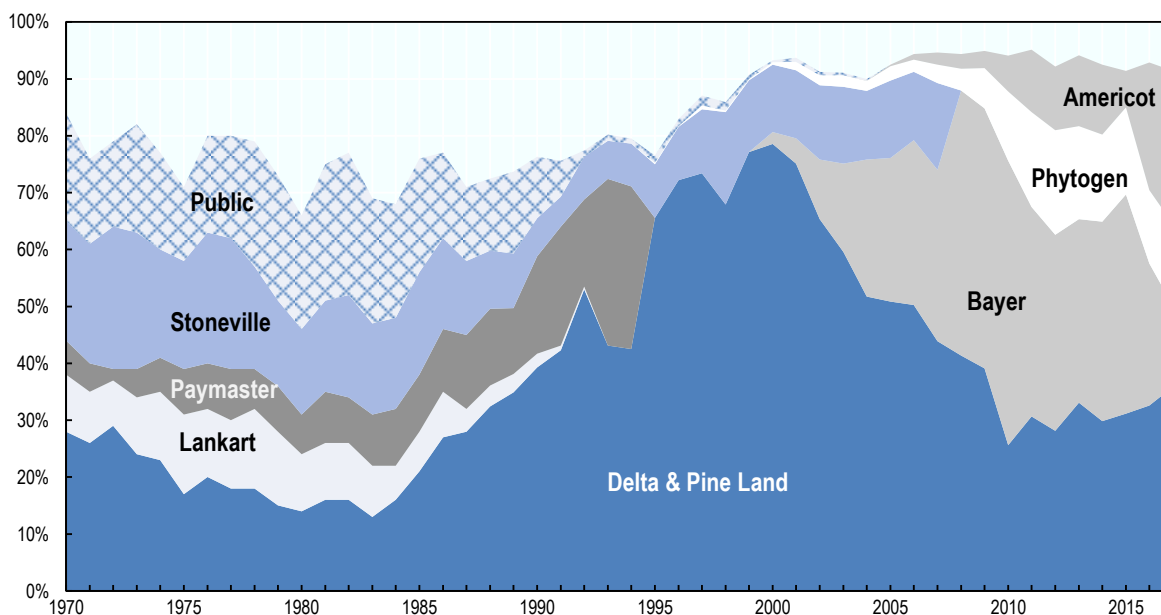
First, the use of farm-saved seed declined strongly. Whereas purchased seed constituted only 50% of the total in 1982, this share increased to 75% by 1997 (Fernandez-Cornejo, 2004^[72]). At the same time, the role of public plant breeding of US cotton became much less significant; by 1992, public institutes accounted for only 1% of the market. The Mississippi Agricultural Experiment Station had divested its popular DES-119 variety to Delta & Pine Land in 1991, while the market share of the Texas Agricultural Experiment Station fell due to the waning popularity of its flagship varieties, SP 21 and CAB-CS.

Second, Delta & Pine Land emerged as the clear market leader during this time thanks to successful new varieties such as DP 50, which by itself occupied 17% of the US cotton seed market by 1991. In 1994, Delta & Pine Land also acquired Paymaster and Lankart, further increasing its market share. By the year 2000, the estimated market share of Delta & Pine Land was almost 80%.

Third, in 1996 genetically modified cotton seed was introduced. Delta & Pine Land collaborated with Monsanto to introduce Bollgard (insect-resistant) traits into Delta & Pine

Land's cotton seeds. The resulting NuCOTN varieties were quickly adopted, reaching 17% of the total cotton seed market in 1997. As shown in Figure 3.13, GM cotton continued to spread, reaching 72% in 2000 and close to 100% in recent years.¹⁵

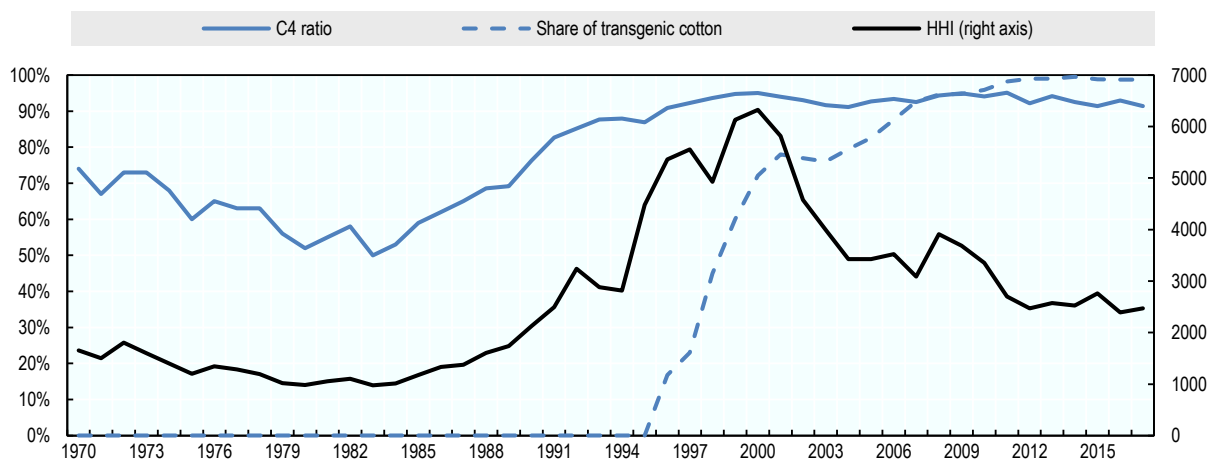
Figure 3.12. Market shares in US upland cotton seed, 1970-2017



Note: Showing main firms only. “Public” groups together public plant breeding research by the Agricultural Experiment Stations of Arkansas, Oklahoma, Texas, University of New Mexico, and Mississippi. Bayer includes Aventis CropScience (2000-2002). See main text for details on the ownership of Delta & Pine Land and Stoneville. Paymaster and Lankart were acquired by Delta & Pine Land in 1994.

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted,” various years (1982-2017), and Fernandez-Cornejo (2004^[72]) for 1970-1982.

Figure 3.13. Seed market concentration and GM adoption in US cotton seed



Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted,” various years (1982-2017), and Fernandez-Cornejo (2004^[72]) for 1970-1982.

Complementarities between germplasm, GM technology and agrochemicals led to mergers and acquisitions in the sector, leading to a complex set of changes in ownership. In 1997, Monsanto acquired Stoneville, and in 1998 Monsanto announced plans to merge with Delta & Pine Land. In preparation for this merger, Monsanto divested itself of Stoneville in 1999. However, the Department of Justice blocked the merger, leaving Monsanto without a strong position in cotton seed. Monsanto hence re-acquired Stoneville in 2005, but in 2006 undertook another attempt to acquire Delta & Pine Land, this time with more success. In 2007, Delta & Pine Land became a subsidiary of Monsanto, and Monsanto divested itself once again of Stoneville.

Bayer became active in the US cotton seed industry in 2002 after the merger with Aventis CropScience, and acquired AFD Seeds in 2005 and California Planting Cotton Seed Distributors (CPCSD) in 2007. That same year, Bayer acquired Stoneville from Monsanto.¹⁶ Bayer's cotton seed sales grew strongly during the early 2000s, to the detriment of Delta & Pine Land. Similarly, Americot has seen strong sales growth in recent years, a success which appears due in part to the NexGen breeding programmes it acquired from Monsanto in 2007 (Yancy, 2013^[73]).

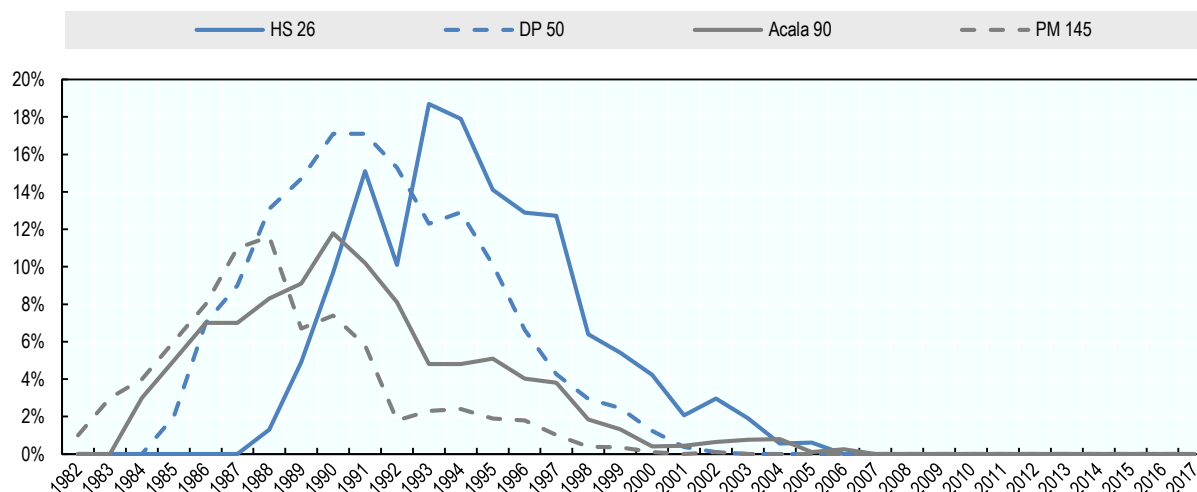
Historically, neither Dow nor DuPont have held strong positions in the cotton seed industry, but since the early 2000s Dow has played an increasingly active role through the PhytoGen Seed Company, a joint venture between Dow and the J.G. Boswell Company. PhytoGen sales have grown strongly since, reaching 18% of the market in 2012.

Innovation and product lifecycles

Innovation is a structural feature of the cotton seed market, and changes in firms' market shares are closely linked with the success of new varieties. Moreover, the turnover of varieties appears to have accelerated in recent years. Figure 3.14 shows the product lifecycle of four cotton varieties introduced before the emergence of GM cotton. Of these, DP 50 and Acala 90 were introduced by Delta & Pine Land, while PM 145 and HS 26 were introduced by Paymaster. The success of the two Delta & Pine Land varieties (which had a joint market share of 29% in 1990) explains in large part the rise of this company in the late 1980s. The 1994 acquisition of Paymaster added the two other successful cotton varieties to Delta & Pine Land's portfolio, although they had both peaked by that time.

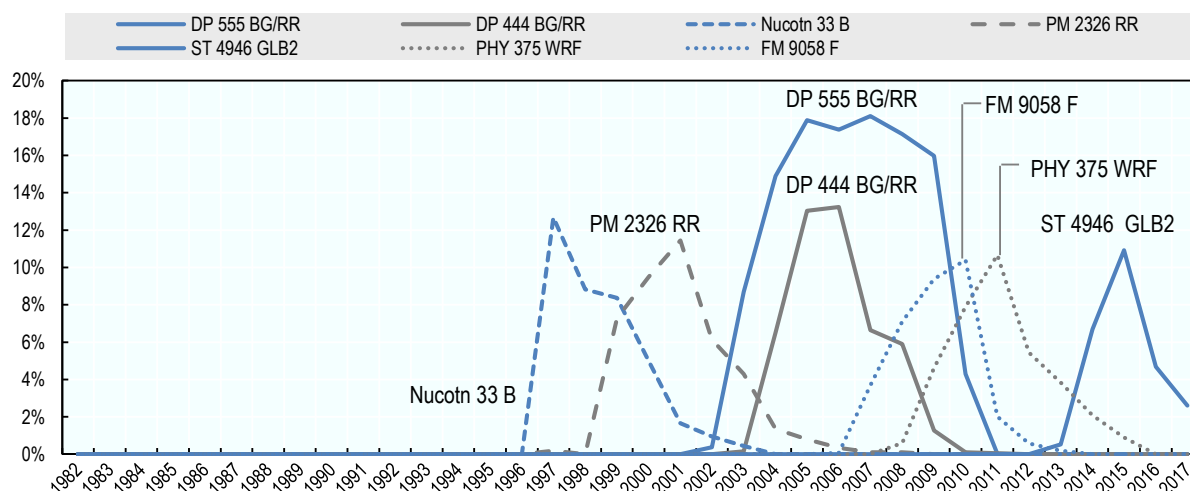
Similarly, Figure 3.15 shows product lifecycles for successful cotton varieties launched after 1996. A striking difference is the shape of product lifecycles which seem to have been compressed. After the introduction of GM, new varieties appear to be adopted and abandoned faster. Whereas HS 26 took about seven years (between 1987 and 1994) to reach its peak, and another ten years to disappear from the market, Delta & Pine Land's DP 555 BG/RR (known in the sector as "triple nickel") took only three years to reach its peak after its introduction in 2002, and was already displaced by other varieties by 2011. Other varieties show a similar pattern of sharper increases and decreases in market share.

The main successful varieties before the mid-2000s were all products of Delta & Pine Land. By contrast, the late 2000s saw the emergence of varieties by Bayer (FibreMax, FM and Stoneville, ST) and PhytoGen (PHY). The growth in market share of these firms thus corresponds to the introduction of successful new varieties.

Figure 3.14. Product lifecycle of successful pre-GM cotton varieties

Note: Showing varieties introduced between 1982 and 1996 which obtained at least 10% market share.

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted,” various years (1982-2017).

Figure 3.15. Product lifecycle of successful post-GM cotton varieties

Note: Varieties introduced since 1996 which reached at least 10% market share before 2016. To improve visual presentation, one variety (PM 1218 BG/RR) is not shown, as its path nearly coincides with that of PM 2326 RR.

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted,” various years (1982-2017).

The market for cotton GM traits

The concentration of GM traits is considerably greater than that of the cotton seed market itself (Figure 3.16). Since its introduction in the early 1990s, Monsanto’s insect-resistant BollGard traits and herbicide-tolerant Roundup Ready traits (including newer generations of this technology, such as Xtend) have been present in the majority of crop acres for most years.

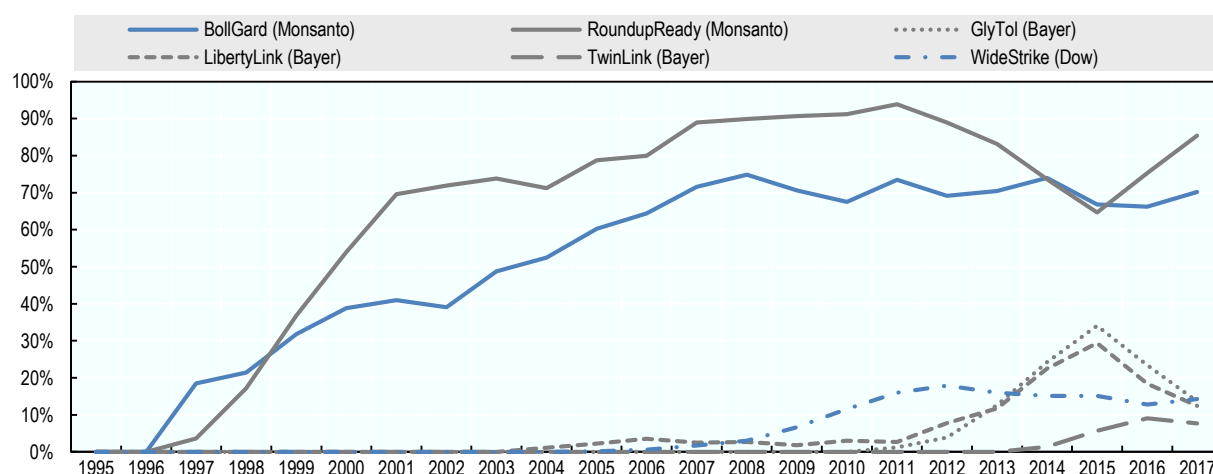
In 2015, Bayer’s GlyTol and LibertyLink traits (both herbicide tolerance traits) gained popularity at the expense of Monsanto’s Roundup Ready traits, in line with Bayer’s growing

share of the cotton seed market (Figure 3.12). As Bayer subsequently lost market share in cotton seed to Americot and Phytogen, its share of the GM traits market also fell as neither of these companies sell varieties that incorporate Bayer's traits.

Dow's WideStrike insect resistance traits have enjoyed a 12% to 18% share of US cotton acreage since 2010, as Phytogen (a Dow affiliate) incorporated WideStrike technology instead of Monsanto's BollGard technology.

Syngenta has a presence in the market for GM cotton traits through its Vip3a insect resistance trait. This trait has been licensed to Bayer, Dow and Monsanto, and is included in these companies' products TwinLinkPlus, WideStrike 3 and BollGard 3, respectively.¹⁷ Combining the market shares of these products, Syngenta traits were present in 0.7% of cotton acres in 2016 and 3.7% in 2017.

Figure 3.16. Market share of GM traits in the US cotton seed market



Note: This figure shows estimated market shares of GM traits over time. Since traits are often stacked, shares sum up to more than one in most years. Figures aggregate different generations of the same technology (e.g. Roundup Ready, Roundup Ready Flex, Roundup Ready XtendFlex).

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted,” various years (1995-2017).

Mergers and the role of competition authorities

The evolution of the US cotton seed market illustrates how decisions by competition authorities can shape the future evolution of a sector. In 2007, the Department of Justice allowed Monsanto's acquisition of Delta & Pine Land, but imposed several conditions to address its concerns (Hogan Lovells, 2007^[74]).

A first concern was that the merger would bring Stoneville (then owned by Monsanto) and Delta & Pine Land under the same owner, thus strongly reducing competition in cotton seed. A second concern was that post-merger, Monsanto could refuse access to its GM traits to competitors of Delta & Pine Land, thus reinforcing its strong position in cotton seed; and vice versa, Delta & Pine Land could refuse incorporating GM traits of Monsanto's competitors, reinforcing Monsanto's strong position in the GM traits market. The Department of Justice therefore required several remedies.

Monsanto was required to divest Stoneville as well as several Delta & Pine Land cotton varieties, additional Monsanto germplasm, and Monsanto molecular technology. Monsanto

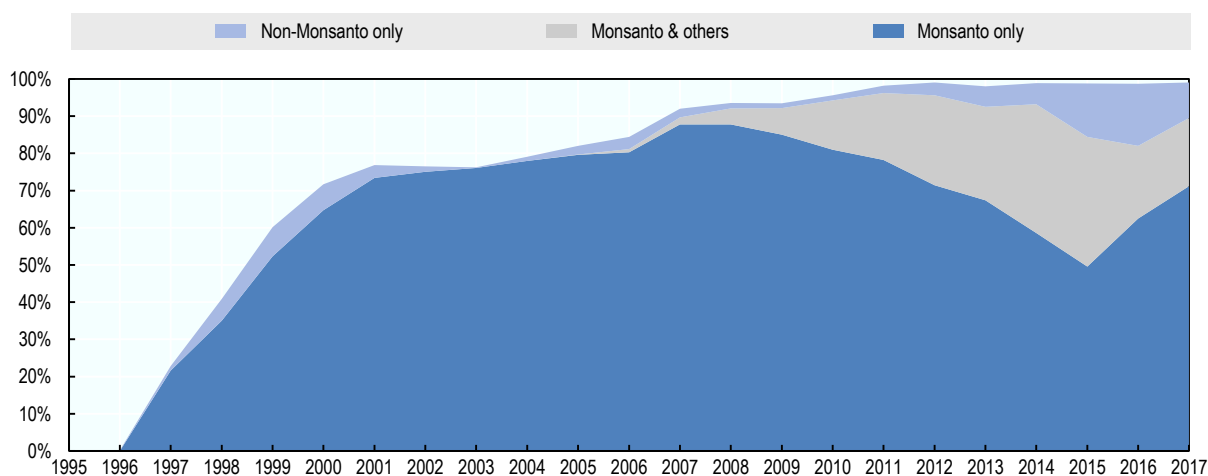
was also required to provide Stoneville with a license to Monsanto's GM traits on the same terms as Delta & Pine Land had previously enjoyed. These assets were acquired by Bayer CropScience, with the exception of the NexGen brand which was acquired by Americot.

At the time of the merger, Syngenta and Delta & Pine Land were working to incorporate Syngenta's VipCot insect resistance trait into 43 Delta & Pine Land cotton seed varieties. Monsanto was required to offer Syngenta the right to acquire these varieties to complete the work.

Monsanto was also required to revise its GM trait licenses to allow the stacking of Monsanto and non-Monsanto traits together.

In terms of market concentration in the seed market, these measures indeed seem to have prevented a single firm from obtaining a dominant position. Delta & Pine Land's market share fell from 50% in 2006 to a low of 28% in 2014, although it recovered to 36% in 2017. Bayer's acquisition of Stoneville immediately increased Bayer's market share from around 30% to around 45%, and this share continued to grow to 50% in 2010. In the following years, Bayer would lose market share to other players, notably Americot. By 2017, Bayer's market share declined to 14%, while Americot increased its market share from 12% in 2014 to 27% in 2017. As noted above, Americot's recent success can be traced directly to the NexGen varieties it acquired from Monsanto during the 2007 divestitures. Phytogen, too, grew strongly after 2007. Whereas its market share was only 2-3% prior to the Monsanto-Delta merger, it increased to 18% in 2012. Hence, it appears that the measures put in place in 2007 indeed managed to maintain competition in the cotton seed market.

Figure 3.17. Share of cotton GM traits by owner



Note: Figure shows share of US cotton acreage by owner of GM traits. "Non-Monsanto only" includes Stoneville's BXN Buctril 4EC herbicide-tolerant varieties (present in the market between 1997 and 2001); Bayer's GlyTol, LibertyLink, GT, and GLT offerings (Bayer-only), Bayer's GLTP offering (Bayer and Syngenta), and Dow's WideStrike (Dow-only) offering. "Monsanto and others" includes stacks of Roundup Ready technology with Dow's Widesrike technology (W3FE, W3F, WR, WRF) and stacks of BollGard technology with Bayer's LibertyLink (LLB2, GLB2).

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, "Cotton Varieties Planted," various years (1995-2017).

The impact of the events of 2007 are also seen in the market for GM traits (Figure 3.17). Prior to 2007, nearly 100% of the available GM trait combinations were Monsanto only, with a combination of Monsanto's BollGard insect resistance trait and Roundup Ready herbicide tolerance trait the most widely sold. After 2007, Monsanto was required to allow other firms to combine Monsanto and non-Monsanto GM traits. These combinations became more frequently available after 2007 and were planted on 35% of total cotton acres in 2014 and 2015. Likewise, varieties offering only non-Monsanto GM traits were practically non-existent in 2007. While these have remained a smaller part of the market, their share has increased over time, reaching 17% in 2016. In recent years, Monsanto-only GM traits have again increased their share, driven largely by the growth in Americot seed sales (which only incorporates Monsanto GM technology). While the structure of the market for GM traits hence clearly changed after 2007, Monsanto has maintained its leading position and other firms have found it difficult to displace Monsanto-only offerings.

3.5. Implications for the current merger wave

The literature reviewed here strongly suggests that innovation has been the main driver behind both horizontal and non-horizontal mergers and acquisitions over the past three decades. Firms sought to combine complementary intellectual assets (seed, traits, tools, and chemicals) through non-horizontal combinations. At the same time, R&D spending became a strategic tool for firms. As firms increased their R&D spending, the high fixed costs in turn stimulated horizontal consolidation.

These structural drivers are also at work in the current mergers. Statements by industry executives emphasize the importance of combining complementary product portfolios and the possibility of new complementarities arising from digital and precision agriculture (Bonny, 2017_[12]).¹⁸

The welfare effects of mergers depend strongly on whether a merger is non-horizontal or horizontal. Non-horizontal mergers are more likely to lead to efficiency gains (such as more efficient R&D through the combination of complementary assets), while for horizontal mergers there is a greater risk of negative effects on consumers through higher prices, lower innovation or fewer choices for consumers. At the same time, non-horizontal mergers are not necessarily harmless, as they may block competitors' access to important resources – this was a particular concern in Monsanto's 2007 acquisition of Delta & Pine Land and similar arguments apply to the recent mergers. The current mergers (in particular DowDuPont and Bayer-Monsanto) combine both horizontal and non-horizontal elements, and a key question for competition authorities is therefore to what extent efficiencies offset the risk of negative effects – and which measures need to be taken to reduce negative effects that might emerge. These arguments are reviewed in more detail in the next chapter.

Notes

- ¹ In this report, the combined firm will be referred to as DowDuPont throughout as at the time of writing Corteva was not yet an independent business.
- ² For example, ChemChina acquired the Italian tire maker Pirelli in 2015.
- ³ Some observers have speculated that the acquisition of Syngenta could help reduce Chinese consumers' distrust of GM seeds, which have been virtually banned in China. This interpretation of the Syngenta acquisition is consistent with previous statements by President Xi Jinping, who declared in a 2013 speech that in order to secure China's food security the country would need to "occupy the commanding heights of transgenic technology" instead of allowing foreign firms to dominate the market (The Economist, 2016^[206]).
- ⁴ See also BASF (2017^[209]), Marc Noel and Serafino (2017^[208]) and Bray (2017^[207]).
- ⁵ This geographic split likely reflects an important economic difference between field crop and vegetable seeds. Given their high value per kilogram, it is feasible to ship vegetable seeds from a single location. Field crop seeds, by contrast, are more bulky (i.e. have a lower value by weight), making it less efficient to source from a single location. This in turn means it is more difficult for a seed firm to sell field crop seeds in regions where it does not have an active physical presence (Marien Valstar, personal communication).
- ⁶ While not active in seeds, another important player is FMC, a leading supplier of crop protection chemicals. Following its acquisition of DuPont's global pesticide business, FMC increases its sales of crop protection chemicals from USD 2.3 billion in 2016 to an estimated USD 4 billion in 2018. This makes FMC the fifth largest agricultural chemicals firm, after Bayer-Monsanto, ChemChina-Syngenta, DowDuPont and BASF.
- ⁷ One industry participant noted that this consolidation wave can be traced in part to the oil crises of the 1970s. Following high oil prices, players in the oil industry expected that energy production as well as molecules for plastic could in the future be derived from plants. This "green oil" trend led several petrochemical firms (e.g. Shell, Lubrizol and Elf) to invest in plant breeding and genetics firms.
- ⁸ Fixed costs are sunk when investments cannot (easily) be recovered once they have been made. Classic examples are investments in advertising or R&D. An important strand of literature on industrial organisation, following Sutton (1991^[215]), explains empirical regularities in market structure with reference to such sunk costs. There is debate as to what extent theoretical arguments in this literature would also carry over to "non-sunk" fixed costs. In practice, most industries have a mix of sunk and non-sunk fixed costs (Sutton, 2007^[54]).
- ⁹ Applications in the United States typically also include field trials, while most applications in the European Union were for "import and processing" purposes, for which data from field trials outside of the European Union can be used as input in the regulatory process.
- ¹⁰ For a detailed treatment of regulatory aspects of GM, including global governance and international trade aspects, see Smyth et al. (2017^[251]).
- ¹¹ The "life science" trend was not the only instance of a suspected complementarity which did not materialise. As noted earlier, some consolidation in the industry in the 1980s was inspired by the search for "green oil" (biological substitutes to fossil fuels).
- ¹² In May 2018, digital agriculture was the topic of the OECD Global Forum on Agriculture. Ongoing OECD work is exploring the potential impacts of the digital revolution in agriculture, including implications for policy (Jouanjean and Deboe, 2018^[240]).

- 13 For some firms, these digital offerings build on and extend agronomic services they were already offering to farmers (and which compete with public sector extension services). Advice based on digital farming may also crowd out independent crop consultants
- 14 Much of the discussion in the literature regarding the differences between plant breeders' rights and patents has tended to focus on the US case, where plant varieties can be patented and where patent law does not provide a breeder's exemption. Plant varieties cannot be patented as a whole in most jurisdictions, although biotechnology patents exist in many places. In the United States, use of such patented biotechnology in plant breeding does not benefit from a breeder's exemption. However, this is not true for all jurisdictions (Box 3.1).
- 15 In collaboration with the United States Department of Agriculture, Delta & Pine Land itself had developed the controversial GM technology for genetic sterilisation of seeds known as "terminator genes." Given strong public opposition, this technique has never been commercially implemented.
- 16 As part of the Bayer-Monsanto merger, Bayer is divesting its FiberMax and Stoneville cotton seed business to BASF
- 17 BollGard 3 varieties were not yet available in the 2017 season.
- 18 In addition to these underlying drivers, some other factors have been mentioned as explaining the timing of the current consolidation (Bonny, 2017[12]). First, after years of high crop prices creating favourable conditions for agricultural input industries, the decrease in agricultural prices in 2015-2016 negatively affected the seed and (especially) agrochemical industries. At the same time, the pesticide industry was experiencing tightening regulation in several countries. These factors may have encouraged industry participants to consider combinations with other firms. This tendency was further stimulated by low interest rates, which make it easier to finance large acquisitions.

Annex 3.A. Selected data tables

Annex Table 3.A.1. Pro forma 2016 sales per segment for Dow and DuPont (agriculture)

USD billions	Dow	DuPont	Pro forma total
Maize seeds	0.96	4.47	5.43
Soybean seeds	0.23	1.33	1.56
Other seeds	0.36	0.86	1.21
Total seeds and traits	1.54	6.66	8.20
Herbicides	2.78	0.95	3.73
Insecticides	1.39	1.24	2.63
Fungicides	0.46	0.67	1.13
Total crop protection	4.63	2.85	7.49
Total	6.17	9.52	15.69

Note: Pro forma estimates based on the 2016 sales figures for the companies, not taking into account divestitures. Data is approximate and based on company materials.

Source: Company annual reports; Dow presentation at Bank of America Merrill Lynch Global Agriculture Conference, March 2017.

Annex Table 3.A.2. Sales per region and segment for Syngenta, 2017

USD billions	Crop protection	Seeds	Total
EMEA	2.89	1.02	3.91
Latin America	2.43	0.48	2.91
North America	2.35	1.04	3.40
Asia Pacific	1.57	0.28	1.86
Total	9.25	2.83	12.08

Note: EMEA is Europe, Middle East and Africa.

Source: Company annual report.

Annex Table 3.A.3. Sales per segment for Bayer and Monsanto, 2017

USD billions	Bayer	Bayer divested	Monsanto	Total after divestitures
Seeds and Traits	0.1	1.6	10.9	11.0
Herbicides	2.1	0.9	3.7	5.8
Fungicides	3.0	-	-	3.0
Insecticides	1.4	-	-	1.4
Seed treatment	1.1	-	-	1.1
Other	0.8	-	-	0.8
Total	8.5	2.5	14.6	23.1

Note: Pro forma estimates based on the 2017 sales figures for the companies. The segment and region split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed segment split of the divested businesses: EUR 800 million in herbicides and EUR 1.4 billion in seeds and traits. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts. Financial data converted using an average exchange rate of USD/EUR 1.15.

Source: OECD estimates based on company annual reports, Bayer (2016[37]) and BASF Q2 2018 Analyst Conference Call handout.

Annex Table 3.A.4. Sales per region for Bayer and Monsanto, 2016

USD billions	Bayer after divestitures	Bayer divested	Monsanto	After divestitures
North America	1.6	1.6	9.4	11.0
EMEA	3.5	0.3	1.8	5.3
Latin America	1.8	0.3	2.8	4.6
Asia Pacific	1.6	0.2	0.6	2.1
Other	-	-	0.1	0.1
Total	8.5	2.5	14.6	23.1

Note: Pro forma estimates based on the 2017 sales figures for the companies. The segment and region split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed split by regions: EUR 1.4 billion in North America, EUR 300 million in Latin America, EUR 300 million in EMEA, EUR 200 million in Asia Pacific. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts. EMEA stands for Europe, Middle East and Africa. North America includes Mexico. Financial data converted using an average exchange rate of USD/EUR 1.15.

Source: OECD estimates based on company annual reports, Bayer (2016[37]) and BASF Q2 2018 Analyst Conference Call handout.

Annex Table 3.A.5. BASF sales per segment, 2016

USD billions	BASF before acquisition	Acquired from Bayer	BASF after acquisition
Fungicides	2.7	-	2.7
Herbicides	2.7	0.9	3.6
Insecticides	0.8	-	0.8
Seeds & traits	-	1.6	1.6
Other	0.4	-	0.4
Total	6.6	2.5	9.1

Note: Financial data converted using an average exchange rate of USD/EUR 1.15. The segment split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed segment split of the divested businesses: EUR 800 million in herbicides and EUR 1.4 billion in seeds and traits. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts.

Source: OECD estimates based on company annual reports and BASF Q2 2018 Analyst Conference Call handout.

Annex Table 3.A.6. BASF sales per region, 2016

USD billions	BASF before acquisition	Acquired from Bayer	BASF after acquisition
Europe	2.3	0.3	2.6
North America	2.3	1.6	3.9
South America, Middle East, Africa	0.7	0.2	0.9
Asia Pacific	1.3	0.3	1.6
Total	6.6	2.5	9.1

Note: Financial data converted using an average exchange rate of USD/EUR 1.15. The segment and region split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed region split of the divested businesses: EUR 1.4 billion in North America, EUR 300 million in Latin America, EUR 300 million in EMEA, EUR 200 million in Asia Pacific. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts.

Source: OECD estimates based on company annual reports and BASF Q2 2018 Analyst Conference Call handout.

Annex Table 3.A.7. Limagrain/Vilmorin sales per region and segment, 2017

USD billions	Field seeds	Vegetable seeds	Total	of which AgReliant
Europe	0.62	0.29	0.91	
Americas	0.31	0.24	0.55	0.31
Africa and Middle East	0.05	0.12	0.17	
Asia and Pacific	0.05	0.12	0.17	
Total	1.02	0.77	1.80	
of which AgReliant	0.31			0.31

Note: Using an average exchange rate of 1.15 USD/EUR. Not showing approximately USD 60 million of “other” sales.

Source: OECD estimates based on company annual report. AgReliant is a 50/50 joint venture with KWS.

Annex Table 3.A.8. KWS sales per segment, 2016-17

USD billions	KWS	AgReliant	Total
Maize and oilseeds	0.56	0.35	0.92
Sugar beet	0.50		0.50
Cereals	0.12		0.12
Total	1.19	0.35	1.54

Note: Using an average exchange rate of 1.11 USD/EUR. Data refer to 2016-17.

Source: OECD estimates based on company annual report. AgReliant is a 50/50 joint venture with Limagrain/Vilmorin.

Annex Table 3.A.9. KWS sales per region, 2016-17

USD billions	KWS	AgReliant	Total
Germany	0.25		0.25
Other Europe	0.51		0.51
Americas	0.35	0.35	0.71
Rest of World	0.07		0.07
Total	1.19	0.35	1.54

Note: Using an average exchange rate of 1.11 USD/EUR. Data refer to 2016-17.

Source: OECD estimates based on company annual report. AgReliant is a 50/50 joint venture with Limagrain/Vilmorin.

Annex Table 3.A.10. Pro forma 2017 sales of leading firms post-mergers

USD billions	Seeds and biotech	Agricultural chemicals	Total
Bayer-Monsanto	11.03	12.09	23.12
ChemChina-Syngenta	2.83	13.55	16.38
DowDuPont	8.00	6.34	14.34
BASF	1.61	7.47	9.08
Vilmorin	1.86	-	1.86
KWS	1.54	-	1.54

Note: Pro forma estimates based on the 2017 sales figures for the companies (or most recent data available). Bayer-Monsanto and BASF include estimated effects of divested Bayer assets (about USD 2.5 billion in total). ChemChina-Syngenta includes an estimated USD 4.3 billion in agro-chemical sales for ChemChina. DowDuPont based on pro forma 2017 data reported by the company (accounting for divestitures). Data for Vilmorin and KWS include sales of AgReliant.

Source: OECD estimates based on company annual reports; Colvin (2017[32]) for ChemChina.

Annex Table 3.A.11. GM acreage shares in US upland cotton, 1970-2017

	Delta & Pine Land	Lankart	Paymaster	Stoneville	Bayer	Phytogen	Americot	Public	Other
1974	23.0%	12.0%	6.0%	19.0%	0.0%	0.0%	0.0%	17.0%	23.0%
1975	17.0%	14.0%	8.0%	19.0%	0.0%	0.0%	0.0%	13.0%	29.0%
1976	20.0%	12.0%	8.0%	23.0%	0.0%	0.0%	0.0%	17.0%	20.0%
1977	18.0%	12.0%	9.0%	23.0%	0.0%	0.0%	0.0%	18.0%	20.0%
1978	18.0%	14.0%	7.0%	18.0%	0.0%	0.0%	0.0%	22.0%	21.0%
1979	15.0%	13.0%	8.0%	15.0%	0.0%	0.0%	0.0%	22.0%	27.0%
1980	14.0%	10.0%	7.0%	15.0%	0.0%	0.0%	0.0%	20.0%	34.0%
1981	16.0%	10.0%	9.0%	16.0%	0.0%	0.0%	0.0%	24.0%	25.0%
1982	16.0%	10.0%	8.0%	18.0%	0.0%	0.0%	0.0%	25.0%	23.0%
1983	13.0%	9.0%	9.0%	16.0%	0.0%	0.0%	0.0%	22.0%	31.0%
1984	16.0%	6.0%	10.0%	16.0%	0.0%	0.0%	0.0%	20.0%	32.0%
1985	21.0%	7.0%	10.0%	18.0%	0.0%	0.0%	0.0%	20.0%	24.0%
1986	27.0%	8.0%	11.0%	16.0%	0.0%	0.0%	0.0%	15.0%	23.0%
1987	28.0%	4.0%	13.0%	13.0%	0.0%	0.0%	0.0%	13.0%	29.0%
1988	32.4%	3.7%	13.5%	10.2%	0.0%	0.0%	0.0%	12.7%	27.5%
1989	34.9%	3.2%	11.6%	9.6%	0.0%	0.0%	0.0%	14.4%	26.3%
1990	39.3%	2.4%	17.1%	6.7%	0.0%	0.0%	0.0%	10.8%	23.7%
1991	42.3%	0.8%	20.9%	5.3%	0.0%	0.0%	0.0%	6.3%	24.4%
1992	53.0%	0.5%	15.3%	7.5%	0.0%	0.0%	0.0%	1.1%	22.6%
1993	43.1%	0.0%	29.3%	6.7%	0.0%	0.0%	0.0%	1.1%	19.8%
1994	42.5%	0.0%	28.6%	7.5%	0.0%	0.0%	0.0%	0.9%	20.5%
1995	65.6%	0.0%	0.0%	9.4%	0.0%	0.3%	0.0%	1.3%	23.5%
1996	72.2%	0.0%	0.0%	9.4%	0.0%	0.1%	0.0%	1.3%	17.0%
1997	73.4%	0.0%	0.0%	11.3%	0.0%	0.6%	0.0%	1.8%	12.9%
1998	67.9%	0.0%	0.0%	16.2%	0.0%	0.3%	0.0%	1.5%	14.1%
1999	77.2%	0.0%	0.0%	12.6%	0.0%	0.2%	0.0%	0.8%	9.3%
2000	78.6%	0.0%	0.0%	11.9%	2.1%	0.4%	0.0%	0.3%	6.7%
2001	75.1%	0.0%	0.0%	12.0%	4.5%	1.5%	0.0%	0.7%	6.3%
2002	65.3%	0.0%	0.0%	13.0%	10.5%	1.8%	0.0%	0.6%	8.8%
2003	59.6%	0.0%	0.0%	13.5%	15.6%	2.0%	0.0%	0.5%	8.9%
2004	51.7%	0.0%	0.0%	12.1%	24.1%	1.8%	0.1%	0.3%	10.0%
2005	50.8%	0.0%	0.0%	13.6%	25.3%	2.5%	0.3%	0.0%	7.5%
2006	50.3%	0.0%	0.0%	12.0%	29.0%	2.1%	1.0%	0.0%	5.6%
2007	43.9%	0.0%	0.0%	15.3%	30.1%	3.2%	2.2%	0.0%	5.4%
2008	41.4%	0.0%	0.0%	0.0%	46.6%	3.9%	2.6%	0.0%	5.6%
2009	39.1%	0.0%	0.0%	0.0%	45.7%	7.1%	3.0%	0.0%	5.1%
2010	25.6%	0.0%	0.0%	0.0%	50.0%	12.2%	6.3%	0.0%	5.9%
2011	30.7%	0.0%	0.0%	0.0%	36.8%	16.7%	11.0%	0.0%	4.9%
2012	28.1%	0.0%	0.0%	0.0%	34.4%	18.4%	11.2%	0.0%	7.8%
2013	33.1%	0.0%	0.0%	0.0%	32.3%	16.3%	12.5%	0.0%	5.8%
2014	29.9%	0.0%	0.0%	0.0%	35.0%	15.3%	12.3%	0.0%	7.5%
2015	31.1%	0.0%	0.0%	0.0%	38.6%	15.3%	6.4%	0.0%	8.6%
2016	32.6%	0.0%	0.0%	0.0%	25.0%	12.9%	22.5%	0.0%	7.1%
2017	35.9%	0.0%	0.0%	0.0%	14.2%	14.4%	27.0%	0.0%	8.6%

Note: Showing main firms only. “Public” groups together public plant breeding research by the Agricultural Experiment Stations of Arkansas, Oklahoma, Texas, University of New Mexico, and Mississippi. Bayer includes Aventis CropScience (2000-2002). See main text for details on the ownership of Delta & Pine Land and Stoneville. Paymaster and Lankart were acquired by Delta & Pine Land in 1994.

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted”, various years (1982-2017); and Fernandez-Cornejo (2004) for 1974-1982.

Annex Table 3.A.12. Market share of GM traits in the US cotton seed market

	Monsanto			Bayer				Dow			Stoneville
	BollGard	Roundup Ready	RR Flex	XtendFlex	All RR	GlyTol	LibertyLink	TwinLink	WideStrike	Enlist	BXN
	IR	HT	HT	HT	HT	HT	HT	IR	IR	HT	HT
1995	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1996	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1997	18%	4%	0%	0%	4%	0%	0%	0%	0%	0%	1%
1998	21%	17%	0%	0%	17%	0%	0%	0%	0%	0%	6%
1999	32%	37%	0%	0%	37%	0%	0%	0%	0%	0%	8%
2000	39%	54%	0%	0%	54%	0%	0%	0%	0%	0%	7%
2001	41%	70%	0%	0%	70%	0%	0%	0%	0%	0%	3%
2002	39%	72%	0%	0%	72%	0%	0%	0%	0%	0%	1%
2003	49%	74%	0%	0%	74%	0%	0%	0%	0%	0%	0%
2004	52%	71%	0%	0%	71%	0%	1%	0%	0%	0%	0%
2005	60%	79%	0%	0%	79%	0%	2%	0%	0%	0%	0%
2006	64%	73%	7%	0%	80%	0%	4%	0%	1%	0%	0%
2007	72%	54%	35%	0%	89%	0%	2%	0%	2%	0%	0%
2008	75%	39%	51%	0%	90%	0%	3%	0%	3%	0%	0%
2009	71%	23%	68%	0%	91%	0%	2%	0%	7%	0%	0%
2010	68%	7%	85%	0%	91%	0%	3%	0%	12%	0%	0%
2011	73%	0%	94%	0%	94%	1%	3%	0%	16%	0%	0%
2012	69%	0%	89%	0%	89%	4%	8%	0%	18%	0%	0%
2013	70%	0%	83%	0%	83%	13%	12%	0%	16%	0%	0%
2014	74%	0%	74%	0%	74%	24%	22%	1%	15%	0%	0%
2015	67%	0%	56%	9%	65%	34%	29%	6%	15%	0%	0%
2016	66%	0%	32%	43%	75%	23%	18%	9%	13%	0%	0%
2017	70%	0%	22%	64%	85%	14%	12%	8%	14%	3%	0%

Note: Table shows share of US cotton acreage by GM trait. Due to stacked traits, totals may exceed the share of cotton acreage planted with GM. IR: insect-resistant; HT: herbicide-tolerant. “All RR” is the sum of Roundup Ready, RR Flex and XtendFlex.

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted”, various years (1995-2017).

Annex Table 3.A.13. Pro forma 2016 sales per segment for Dow and DuPont (agriculture)

USD billions	Dow	DuPont	Pro forma total
Maize seeds	0.96	4.47	5.43
Soybean seeds	0.23	1.33	1.56
Other seeds	0.36	0.86	1.21
Total seeds and traits	1.54	6.66	8.20
Herbicides	2.78	0.95	3.73
Insecticides	1.39	1.24	2.63
Fungicides	0.46	0.67	1.13
Total crop protection	4.63	2.85	7.49
Total	6.17	9.52	15.69

Note: Pro forma estimates based on the 2016 sales figures for the companies, not taking into account divestitures. Data is approximate and based on company materials.

Source: Company annual reports; Dow presentation at Bank of America Merrill Lynch Global Agriculture Conference, March 2017.

Annex Table 3.A.14. Sales per region and segment for Syngenta, 2017

USD billions	Crop protection	Seeds	Total
EMEA	2.89	1.02	3.91
Latin America	2.43	0.48	2.91
North America	2.35	1.04	3.40
Asia Pacific	1.57	0.28	1.86
Total	9.25	2.83	12.08

Note: EMEA is Europe, Middle East and Africa.

Source: Company annual report.

Annex Table 3.A.15. Sales per segment for Bayer and Monsanto, 2017

USD billions	Bayer	Bayer divested	Monsanto	Total after divestitures
Seeds and Traits	0.1	1.6	10.9	11.0
Herbicides	2.1	0.9	3.7	5.8
Fungicides	3.0	-	-	3.0
Insecticides	1.4	-	-	1.4
Seed treatment	1.1	-	-	1.1
Other	0.8	-	-	0.8
Total	8.5	2.5	14.6	23.1

Note: Pro forma estimates based on the 2017 sales figures for the companies. The segment and region split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed segment split of the divested businesses: EUR 800 million in herbicides and EUR 1.4 billion in seeds and traits. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts. Financial data converted using an average exchange rate of USD/EUR 1.15.

Source: OECD estimates based on company annual reports, Bayer (2016[37]) and BASF Q2 2018 Analyst Conference Call handout.

Annex Table 3.A.16. Sales per region for Bayer and Monsanto, 2016

USD billions	Bayer after divestitures	Bayer divested	Monsanto	After divestitures
North America	1.6	1.6	9.4	11.0
EMEA	3.5	0.3	1.8	5.3
Latin America	1.8	0.3	2.8	4.6
Asia Pacific	1.6	0.2	0.6	2.1
Other	-	-	0.1	0.1
Total	8.5	2.5	14.6	23.1

Note: Pro forma estimates based on the 2017 sales figures for the companies. The segment and region split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed split by regions: EUR 1.4 billion in North America, EUR 300 million in Latin America, EUR 300 million in EMEA, EUR 200 million in Asia Pacific. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts. EMEA stands for Europe, Middle East and Africa. North America includes Mexico. Financial data converted using an average exchange rate of USD/EUR 1.15.

Source: OECD estimates based on company annual reports, Bayer (2016[37]) and BASF Q2 2018 Analyst Conference Call handout.

Annex Table 3.A.17. BASF sales per segment, 2016

USD billions	BASF before acquisition	Acquired from Bayer	BASF after acquisition
Fungicides	2.7	-	2.7
Herbicides	2.7	0.9	3.6
Insecticides	0.8	-	0.8
Seeds & traits	-	1.6	1.6
Other	0.4	-	0.4
Total	6.6	2.5	9.1

Note: Financial data converted using an average exchange rate of USD/EUR 1.15. The segment split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed segment split of the divested businesses: EUR 800 million in herbicides and EUR 1.4 billion in seeds and traits. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts.

Source: OECD estimates based on company annual reports and BASF Q2 2018 Analyst Conference Call handout.

Annex Table 3.A.18. BASF sales per region, 2016

USD billions	BASF before acquisition	Acquired from Bayer	BASF after acquisition
Europe	2.3	0.3	2.6
North America	2.3	1.6	3.9
South America, Middle East, Africa	0.7	0.2	0.9
Asia Pacific	1.3	0.3	1.6
Total	6.6	2.5	9.1

Note: Financial data converted using an average exchange rate of USD/EUR 1.15. The segment and region split of EUR 2.2 billion (USD 2.5 billion) in divested Bayer sales is approximate and based on BASF materials. Assumed region split of the divested businesses: EUR 1.4 billion in North America, EUR 300 million in Latin America, EUR 300 million in EMEA, EUR 200 million in Asia Pacific. These assumptions are consistent with investor materials shared by BASF during a 27 July 2018 conference call with financial analysts.

Source: OECD estimates based on company annual reports and BASF Q2 2018 Analyst Conference Call handout.

Annex Table 3.A.19. Limagrain/Vilmorin sales per region and segment, 2017

USD billions	Field seeds	Vegetable seeds	Total	of which AgReliant
Europe	0.62	0.29	0.91	
Americas	0.31	0.24	0.55	0.31
Africa and Middle East	0.05	0.12	0.17	
Asia and Pacific	0.05	0.12	0.17	
Total	1.02	0.77	1.80	
<i>of which AgReliant</i>	0.31			0.31

Note: Using an average exchange rate of 1.15 USD/EUR. Not showing approximately USD 60 million of “other” sales.

Source: OECD estimates based on company annual report. AgReliant is a 50/50 joint venture with KWS.

Annex Table 3.A.20. KWS sales per segment, 2016-17

USD billions	KWS	AgReliant	Total
Maize and oilseeds	0.56	0.35	0.92
Sugar beet	0.50		0.50
Cereals	0.12		0.12
Total	1.19	0.35	1.54

Note: Using an average exchange rate of 1.11 USD/EUR. Data refer to 2016-17.

Source: OECD estimates based on company annual report. AgReliant is a 50/50 joint venture with Limagrain/Vilmorin.

Annex Table 3.A.21. KWS sales per region, 2016-17

USD billions	KWS	AgReliant	Total
Germany	0.25		0.25
Other Europe	0.51		0.51
Americas	0.35	0.35	0.71
Rest of World	0.07		0.07
Total	1.19	0.35	1.54

Note: Using an average exchange rate of 1.11 USD/EUR. Data refer to 2016-17.

Source: OECD estimates based on company annual report. AgReliant is a 50/50 joint venture with Limagrain/Vilmorin.

Annex Table 3.A.22. Pro forma 2017 sales of leading firms post-mergers

USD billions	Seeds and biotech	Agricultural chemicals	Total
Bayer-Monsanto	11.03	12.09	23.12
ChemChina-Syngenta	2.83	13.55	16.38
DowDuPont	8.00	6.34	14.34
BASF	1.61	7.47	9.08
Vilmorin	1.86	-	1.86
KWS	1.54	-	1.54

Note: Pro forma estimates based on the 2017 sales figures for the companies (or most recent data available). Bayer-Monsanto and BASF include estimated effects of divested Bayer assets (about USD 2.5 billion in total). ChemChina-Syngenta includes an estimated USD 4.3 billion in agro-chemical sales for ChemChina. DowDuPont based on pro forma 2017 data reported by the company (accounting for divestitures). Data for Vilmorin and KWS include sales of AgReliant.

Source: OECD estimates based on company annual reports; Colvin (2017[32]) for ChemChina.

Annex Table 3.A.23. GM acreage shares in US upland cotton, 1970-2017

	Delta & Pine Land	Lankart	Paymaster	Stoneville	Bayer	Phytogen	Americot	Public	Other
1974	23.0%	12.0%	6.0%	19.0%	0.0%	0.0%	0.0%	17.0%	23.0%
1975	17.0%	14.0%	8.0%	19.0%	0.0%	0.0%	0.0%	13.0%	29.0%
1976	20.0%	12.0%	8.0%	23.0%	0.0%	0.0%	0.0%	17.0%	20.0%
1977	18.0%	12.0%	9.0%	23.0%	0.0%	0.0%	0.0%	18.0%	20.0%
1978	18.0%	14.0%	7.0%	18.0%	0.0%	0.0%	0.0%	22.0%	21.0%
1979	15.0%	13.0%	8.0%	15.0%	0.0%	0.0%	0.0%	22.0%	27.0%
1980	14.0%	10.0%	7.0%	15.0%	0.0%	0.0%	0.0%	20.0%	34.0%
1981	16.0%	10.0%	9.0%	16.0%	0.0%	0.0%	0.0%	24.0%	25.0%
1982	16.0%	10.0%	8.0%	18.0%	0.0%	0.0%	0.0%	25.0%	23.0%
1983	13.0%	9.0%	9.0%	16.0%	0.0%	0.0%	0.0%	22.0%	31.0%
1984	16.0%	6.0%	10.0%	16.0%	0.0%	0.0%	0.0%	20.0%	32.0%
1985	21.0%	7.0%	10.0%	18.0%	0.0%	0.0%	0.0%	20.0%	24.0%
1986	27.0%	8.0%	11.0%	16.0%	0.0%	0.0%	0.0%	15.0%	23.0%
1987	28.0%	4.0%	13.0%	13.0%	0.0%	0.0%	0.0%	13.0%	29.0%
1988	32.4%	3.7%	13.5%	10.2%	0.0%	0.0%	0.0%	12.7%	27.5%
1989	34.9%	3.2%	11.6%	9.6%	0.0%	0.0%	0.0%	14.4%	26.3%
1990	39.3%	2.4%	17.1%	6.7%	0.0%	0.0%	0.0%	10.8%	23.7%
1991	42.3%	0.8%	20.9%	5.3%	0.0%	0.0%	0.0%	6.3%	24.4%
1992	53.0%	0.5%	15.3%	7.5%	0.0%	0.0%	0.0%	1.1%	22.6%
1993	43.1%	0.0%	29.3%	6.7%	0.0%	0.0%	0.0%	1.1%	19.8%
1994	42.5%	0.0%	28.6%	7.5%	0.0%	0.0%	0.0%	0.9%	20.5%
1995	65.6%	0.0%	0.0%	9.4%	0.0%	0.3%	0.0%	1.3%	23.5%
1996	72.2%	0.0%	0.0%	9.4%	0.0%	0.1%	0.0%	1.3%	17.0%
1997	73.4%	0.0%	0.0%	11.3%	0.0%	0.6%	0.0%	1.8%	12.9%
1998	67.9%	0.0%	0.0%	16.2%	0.0%	0.3%	0.0%	1.5%	14.1%
1999	77.2%	0.0%	0.0%	12.6%	0.0%	0.2%	0.0%	0.8%	9.3%
2000	78.6%	0.0%	0.0%	11.9%	2.1%	0.4%	0.0%	0.3%	6.7%
2001	75.1%	0.0%	0.0%	12.0%	4.5%	1.5%	0.0%	0.7%	6.3%
2002	65.3%	0.0%	0.0%	13.0%	10.5%	1.8%	0.0%	0.6%	8.8%
2003	59.6%	0.0%	0.0%	13.5%	15.6%	2.0%	0.0%	0.5%	8.9%
2004	51.7%	0.0%	0.0%	12.1%	24.1%	1.8%	0.1%	0.3%	10.0%
2005	50.8%	0.0%	0.0%	13.6%	25.3%	2.5%	0.3%	0.0%	7.5%
2006	50.3%	0.0%	0.0%	12.0%	29.0%	2.1%	1.0%	0.0%	5.6%
2007	43.9%	0.0%	0.0%	15.3%	30.1%	3.2%	2.2%	0.0%	5.4%
2008	41.4%	0.0%	0.0%	0.0%	46.6%	3.9%	2.6%	0.0%	5.6%
2009	39.1%	0.0%	0.0%	0.0%	45.7%	7.1%	3.0%	0.0%	5.1%
2010	25.6%	0.0%	0.0%	0.0%	50.0%	12.2%	6.3%	0.0%	5.9%
2011	30.7%	0.0%	0.0%	0.0%	36.8%	16.7%	11.0%	0.0%	4.9%
2012	28.1%	0.0%	0.0%	0.0%	34.4%	18.4%	11.2%	0.0%	7.8%
2013	33.1%	0.0%	0.0%	0.0%	32.3%	16.3%	12.5%	0.0%	5.8%
2014	29.9%	0.0%	0.0%	0.0%	35.0%	15.3%	12.3%	0.0%	7.5%
2015	31.1%	0.0%	0.0%	0.0%	38.6%	15.3%	6.4%	0.0%	8.6%
2016	32.6%	0.0%	0.0%	0.0%	25.0%	12.9%	22.5%	0.0%	7.1%
2017	35.9%	0.0%	0.0%	0.0%	14.2%	14.4%	27.0%	0.0%	8.6%

Note: Showing main firms only. “Public” groups together public plant breeding research by the Agricultural Experiment Stations of Arkansas, Oklahoma, Texas, University of New Mexico, and Mississippi. Bayer includes Aventis CropScience (2000-2002). See main text for details on the ownership of Delta & Pine Land and Stoneville. Paymaster and Lankart were acquired by Delta & Pine Land in 1994.

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted”, various years (1982-2017); and Fernandez-Cornejo (2004) for 1974-1982.

Annex Table 3.A.24. Market share of GM traits in the US cotton seed market

	Monsanto		Bayer					Dow		Stoneville	
	BollGard	Roundup Ready	RR Flex	XtendFlex	All RR	GlyTol	LibertyLink	TwinLink	WideStrike	Enlist	BXN
	IR	HT	HT	HT	HT	HT	HT	IR	IR	HT	HT
1995	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1996	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1997	18%	4%	0%	0%	4%	0%	0%	0%	0%	0%	1%
1998	21%	17%	0%	0%	17%	0%	0%	0%	0%	0%	6%
1999	32%	37%	0%	0%	37%	0%	0%	0%	0%	0%	8%
2000	39%	54%	0%	0%	54%	0%	0%	0%	0%	0%	7%
2001	41%	70%	0%	0%	70%	0%	0%	0%	0%	0%	3%
2002	39%	72%	0%	0%	72%	0%	0%	0%	0%	0%	1%
2003	49%	74%	0%	0%	74%	0%	0%	0%	0%	0%	0%
2004	52%	71%	0%	0%	71%	0%	1%	0%	0%	0%	0%
2005	60%	79%	0%	0%	79%	0%	2%	0%	0%	0%	0%
2006	64%	73%	7%	0%	80%	0%	4%	0%	1%	0%	0%
2007	72%	54%	35%	0%	89%	0%	2%	0%	2%	0%	0%
2008	75%	39%	51%	0%	90%	0%	3%	0%	3%	0%	0%
2009	71%	23%	68%	0%	91%	0%	2%	0%	7%	0%	0%
2010	68%	7%	85%	0%	91%	0%	3%	0%	12%	0%	0%
2011	73%	0%	94%	0%	94%	1%	3%	0%	16%	0%	0%
2012	69%	0%	89%	0%	89%	4%	8%	0%	18%	0%	0%
2013	70%	0%	83%	0%	83%	13%	12%	0%	16%	0%	0%
2014	74%	0%	74%	0%	74%	24%	22%	1%	15%	0%	0%
2015	67%	0%	56%	9%	65%	34%	29%	6%	15%	0%	0%
2016	66%	0%	32%	43%	75%	23%	18%	9%	13%	0%	0%
2017	70%	0%	22%	64%	85%	14%	12%	8%	14%	3%	0%

Note: Table shows share of US cotton acreage by GM trait. Due to stacked traits, totals may exceed the share of cotton acreage planted with GM. IR: insect-resistant; HT: herbicide-tolerant. “All RR” is the sum of Roundup Ready, RR Flex and XtendFlex.

Source: OECD analysis using United States Department of Agriculture – Agricultural Marketing Service, “Cotton Varieties Planted”, various years (1995-2017).

4. Theory and evidence on the potential effects of mergers

This chapter reviews theoretical and empirical literature on the potential effect of mergers on prices, innovation, and product choice. In addition to insights from the general economics literature, empirical evidence on the market for seed and GM technology is examined..

Mergers can have negative impacts on consumers through higher prices, a lower rate of innovation, and reduced product choices. However, it is by no means certain that a given merger will have these negative effects, or that the effects will be large. Depending on the circumstances, negative effects may be offset by positive effects through efficiency gains.

This chapter discusses the possible impact of mergers in more detail, using economic theory and empirical evidence. The possible effects on prices are discussed first as this topic has been developed the most in the literature. The effects on innovation and on product choices are then discussed.

4.1. Potential effects on prices

The literature on mergers typically distinguishes between horizontal and non-horizontal mergers.¹ In a horizontal merger, the merging firms are both active in the same market, and the merger therefore increases market concentration. All other types are by definition non-horizontal mergers (also known as conglomerate mergers); typical examples are mergers between firms that have a supplier-customer relation (a vertical merger) or between firms selling complementary products. As Chapter 3 demonstrated, this distinction is relevant in the seed industry as consolidation combines both horizontal and non-horizontal aspects.

Horizontal mergers

Horizontal mergers remove one competitor from the field and create a larger firm which may have more market power. This is known as a *non-coordinated* or *unilateral* effect of a merger.

Non-coordinated effects are more likely when consumers have fewer alternatives, e.g. when the merging firms have large market shares or when other firms in the industry are not supplying close substitutes. The merger itself may also make it less likely that alternatives emerge; for instance, when the merged firm controls important input sources or distribution channels and uses this power to make it more difficult for rivals to compete.² A merger may also eliminate a firm that played an important role in keeping the market competitive, for instance because it was traditionally a price-cutter.

In addition to these non-coordinated effects, a merger can make it easier for the remaining firms in the industry to coordinate their behaviour to raise prices. This is known as a coordinated effect.

In a concentrated industry, firms may (implicitly or explicitly) coordinate to keep prices high, to limit production, and/or to limit capacity expansion. Firms can also try to reduce competition by agreeing to split the market, e.g. by geography or by customer segment. However, such (implicit or explicit) agreements are vulnerable to deviation by one or more firms. If several firms agree to keep prices high, one firm could profit by deviating from the agreement to undercut its rivals. To prevent this, firms could threaten to punish deviations, for instance by starting a price war. Whether an attempt at coordination will succeed depends on how easy it is for firms to monitor each other's behaviour and whether they can credibly threaten to punish deviating firms.

A merger can make successful coordination among firms more likely by making it easier to agree, monitor or punish. First, a merged firm may have a disproportionately high market share in one geography or customer segment. This can make it easier for firms in the industry to implicitly agree to split the market, e.g. because other firms expect that the merged firm would react especially strongly against any intrusions in its "stronghold" market. Second, as the merger reduces the number of firms, it becomes easier to check whether a firm is deviating

from an agreement. Third, a merged firm may be better able to survive a price war, e.g. thanks to lower costs or greater financial resources; this in turn can increase the likelihood that the merged firm can successfully punish a deviant firm through a price war.

Efficiencies

Firms often motivate mergers by pointing to expected efficiency gains from combining their operations, such as lower variable production costs from economies of scale or lower fixed costs by combining legal, marketing and other “overhead” functions.

From a strict social welfare point of view, a merger is welfare-enhancing if total efficiency gains outweigh the total efficiency losses associated with anti-competitive effects. In theory, a merger could therefore increase social welfare while simultaneously hurting customers. In reality, competition authorities typically use customer welfare as relevant benchmark. For this reason, efficiencies are usually only considered as a countervailing factor in a merger analysis if they benefit the customer, if they are merger-specific, and if they are verifiable.

A practical implication of this focus on the customer impact is that reductions in *variable or marginal costs* will be more likely to be counted as a relevant efficiency gain compared with reductions in fixed costs. Lower marginal costs are more likely to be passed on to customers in the form of lower prices and may outweigh the possible tendency to price increases. In contrast, reductions in fixed costs are more likely to be translated into higher profits for the firm, without direct benefits for the customers.³

Non-horizontal mergers

Compared to horizontal mergers, non-horizontal mergers are generally considered a lesser threat to competition. By definition, such mergers do not lead to changes in the level of concentration in the market, while typically offering greater scope for efficiencies. However, this does not mean that non-horizontal mergers are completely risk-free.

Potential efficiency gains

There are several sources of potential efficiency gains with non-horizontal mergers. In the case of a vertical (supplier-customer) merger, the combined firm can avoid costs related to finding suppliers or customers, negotiating contracts, monitoring whether contractual obligations are being fulfilled, etc. In the case of firms selling complementary products targeting the same customers, a merger can lead to cost savings for market research, marketing and advertising, and distribution costs.

For complex complementary products, mergers can facilitate coordination between technical experts by bringing the entire R&D or production process in-house. For instance, developing new herbicides and complementary herbicide-tolerant seeds may require considerable coordination between researchers, and could be facilitated by bringing the teams together in a merged firm.

An additional potential benefit from non-horizontal mergers pertains to resolving spillover problems. For instance, if one firm sells herbicides and another complementary herbicide-tolerant seed, any measure to stimulate the sales of herbicides (e.g. more marketing, lower prices) would also stimulate sales of the complementary seeds. Before a merger, the herbicide firm would not take into account this spillover effect, as it incurred the full costs but did not receive the full benefits of its promotional efforts. A combined firm would receive the full benefits, and hence would have an incentive to invest more in both products.

Foreclosure as a threat to competition

Despite these efficiency effects, non-horizontal mergers could limit competition when the merged firm makes it harder for potential or current competitors to access markets (*customer foreclosure*) or supplies (*input foreclosure*).

In the case of seed markets, customer foreclosure could occur if a plant breeder acquires a large distributor of seeds. The integrated firm could refuse to distribute seed of competing firms, or could make it more difficult to do so by imposing disadvantageous terms and conditions. To restore access to these markets, competing firms would need to incur significant costs, e.g. by setting up their own distribution networks. This raises the costs of rivals and discourages entry into the industry.

Input foreclosure in seed markets could occur if a seed firm acquires a supplier of a widely-used GM trait or technique and subsequently refuses to cross-license this technology to competitors. This would force competitors to invest in developing their own technology, a costly and lengthy process which raises the costs of competitors and discourages entry.

In the specific case of complementary goods, foreclosure can also occur through *bundling* and *tying*. With bundling, products are sold as a package (with or without the option to buy the products separately). With tying, customers buying one good (e.g. herbicide) are required to purchase another good (e.g. herbicide-tolerant seeds) from the same supplier either because of contractual requirements or because products have been designed in such a way that they only work when used together.

Both bundling and tying are common practices that do not necessarily lead to anticompetitive consequences. However, a combined firm with market power in one product (e.g. herbicide) may use bundling or tying to create a strong position in another product (e.g. herbicide-tolerant seeds). In turn, this may discourage entry of potential competitors as they would now be required to invest in both markets.

For all types of foreclosure, the theoretical *possibility* of foreclosure does not necessarily mean it will be in the combined firm's best interest to do so. The merged firm will need to trade off the potential loss of sales in one market (e.g. by refusing to cross-license the technology) with the potential gains in the other market (e.g. the ability to charge higher prices). However, as the European non-horizontal merger guidelines point out, even the likelihood that a merged firm could engage in foreclosure may deter potential entrants.⁴

Removing a potential entrant

A firm which is active in a different but related industry may have the assets, know-how, distribution network, and other necessary resources to potentially enter the market. Even when this firm is not entering the market, the *threat* of entry may be sufficient to act as a restraint on market participants. This situation is known as a “contestable market” (Baumol, 1982^[75]).

Even a highly concentrated market could behave competitively if existing firms take into account the threat of entry by *potential* competitors. A merger with a non-competitor can reduce the contestability of the market by removing this threat. Mergers between competitors can also make entry by other players more difficult by increasing the costs of entry for new firms.

In the context of the seed industry, a “different but related” industry could be interpreted in various ways. For instance, a large agrochemical firm could invest to develop its own breeding programme and GM traits; a seed and biotech firm active in one region could invest

to enter another region; a firm active only in maize seed and traits could invest to develop a product offering in soybean seeds and traits. In each case, the firm is a potential entrant, although the barriers to entry might differ by scenario. As these examples show, both horizontal and non-horizontal mergers could eliminate a potential entrant.

Multimarket contact

Mergers between firms active in different regions or different products could facilitate collusion by increasing the degree of “multimarket contact”. Firms competing across several markets may find it easier to collude, as both the benefits of collusion and the costs of deviating are greater (Bernheim and Whinston, 1990^[76]). A merger between companies A and B which are active in different markets may lead to higher prices by making it easier for the combined firm to collude with a competitor C active in both markets.

In the context of the seed industry, multimarket contact can occur across several dimensions. Firms active in the seed industry can also compete in agrochemicals (or even in non-agricultural products); firms competing in one geography may also face each other as competitors in other geographies; firms competing in the seed market for one crop may also compete in the seed market for other crops.

The scope for multimarket contact is even greater when several mergers are taking place at the same time. A situation of four independent firms split across two markets could be transformed into a situation with two firms competing with each other in both markets. In each market separately, the degree of market concentration may not have changed; but by creating fewer players with multimarket contact, these mergers could facilitate collusion, leading to higher prices for consumers in both markets.

Empirical evidence

Market power versus efficiency effects of mergers

Despite their economic importance, there is surprisingly little recent empirical evidence on the actual effects of mergers – or on the impact of competition policy to prevent negative effects from mergers (Ashenfelter et al. (2009^[77]); Ashenfelter and Hosken (2010^[78]); Carlton (2009^[79])).⁵

A recent contribution is provided by Sheen (2014^[80]). Using data from *Consumer Reports*, an independent magazine evaluating the price and quality of consumer goods, Sheen (2014^[80]) analyses 9 000 products in 20 categories (ranging from interior paint to washing machines) sold by 372 firms between 1980 and 2009. In this large database, 88 mergers are identified and their impact analysed at the level of individual products. Sheen (2014^[80]) finds that after a merger, the quality of products of merging firms converges on their average quality level. However, prices for both the acquiring and the target brand *fall* relative to the competition. This effect is strongest when both companies were active in the same category, and price declines are greater when the merging firms have higher market shares. At the same time, these mergers lead to higher stock market valuations, indicating that lower prices did not come at the expense of profits for the merging firms. The most likely explanation is that merging firms can exploit economies of scale and/or buyer power to lower their variable production costs, and pass part of these savings on to consumers. These results suggest that even in horizontal mergers, efficiency effects may outweigh the incentive to charge higher prices to consumers.⁶

A more recent analysis, however, casts doubt on the existence of efficiency effects after a merger. Blonigen and Pierce (2016^[81]) study productivity and mark-ups (an indicator of market power) using plant-level data of the entire US manufacturing industry from 1997 to 2007, covering 187 000 plants, and look at plant-level effects of mergers and acquisitions. They find little evidence for efficiency gains but rather a strong increase in the market power exerted by firms after the merger.⁷

Kwoka (2015^[82]) reviews 19 studies investigating mergers in various industries. Although comparison of effects from different study contexts is not straightforward, on average these studies seem to show a price increase of 5-6% following a merger, although there is evidence of a reduction in costs of around 8.5%. Effects on efficiency measures appear to vary widely. While most estimated effects appear to be negative, on average the estimated efficiency effect appears to be modestly positive (between 0.3% and 2.2% depending on how results are aggregated). The studies for which cost and efficiency measures are reported, however, mostly focus on one sector (US hospitals).

Either way, efficiency effects that can offset price increases would more likely occur in some industries than in others. For many manufactured goods (such as those covered by Sheen (2014^[80])), variable production costs represent a considerable share of the total cost. Economic theory predicts that a firm with market power will pass on part of the reduction in marginal costs to consumers in the form of lower prices. It is not clear that similar effects would hold in industries where variable costs represent only a minor part of the total cost such as software, telecommunications, or pharmaceuticals. These sectors are characterised by large up-front investments (e.g. in R&D or infrastructure), but variable production costs are typically low (or even practically zero, as in the case of software).

Multimarket contact

Empirical research has demonstrated that multimarket contact is indeed associated with higher prices. Such effects have been found for a wide range of industries, including movie theatres (Feinberg, 2014^[83]), cement (Jans and Rosenbaum, 1997^[84]), hotels (Fernández and Marín, 2003^[85]), and airlines (Ciliberto and Williams, 2014^[86]). In addition to finding evidence that multimarket contact increases prices, there is direct evidence from the airline industry showing that mergers can lead to higher prices by increasing multimarket contact (Singal (1996^[87]), Bilotkach (2011^[88])). In contrast, Waldfogel and Wulf (2006^[89]) found no effect of increased multimarket competition in the radio broadcast industry on advertising prices.

Merger policy

An important limitation of analyses such as those by Sheen (2014^[80]) is that any post-merger analysis can only look at mergers that have been *approved* by competition authorities. It is possible that all mergers which would have led to higher prices were blocked by the authorities, so that only mergers with considerable efficiency effects were allowed to proceed. In other words, the results showing modest or no harmful price effects after mergers could indicate that competition authorities correctly identified and prohibited all potentially harmful mergers. The question is what the price effect would have been of mergers which were *not* allowed to go through – and hence, whether merger policy is effective in blocking harmful mergers.

Ashenfelter and Hosken (2010^[78]) shed some light on this by investigating the price effects of five mergers “on the enforcement margin” – i.e. mergers which *ex ante* seemed potentially anti-competitive but were nevertheless allowed to proceed by the US competition authorities.

Ashenfelter and Hosken (2010^[78]) compare price evolutions of brands of the merging firms with price evolutions of private-label brands and competitor brands, and conclude that prices increased by 3% to 7%.⁸ Given the methodology used, these effects should be considered an upper bound on price effects for mergers that were permitted, and a lower bound for mergers that were blocked. As the authors note, this result suggests that merger enforcement, to a first approximation, is not overly strict or overly lax.

A related question is whether merger policy achieves its objectives, in particular where remedies are used. The term “remedies” refers to measures used by competition agencies to resolve and prevent harm to the competitive process that may result from a merger (OECD, 2011^[90]). Typically, a distinction is made between structural and behavioural remedies. A structural remedy requires the divestiture of an asset, while a behavioural remedy imposes an obligation to engage in, or refrain from, a certain conduct. The sale of a part of the business or the transfer or licensing of intellectual property rights are considered structural remedies. Examples of behavioural remedies include non-discrimination obligations, transparency provisions, or limitations on what firms may include in contracts with customers.

The strictness and effectiveness of merger policy in the United States has been examined by Kwoka (2015^[82]). Highlighting the relative scarcity of empirical research on the impact of merger policy, Kwoka (2015^[82]) constructs a dataset of 47 studies on the effects of individual mergers, as well as a dataset of 19 studies investigating groups of mergers. Some results from this meta-analysis were discussed earlier.⁹ In addition, Kwoka (2015^[82]) analyses trends in behaviour of US competition agencies using publicly available data. This leads to three main conclusions.

First, merger policy in the United States is relatively lenient and has become increasingly so over time. Only a small fraction of mergers are investigated, and an even smaller fraction is challenged. Competition agencies are also more lenient than the Horizontal Merger Guidelines would suggest, except at very high levels of market concentration.

Second, mergers typically lead to price increases. In the dataset assessing individual mergers, around 80% of mergers resulted in price increases after controlling for other factors; 31% of mergers resulted in price increases exceeding 10%.

Third, and perhaps most surprising, Kwoka (2015^[82]) finds that enforcement actions of competition authorities do not appear to have much impact in preventing negative effects of mergers. For all cases where the agencies challenged mergers, prices nevertheless increased on average by 7.7%. Cases where a divestiture was required saw price increases of 6% on average, while conduct remedies were associated with price increases of 13%.

Some of these findings have been challenged. Vita and Osinski (2016^[91]), two researchers at the Federal Trade Commission, have highlighted what they see as methodological shortcomings in this analysis, in particular the small number of observations on which the analysis of divestitures and (especially) conduct remedies is based. Moreover, as Kwoka (2015^[82]) himself indicates, it is possible that prices would have increased even more in the cases where divestitures and conduct remedies were applied. Nonetheless, given the high standards of empirical rigour imposed by Kwoka (2015^[82]) in selecting the studies for his meta-analysis, these results do suggest that remedies often fail to protect or restore competitive conditions.

In the European Union, the Directorate-General for Competition (DG Competition, 2005^[92]) has reviewed 96 remedies imposed between 1996 and 2000 using a combination of case files and interviews. More than 85% of the remedies studied involved a divestiture or a similar

measure. Overall, the report concluded that 81% of the divestitures were fully or partially effective, while 7% were ineffective and 12% unclear.

A very different empirical approach was used by Duso et al. (2011^[93]). To isolate the impact of merger remedies, they compare how the stock market reacts to initial announcements of mergers with how the stock market reacts when the European Commission makes its final decision on the merger and the required remedies. To be able to separate efficiency effects from anticompetitive (market power) effects, Duso et al. (2011^[93]) look also at how share prices of competitors of the merging firms react. If a merger is expected to lead to higher prices through market power, this is likely to increase the scope for competitors to also raise prices. Conversely, if a merger would lead to efficiency gains but no market power effects, the merged firm could reduce prices and put pressure on the profits of competitors. Hence, the behaviour of the share price of competitors can be used as an indication of whether a merger is pro- or anti-competitive.

After correcting for the market's expectation of the EU decision, Duso et al. (2011^[93]) find that remedies are only partially effective, as they do not fully remove anti-competitive rents. However, remedies appear to be more effective when applied to an industry with which the European Commission has experience. Overall, Duso et al. (2011^[93]) conclude that remedies might be a good policy tool when the anti-competitive concerns of a merger are not too serious, but that outright prohibitions may be the only way to restore effective competition for complex mergers with serious risks to competition.

Evidence on seed markets

For the United States, several studies have explored the determinants of prices of seed (in particular GM seed) and the link with market concentration. Particularly important in this regard are a number of studies by Guanming Shi, Jean-Paul Chavas and Kyle Stiegert on soybeans (Shi, Chavas and Stiegert, 2009^[94]), maize (Shi, Chavas and Stiegert, 2010^[95]), and cotton (Shi, Stiegert and Chavas, 2011^[96]).

The results across these three crops are similar. First, there is evidence that a higher degree of market concentration contributes to higher seed prices. For instance, moving from a hypothetical market with perfect competition to a monopoly would increase conventional maize seed prices by USD 15 per bag. (As a comparison point, the average price of conventional maize seed in 2007 was USD 94 per bag.)

There is also evidence of cross-market effects. For example, a higher degree of market concentration for maize seeds with traits protecting against European corn borer appears to reduce the price of maize seeds with traits protecting against root worm, and vice versa. This is perhaps due to complementarity effects on the supply side. For some other combinations, however, the cross-market effect is to increase prices even further. This may be the case when two products are substitutes.

Third, seeds with stacked GM traits are typically cheaper than would be expected based on the prices of the single-trait seeds (a finding consistent with the data in Figure 2.14). GM seed is sold at higher prices than conventional seed, reflecting a price premium charged for GM traits. When looking at prices of stacked seeds (with two or more GM traits), however, this price premium appears to be consistently less than the sum of the price premiums of the same traits in single-trait seeds. This may reflect economies of scope on the supply or demand side. The difference is considerable. For example, the price premium for the trait protecting against European corn borer was around USD 26 per bag in a single-trait maize seed, while that for root worm was USD 46 per bag, or a combined premium of around USD 72 per bag.

Maize seed with both traits would sell only for a premium of around USD 61 per bag, or 16% less than would be implied by simple additive pricing.

In short, these studies confirm the theoretical expectations that higher market concentration appears linked to higher prices, although efficiency effects may mitigate this effect to varying extents.

Regarding the likely effects of the recent mergers, the only published simulation of price effects is the analysis by Bryant et al. (2016^[97]) for the US maize, soybean and cotton seed markets (also see the non-technical summary in Maisashvili et al. (2016^[98])). Bryant et al. (2016^[97]) adapt a methodology developed by Hausman et al. (1994^[99]), Hausman and Leonard (1996^[100]) and Hausman (2010^[101]), which combines data on market shares, own-price elasticities and cross-price elasticities to simulate post-merger prices. Bryant et al. (2016^[97]) report the following market shares for US seed markets:

Table 4.1. Seed market shares in the United States, 2014-15

	Maize	Soybeans	Cotton
Monsanto	35.5%	28.0%	31.2%
DuPont Pioneer	34.5%	33.2%	0.0%
Dow	6.0%	5.2%	15.3%
Syngenta	5.7%	9.8%	0.0%
Bayer	0.0%	0.0%	38.5%
Americot	0.0%	0.0%	6.4%
AgReliant	7.0%	3.1%	0.0%
Public saved	0.0%	2.4%	0.0%
Others	11.3%	18.3%	8.6%
Total	100.0%	100.0%	100.0%

Note: Data for maize and soybeans refers to 2014; data for cotton refers to upland cotton for 2015.

Source: Bryant et al. (2016^[97])

In the years considered in their study, Bayer was not active in maize and soybean markets, whereas DuPont Pioneer was not active in cotton markets. Hence, the relevant analyses conducted by Bryant et al. (2016^[97]) look at the expected impact of the DowDuPont merger in maize and soybean markets, and the expected impact of the Bayer-Monsanto merger in cotton. The methodology used by Bryant et al. (2016^[97]) allows to predict the price changes for each market player separately. In addition, Bryant et al. (2016^[97]) construct a market-share weighted expected price increase representing the overall change in prices.

The simulations predict that Dow would increase its prices for maize seed by 6.3% and for soybean seed by 5.8%, while DuPont Pioneer would increase its prices by 1.3% for soybean seed and 1.6% for maize seed. Overall, the expected price increase for the maize seed market as a whole would be around 2.3%, and for the soybean seed market around 1.9%.

The strongest simulated effects are for the cotton seed market, where prices were expected to increase by around 18% on average. The Bayer-Monsanto merger (using 2015 data and assuming no divestitures) would have brought together the two leading firms in the US cotton market, with a combined market share of around 70%. (Bayer sold its US cotton seed business to BASF to obtain regulatory approval of its acquisition of Monsanto).

Merger simulations have their limitations, and these apply to the analysis by Bryant et al. (2016^[97]).¹⁰ The analysis is done at a high level of aggregation (the United States as a single market), assumes that only the merging firms will increase their prices, and assumes that

other factors (e.g. product choice or innovation) remain unchanged.¹¹ Overall, the analysis suggests that price increases will be greater where combined market shares are higher, and that the biggest price increase will occur for the firm with the smaller initial market share. This could be used as a rule of thumb in other markets.

4.2. Potential effects on innovation

Traditionally, the evaluation of mergers has been mostly concerned with the potential impact on prices. In recent years, however, competition authorities have increasingly focused on the potential harmful effects on innovation. For instance, in 2016 the US Department of Justice sought to block Monsanto's proposed sale of Precision Planting LLC, a firm producing high-speed planting machines, to the farm equipment manufacturer John Deere (as discussed in Section 3.3). John Deere was the only other producer of such equipment, and the Department of Justice argued that it was the intense rivalry between the two firms which had led to the rapid introduction of innovative new features (MacDonald, 2017_[102]).

However, the link between (a lack of) competition and innovation is not straightforward. Reviewing theoretical and empirical research, Aghion and Griffith (2005_[103]) argue for an inverted U-shaped relationship, where both very low and very high levels of competition discourage innovation (see Aghion et al. (2005_[104]), Hashmi (2013_[105])). Where there is little competition, firms face no pressure to invest in innovation as there is no threat to their profits. But in a highly competitive market, profits from a successful innovation are competed away quickly, thus making it hard to recover the investments in R&D.

A drawback of the “inverted U” literature is that it focuses on the overall degree of competition in a market, but says little about the effects of specific mergers. Focusing on antitrust policy, Shapiro (2012_[106]) reviews the literature on competition and innovation and sets forth three principles on innovation:

- *The contestability principle*: Innovation is stimulated if a firm has the prospect of gaining, or protecting, profitable sales by providing greater value to customers
- *The appropriability principle*: Innovation is stimulated if a firm can appropriate a greater share of the social benefits resulting from its innovation
- *The synergy principle*: Innovation is stimulated if firms can combine complementary assets, leading to greater innovation capabilities

While the contestability and appropriability principles relate to firms' incentives, the synergy principle relates to firms' ability to innovate. A fourth principle, which is implicit in Shapiro (2012_[106]) but worth making explicit, can be added:

- *The parallel paths principle*: All else equal, having multiple firms seeking to innovate in the same domain increases the likelihood of discovery and introduction of new processes and products.

These principles are discussed in turn.

Contestability

As Shapiro (2012_[106]) points out, the contestability principle operates if a successful innovator can expect to win profitable sales from competitors. Contestability is undermined to the extent that market shares are “sticky,” for instance because of brand loyalty among consumers or high switching costs. In such a context, firms' incentives to innovate are reduced, as innovation would not lure away consumers from competing firms.

Similarly, an innovative product developed by a firm with a large market share may negatively affect the sales of its existing products rather than winning market share from competitors, an effect known as “cannibalisation.” This effect will be more prominent as the firm’s initial market share is greater. Again, this would mean a successful innovator could not expect to win profitable sales from competitors. If two firms merge, they would have more to lose from such cannibalisation effects and the incentive to innovate could be reduced.

The threat that a potential competitor might enter the market, however, can induce the incumbent to invest in innovation to protect its market share.¹² To the extent that smaller firms could challenge the incumbent through innovation, the market is contestable and the incumbent will have an incentive to continue investing in innovation. Hence, a high market share by itself says little about incentives to innovate; rather, the contestability of the market is what drives innovation.¹³ Conversely, a small market share is consistent with strong incentives to innovate as long as there is a reasonable chance of capturing a large amount of profitable sales in the future.

Appropriability

Contestability is necessary, but not sufficient to ensure that a firm benefits from its innovative activities. If competing firms can freely and quickly imitate a new process or product, the innovating firm will not be able to enjoy its competitive advantage for long. Appropriability is therefore clearly linked to intellectual property rights, but imitation is not the only way in which the benefits of innovation can be dissipated. If innovation increases the demand for a complementary product, part of the benefit of innovation will spill over to producers of the complementary product. Such spillovers also reduce the appropriability of innovation. From a market structure point of view, appropriability can be increased if suppliers of complementary products merge. Such a merger could therefore increase innovation.¹⁴

Synergy

The synergy principle draws attention to the fact that innovation does not occur in a vacuum. Merging firms with complementary assets can increase innovation capabilities, for instance by improving coordination between R&D teams working on complementary products. However, as Shapiro (2012_[106]) points out, “merger synergies are far easier to claim than to achieve.”

In the case of the seed industry, R&D synergies could arise from closer collaboration between teams working on plant breeding, traits, and crop protection chemicals. For instance, it may be easier to develop GM seed with stacked traits if more of these traits are developed within the same firm, as firms may be reluctant to share sensitive data with competitors. As another example, the development of crop protection chemicals requires a good understanding of local agronomic conditions. This expertise might in turn help plant breeders and geneticists in their R&D efforts.

Parallel paths

As the parallel paths principle indicates, all else equal, it is useful to have firms working in parallel on innovations. Parallel paths increase the likelihood that at least one firm will make a useful discovery. Although in theory firms can pursue multiple approaches in parallel in-house, this may prove difficult in practice due to organisational obstacles (Shapiro, 2012_[106]). Moreover, if a firm is developing different approaches in-house, the firm will still have an incentive to release only one product innovation at a time.

Comanor and Scherer (2013^[107]), studying the pharmaceutical industry, argue that firms underinvest in parallel R&D approaches, and that mergers often lead to shutting down “duplicative” R&D efforts. They provide evidence from pharmaceutical trials in the United States indicating that companies typically only have one molecule in trial for a disease. Comanor and Scherer (2013^[107]) argue this may indicate that companies fail to appreciate the value of parallel R&D approaches, viewing these as wasteful duplication. One implication of this argument is that technological progress is maximised when there are multiple firms in an industry pursuing R&D.

Empirical evidence

General literature

The empirical literature on the effect of mergers on R&D has tended to produce mixed evidence (Cassiman et al., 2005^[108]). One explanation is that earlier studies did not always distinguish between different characteristics of merging firms. Recent research, which does make this distinction, has tended to find clearer results.

Cassiman et al. (2005^[108]) use an in-depth analysis of 31 mergers and acquisitions to explore the impact of firms’ technological and market relatedness. They find that where firms have complementary technologies, their R&D efforts and efficiency increase after the merger. However, where merging firms’ technologies are substitutes, there is a decrease of R&D efforts after the merger. The reduction in R&D for “substitute” firms is especially pronounced if the firms were direct rivals before the merger. The reduction in R&D occurs through various channels, including greater turnover of key employees, a more focused R&D portfolio, a shorter R&D horizon, and less internal funds provided for R&D.

Bena and Li (2014^[109]) emphasise that innovation is a key motivation for mergers and acquisitions as the firms involved in mergers and acquisitions are disproportionately more likely to be involved in innovation. For instance, in their sample of public mergers in the United States between 1984 and 2006, almost two-thirds of firms were engaged in patenting activities. In contrast, when looking at all firms (merging and non-merging), only 30% report R&D expenses and less than 10% regularly delivered patentable output. Bena and Li (2014^[109]) show that the likelihood of a merger is higher if firms have “technological overlap.” By comparing successful mergers with a control group of firms where an acquisition bid was withdrawn, Bena and Li (2014^[109]) also demonstrate the effect of mergers on innovation. In particular, for mergers where there was a technological overlap prior to the merger, there is an increase in the combined firms’ post-merger innovation output. This result shows that where technological complementarities are driving a merger, the impact on innovation is expected to be positive.

These results confirm the principles regarding mergers and innovation proposed earlier and based on Shapiro (2012^[106]). When merging firms have substitutive technologies, the tendency is to cut costs by reducing redundant efforts – hence closing down parallel paths. This effect is especially pronounced if firms were product market rivals, as the merger also removes an incentive to innovate (cfr. the contestability principle). When the technologies of merging firms are complementary, the synergy effect and the appropriability effect dominate and lead to improvements of R&D efforts and outcomes.

The pharmaceutical industry

Further insights on the effect of mergers on innovation are found by looking at the experience of the pharmaceutical industry. Similar to the seeds and biotech industry, the pharmaceutical

industry is highly R&D intensive and has experienced merger waves. In an essay in *Nature Reviews: Drug Discovery*, John L. LaMattina, the former head of Pfizer's global R&D organisation, has argued in an essay in *Nature Reviews: Drug Discovery* that these mergers are an important driver behind a fall in innovative activity (LaMattina, 2011_[110]). He argued this was not always the case; the 1989 merger between Bristol Myers and Squibb did not lead to major R&D cuts. However, during Pfizer's acquisitions in the early 2000s, it closed numerous research sites, including those where major discoveries had been made. LaMattina (2011_[110]) also points out that before Pfizer's merger with Wyeth in 2009, the two firms had a combined R&D budget of USD 11 billion, whereas the firm post-merger had the goal to reduce the R&D budget to USD 6.5-7 billion. LaMattina (2011_[110]) concludes that in pharmaceuticals, "industry consolidation has resulted in less competition and less investment in R&D."

The negative effects of mergers on R&D in the pharmaceutical industry were confirmed empirically by Omaghi (2009_[111]). Using a dataset covering the universe of large pharmaceutical firms between 1988 and 2004, Omaghi (2009_[111]) found that merged firms spend less on R&D and file fewer patent applications than a control group of comparable firms.¹⁵ Omaghi (2009_[111]) also attempted to estimate the role of product-market relatedness and technological similarity, although the dataset did not allow for a proper distinction between substitutes and complements.

The seed and biotech industry

There is relatively little literature on the specific impact of market concentration on innovation in the seed industry. An exception is Schimmelpfennig et al. (2004_[112]), who focus on maize, cotton and soybeans in the United States and report an inverse relationship between firm concentration and R&D intensity. While an important contribution to the literature, there are several methodological aspects of the study which raise doubts around the validity of its findings.

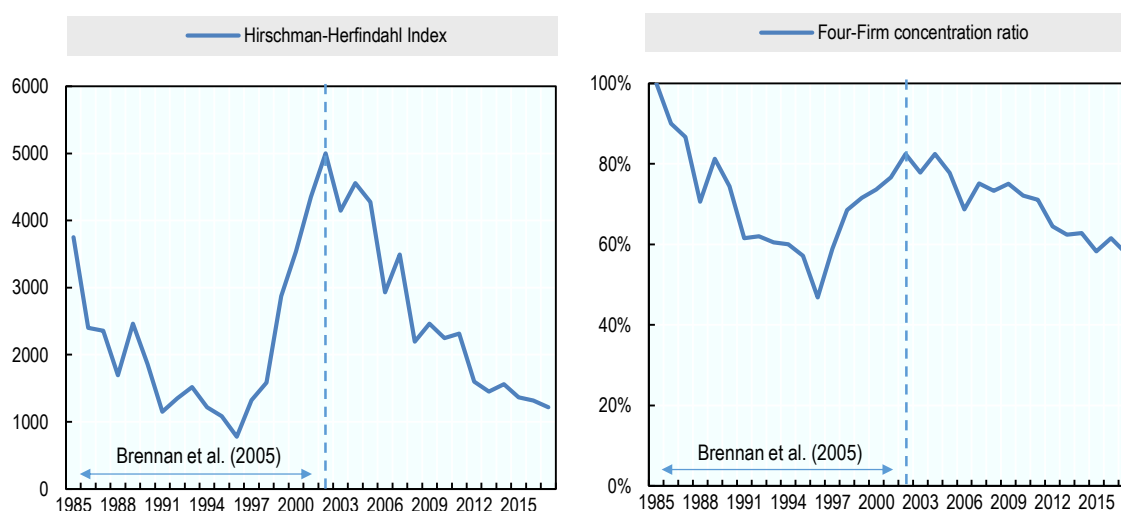
The structural approach used by the authors to estimate the effect of concentration on R&D intensity assumes all firms are symmetric and hence have equal market shares. The authors' measure of market concentration is therefore defined as $(1/n)$ where n is the number of firms conducting field trials, regardless of their actual market shares. The R&D intensity is measured as the number of registered biotech field trials divided by a measure of market size. While the authors find a negative correlation, the interpretation of this result is problematic. During most of the period under study (1989-1998), the number of firms conducting field trials increased strongly. At the same time, the number of field trials increased as well. Hence, the negative correlation between market concentration and R&D intensity is most likely picking up the simultaneous *increase* in the number of firms conducting trials and the total number of trials in the early 1990s. This study therefore does not lend strong support to the view that market concentration in the US seed and biotech industry negatively affects innovation.

A related paper by Brennan et al. (2005_[113]) looks at market concentration in US field trials for biotechnology as an indicator of competition in the "innovation market." They calculate a Hirschman-Herfindahl Index (HHI) of the "market shares" of different firms in the total number of field trials, which can be seen as a proxy for crop-specific R&D effort.¹⁶ Between 1988 and 1996, there was a downward trend in the HHI. However, the concentration in field trials grows strongly after that date, increasing from less than 1 500 in 1996 to about 5 000 in 2002. The increase is driven in large part by Monsanto. In 1996, it was responsible for less than 30% of field trials, but by 2002, Monsanto conducted 70% of all field trials. Brennan

et al. (2005_[113]) show that a similar pattern is found when looking at ownership of agricultural biotechnology patents. Furthermore, “market shares” in patents appear robust over time. The authors conclude there is a risk of high concentration negatively affecting innovation.

An updated version of the “field trial” analysis by Brennan et al. (2005_[113]) is found in Figure 4.1, showing the HHI and the four-firm concentration ratio for approved field trials in US biotech. There was indeed a strong increase in concentration in the late 1990s. However, it appears that this trend reversed around 2002-2004. The HHI, which had increased to a high level of 5 000 points in 2002, fell to levels comparable to those seen in the early 1990s. Similarly, the four-firm concentration ratio fell from 80% back to around 62% in recent years. Based on these data, it could be argued that Brennan et al. (2005_[113]) captured what seems to have been a temporary event.

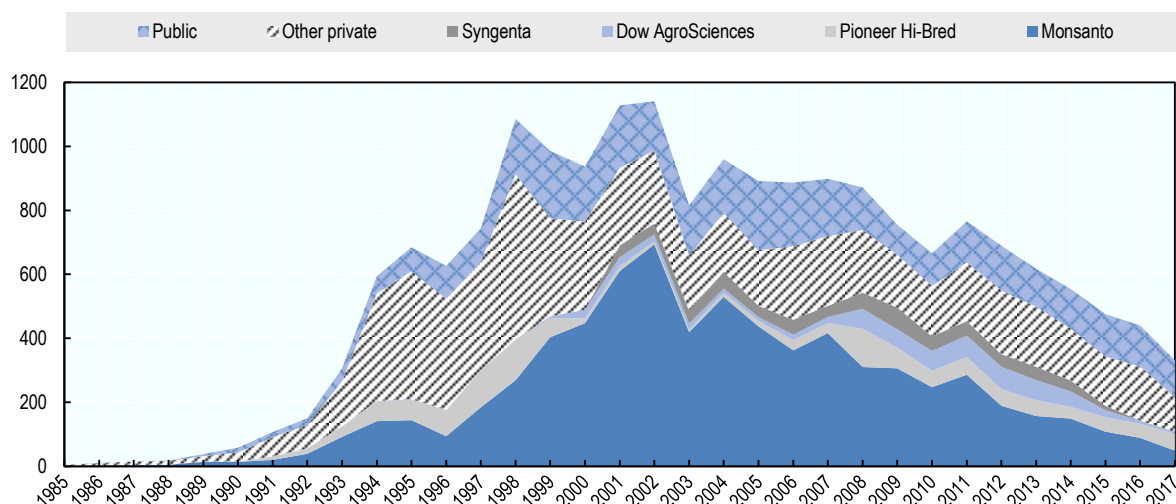
Figure 4.1. Concentration in US field trials for biotech, 1985-2017



Note: Data up-to-date to 4 December 2017. Scope includes all applications for permits and all notifications regarding “Release” (including e.g. combinations of Release & Import, Release & Interstate) which have been approved or accepted (for permits) or acknowledged (for notifications), and which were submitted by a private firm (defined as any entity which is not a university or a US government agency). Year is defined by the date the application was received.

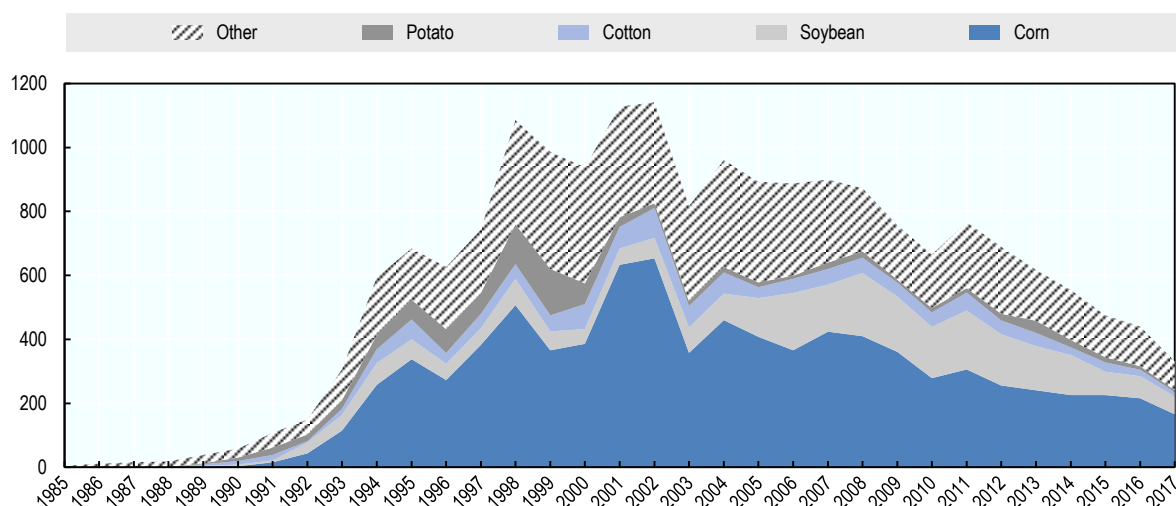
Source: United States Department of Agriculture, APHIS BRS data file.

Underlying these numbers is a major structural change (Figure 4.2). Between the early 1990s and the early 2000s, Monsanto strongly increased its field trials until it accounted for more than half of all field trials. After 2002, however, Monsanto’s annual number of field trials fell significantly, accounting for nearly all of the decrease in field trials during this period. Excluding Monsanto, there is no clear downward trend in the number of field trials in the post-2002 period. The results are nearly identical if applications rather than approvals are used.¹⁷ In other words, both the increase and decrease in concentration of field trials (whether measured with the HHI or the four-firm concentration ratio) reflect the impact of Monsanto. Figure 4.3 shows the same data expressed per crop. The rise and fall of field trials is largely explained by variations in field trials for maize. Over the entire period, field trials for maize accounted for about 45% of all field trials, followed by soybeans (13%). The peak in soybean field trials (around 2008) appears to occur a few years later than the peak for maize (around 2002).

Figure 4.2. Number of approved US biotech field trials per firm, 1985-2017

Note: Data up-to-date to 4 December 2017. Scope includes all applications for permits and all notifications regarding “Release” (including e.g. combinations of Release & Import, Release & Interstate) which have been approved or accepted (for permits) or acknowledged (for notifications). “Public” includes universities and US government agencies. Year is defined by the date the application was received.

Source: United States Department of Agriculture, APHIS BRS data file.

Figure 4.3. Number of approved US biotech field trials per crop, 1985-2017

Note: Data up-to-date to 4 December 2017. Scope includes all applications for permits and all notifications regarding “Release” (including, for example, combinations of Release & Import, Release & Interstate) which have been approved or accepted (for permits) or acknowledged (for notifications). Year is defined by the date the application was received.

Source: United States Department of Agriculture, APHIS BRS data file.

It is not clear what explains the large variation over time in field trials, although it has been suggested that the overall decrease in field trial applications may reflect maturity of the “first generation” of GM and a slow introduction of subsequent generations of GM crops (Anderson and Sheldon, 2017^[55]). At any rate, it is clear that the increase and decrease in measured concentration in field trials directly correspond to the increase and decrease in field trials by Monsanto. Looking at overall market averages, this “composition effect” would give the misleading impression that high concentration is associated with a higher rate of innovation. More generally, these findings mean that caution is needed when calculating and interpreting concentration measures based on field trial data.

Oehmke and Naseem (2016^[69]) studied mergers, market structure and innovation in the US seeds and biotech industry using the same field trials data described here. They look at field trials for tomatoes, cotton, maize, soybeans, and potatoes over the period 1987-2012. The results show that the total number of organisations conducting field trials has a positive and statistically significant effect on the number of field trials conducted per year. Moreover, the number of public sector organisations conducting trials appears to have a positive impact. However, the same is true for the four-firm concentration ratio of field trials. Hence, both the number of firms and the concentration of field trials among a small number of firms appear to contribute to a larger number of field trials overall.

The four-firm concentration ratios used by Oehmke and Naseem (2016^[69]) are not based on market shares but on the number of field trials per firm. At the same time, Oehmke and Naseem (2016^[69]) use the total number of field trials as their dependent variable. As the previous analysis shows, this can lead to misleading conclusions. If one firm ramps up its R&D efforts faster than others (as Monsanto did in the late 1990s) this increases the total number of field trials, but may also lead to a higher concentration ratio. Conversely, when a single firm with a large number of field trials winds down its programmes faster than others, this gives the impression of a reduction in concentration coinciding with a decline in innovation. An ideal setup would measure how a high degree of concentration in actual market shares (defined by sales) affects subsequent innovation. Hence, it is difficult to assign a clear interpretation to this finding.¹⁸

As noted by Chan (2011^[114]), studies relying exclusively on field trials ignore innovation taking place in conventional breeding. Chan (2011^[114]) looks at the number of new varieties (as measured by patents or plant variety protection certificates) introduced by a sample of 115 firms in the United States between 1976 and 1999. Firms with larger patent portfolios create greater numbers of new varieties, but there is no evidence of economies of scale; in fact, firms appear to experience diminishing returns. Firms that have merged do not appear to produce a significantly greater number of new varieties, nor do they experience greater economies of scale in comparison with firms that did not merge. Chan (2011^[114]) concludes that these results do not support the argument that firms should be allowed to merge to increase efficiencies in innovation. On the other hand, neither do the results imply that mergers would negatively affect innovation. In fact, there appears to be evidence that a more monopolistic structure (as measured by concentration of patents) has a positive effect on rival firms’ innovation.

In summary, the empirical literature broadly confirms the principles identified by Shapiro (2012^[106]), including the “parallel paths” principle. In contrast, there appears to be little evidence so far of a negative link between market concentration and innovation in the seeds and biotechnology industry, based on historical data.¹⁹ This does not imply that the current merger wave poses no risks to innovation, however.

Implications for merger policy

A merger may simultaneously impact all the principles in contradictory directions. For instance, a horizontal merger between rivals may reduce the contestability (by removing a competitor), increase the appropriability (by reducing spillovers), and potentially lead to innovation synergies – while also closing off parallel paths. Shapiro (2012_[106]) suggests that a horizontal merger with possible innovation effects should be evaluated according to the following questions:

- Will a merger between two rivals significantly reduce their *incentive* to innovate (by reducing contestability and/or appropriability)?
- If so, is there an offsetting effect through an enhanced *ability* to innovate (through synergies)?

A similar approach has been proposed by Gilbert and Sunshine (1995_[115]) and is known as an “innovation markets” approach.

As Shapiro (2012_[106]) notes, if a horizontal merger leads to a highly concentrated market, antitrust law uses a “rebuttable presumption of harm” – that is, the merger is assumed to be harmful unless demonstrated otherwise. Although Shapiro (2012_[106]) does not mention explicitly whether this principle should also apply to the specific question of innovation, the parallel paths principle could be interpreted as justifying such an approach.

4.3. Potential effects on product choice

With a horizontal merger, two firms are potentially offering products to the same set of customers. The newly merged firm may decide to reduce its product offering. This section briefly reviews the literature on such possible effects.²⁰ In the case of the seed industry, some observers fear that reducing product choice may have negative ecological effects by diminishing genetic diversity (Mammana, 2014_[66]). This topic is also briefly discussed.

Economic effects

Only a handful of papers have studied the question of how mergers affect product choice.²¹ The conclusion of both theoretical and empirical work is that the effects are ambiguous and context-dependent.

Berry and Waldfogel (2001_[116]) studied the effect of mergers on product choice in the US radio broadcasting sector. In theory, this effect is ambiguous. If post-merger, two radio stations with the same owner are similar, the owner could shut down one of the stations to save costs and avoid competition between the two stations (“cannibalisation”). Alternatively, the owner could reposition one of the two radio stations to increase the differentiation and attract a different audience. A third possibility is that the owner differentiates his two radio stations, but not too much in order to avoid opening up a niche for competitors to enter.²² Empirically, Berry and Waldfogel (2001_[116]) find that consolidation reduced the number of stations, but the stations themselves became more diverse. The combined effect was for consolidation of ownership to increase product choice.

Theoretical work by Gandhi et al. (2008_[117]) confirms that firms may indeed have an incentive to change the positioning of products post-merger to reduce the problem of cannibalisation. However, as Gandhi et al. (2008_[117]) point out, product repositioning may in reality be expensive and time-consuming, thus preventing or reducing the repositioning effect. Given the long time lags involved in developing new varieties and/or new traits, any “repositioning” in the seed industry is likely to take at least several years. It therefore seems

possible that post-merger, a firm with two similar breeding programmes will decide to discontinue one of the breeding programmes. Over time, this would lead to fewer varieties for farmers to choose from, as well as a slower rate of innovation.

Ultimately, whether firms decide to shut down a “duplicate” offering will depend on the specific circumstances. Such an outcome is more likely if the initial products are similar, if the cost of “differentiating” the two products is high, if there is limited scope to differentiate in a meaningful way, and if there is little reason to believe that competitors will introduce a new offering in the segment.

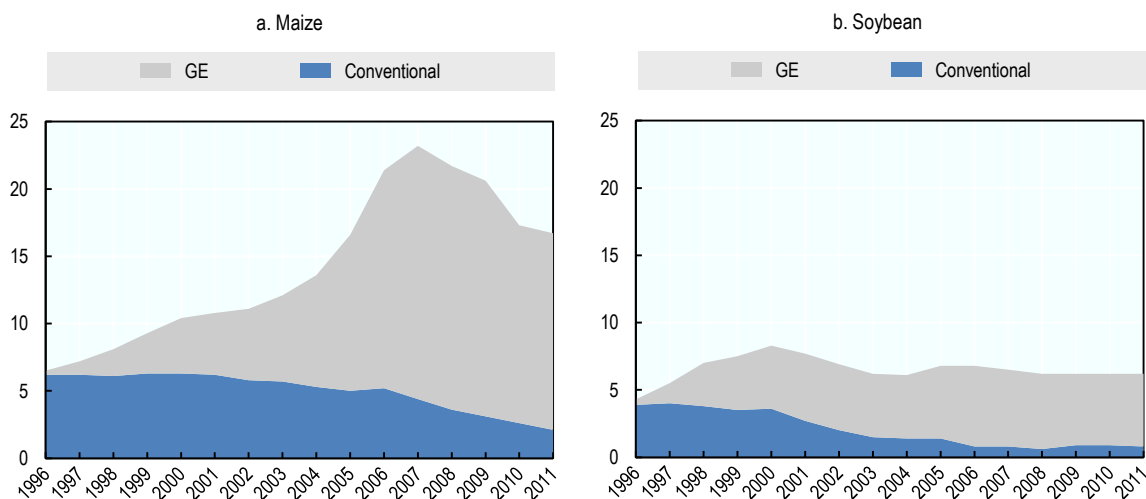
Empirical evidence on seed markets

Only a handful of studies have investigated the issue of product choice in seed markets, and all of these focus on the US market. Schenkelaars et al. (2011^[29]) point out that between 1997 and 2008 the number of maize hybrids available in the US market increased from around 3 000 to 4 300, while the number of soybean varieties almost doubled from 650 to 1 130. Over the same period, the total acreage devoted to these crops remained roughly the same, nor did the number of firms active in the seed market increase. Hence, the greater number of varieties seemed to be driven by more rapid product introductions by seed firms.

Data on the average number of varieties available per crop reporting district (CRD) in the United States are provided by Ciliberto et al. (2017^[24]) (Figure 4.4). These data confirm the argument of Schenkelaars et al. (2011^[29]). For both maize and soybeans, the number of conventional varieties started to decline after 1996 as more farmers adopted genetically modified varieties. Data shows a strong growth in the number of GM varieties. The total number of varieties available temporarily increased in both markets due to the co-existence of conventional and GM varieties, before reaching a peak and then stabilising at a level higher than in 1996. For maize, there were 16.7 varieties available in 2011 compared with 6.5 in 1996 (i.e. 2.6 times as many), while for soybeans there were 6.2 varieties available in 2011 versus 4.3 in 1996 (i.e. 1.4 times as many).

Magnier et al. (2010^[118]) provide an empirical analysis of product life cycles in the US maize seed market. In 1998, a new variety introduced on the market remained available for an average of 4-5 years. This expected lifetime declined gradually between 1998 and 2003, and then more strongly between 2004 and 2007 (a period which corresponds to the strong increase in the number of varieties in Figure 4.4). Varieties introduced in 2007, for example, could only expect to remain on the market for 2.5–3.5 years on average. This decline affected both conventional and GM varieties. These trends suggest intensifying competition between 2004 and 2007, although the decline in the number of maize varieties since then may imply at least a partial reversal. Building on these results, Ma and Shi (2013^[119]) incorporated information on market conditions into the analysis. They found that between 2000 and 2007, products from a firm with a larger market share had a longer expected lifetime. Similarly, integrated firms (i.e. firms combining germplasm and traits) performed better, potentially because they had access to higher-quality germplasm.

As few studies have looked into the matter of product choice in seed markets, it is difficult to generalise from these findings to other geographies, other crops, or other time periods. However, the ongoing consolidation of the US maize seed industry in the 1990s and 2000s does not appear to have reduced the number of product varieties or the speed of new product introductions. However, the studies reviewed here only include data until 2007 (for the product life cycle studies) or 2011 (for the number of varieties in Figure 4.4). It is possible that product choice and dynamism may have deteriorated in recent years, or could do so after a merger.

Figure 4.4. Number of maize and soybean varieties in the United States, 1996-2011

Note: Charts show the average number of seed products per crop reporting district (CRD). A CRD is a region identified by the United States Department of Agriculture's National Agricultural Statistical Service, with relatively homogeneous agronomic and climatic conditions. On average, the dataset used here contains 242 CRDs per year (Ciliberto, Moschini and Perry, 2017^[24]).

Source: Ciliberto et al. (2017^[24]), using GfK Kynetec data.

Effects on genetic diversity

Maintaining genetic diversity is important both as an input into plant breeding (to ensure sufficient variation to select from) and as an output (to ensure a resilient ecology). Genetic homogeneity in agriculture may create a vulnerability to certain pests and diseases, for instance. Some observers (e.g. Mammana (2014^[66])) have expressed concern that mergers could reduce genetic diversity. However, as the literature reviewed in this section shows, this is by no means obvious. Before discussing this question, it is necessary to review the more general literature on genetic diversity and plant breeding.

Conceptual issues

Plant breeding relies on the creation of variation and subsequent selection. Hence, while plant breeding is in one sense a process of reducing genetic diversity through selection, breeding can also deliberately increase diversity through “base broadening”, the practice of incorporating diversity from wild relatives or landraces (van Etten et al., 2017^[120]); as well as through the creation of new variation (e.g. through mutagenesis, genetic modification or genome editing).

To analyse the impact of plant breeding on genetic diversity for agricultural crops, two conceptual distinctions must be made. First, there is a question of the proper geographical scale at which to define genetic diversity. Regions which were formerly distinct and homogeneous could gradually become more similar. This would increase diversity *within* each region, but could be interpreted as reducing diversity *across* regions as these become less distinct, with unclear implications for global diversity. It appears that such a process has occurred regarding the global diversity of food crop species between 1961 and 2009 (Khouri et al., 2014^[121]). Food crop supplies have become more diversified at the national level, as the number of crops contributing to national food supplies has increased, the relative contribution of these crops has become more even, and the dominance of the most important

commodities has decreased. At the same time, countries have become more similar in terms of their food crop supplies, so that the total diversity of food crops globally has narrowed.

Second, even within a specific region, genetic diversity operates at different levels: the diversity of alleles within a variety, of varieties within a crop, and of crops grown in a region (van de Wouw et al., 2010_[122]). All three levels are relevant for agricultural resilience and as a store of genetic material which can be useful for future plant breeding efforts, but different mechanisms or trends can affect these three levels yielding a complicated overall picture. For instance, Bonneuil et al. (2012_[123]), studying genetic diversity of bread wheat in the French *département* of Eure-et-Loir, found that overall diversity decreased compared to the 19th century even though the number of distinct wheat varieties grown had increased. A greater diversity in terms of the number of varieties grown can lead to less genetic diversity when new varieties are genetically more similar and/or when they displace more heterogeneous varieties, and/or when a small number of varieties becomes dominant in the landscape.

The impact of plant breeding on genetic diversity within a crop

From a historical perspective, it seems plausible that the diversity within a crop has been reduced over time by a number of “genetic bottlenecks” as well as through slower-moving trends (van de Wouw et al., 2010_[122]). A first bottleneck likely occurred through domestication, as only a subset of the full range of wild ancestors is selected and reproduced. A second bottleneck is related to geographical dispersal of crops, as typically only a subset of the broader population is transferred to new regions (e.g. the introduction of coffee to South America was based on a single tree). Following such bottlenecks, selection of desirable characteristics could further reduce genetic diversity over time. However, for some species a significant “gene flow” is possible between domesticated and wild varieties. In addition to spontaneous (*de novo*) genetic variation, this would tend to increase the genetic diversity over time.

Van de Wouw et al. (2010_[122]) hypothesise the existence of a third bottleneck related to modernisation as improved cultivars replace land races, but point out that scientific evidence on this hypothesis is hard to find. According to Van de Wouw et al. (2010_[122]), the most likely scenario seems to be that the introduction of modern cultivars led to an initial *increase* in diversity at the regional level as new cultivars supplemented existing genetic diversity in landraces, followed by a decrease as new cultivars substituted for landraces (a pattern similar to that shown in Figure 4.4 for the introduction of GM varieties in maize and soybean). Once this transition was completed, the evidence seems to suggest no further reduction in genetic diversity.

A meta-analysis by the same authors of 44 studies (Van de Wouw et al. (2010_[124])) indeed suggests that in the long run there has been no significant decrease in the genetic diversity of crop varieties released by plant breeders, although there was some variation over time (with a notable decline in the genetic diversity of crops released in the 1960s compared to the preceding decade). Importantly, these analyses look at varieties released by plant breeders, and hence do not take into account the popularity of different crops and varieties. Van de Wouw et al. (2010_[122]) emphasise that farmers’ choices among crops and varieties play an important role in determining the overall diversity in the field.

Regarding the impact of modern plant breeding, Van de Wouw et al. (2010_[124]) concluded that it was not clear whether an active breeding programme contributes to maintaining a high level of diversity or on the other hand leads to genetic erosion, while Rauf et al. (2010_[125]) argued that the introduction of hybrids led to a reduction of genetic diversity. Fu (2015_[126])

has argued that a reduction in genetic diversity is plausible, but that the impact of modern plant breeding on genetic diversity is still poorly understood from both the empirical and the theoretical point of view.

Orphan crops

While the link between plant breeding and genetic diversity within a crop is not clear, it does seem plausible that the threat of “genetic erosion” is highest for those crops in which breeders are not interested, as these crops might gradually disappear altogether (van de Wouw et al., 2010^[124]).

Some crops with minimum commercial value may not receive much plant-breeding effort despite their importance in terms of genetic diversity, food security, or livelihoods in some parts of the world. Such crops have been labelled “underutilised,” “neglected,” “minor” or “orphan” crops. Many of these crops may have a high potential commercial value which goes unrealised because of a lack of scientific knowledge and recognition of the benefits of the crop downstream (i.e. the lack of a market for the final product), or because of market imperfections and market failures (Gruère, Giuliani and Smale, 2006^[127]).²³

A similar situation is found in the market for pharmaceuticals, where commercial incentives would not normally favour R&D on treatments for rare diseases. For this reason, government policies in many countries stimulate research on such “orphan drugs” (Franco, 2013^[128]). Serious policy challenges exist to stimulate research at the global level on diseases such as malaria or tuberculosis and other diseases that affect the developing world (Kremer and Glennerster, 2004^[129]).

Empirical evidence confirms that the size of the market is an important determinant of the degree of innovation in the pharmaceutical industry (Acemoglu and Linn (2004^[130]); Dubois et al. (2015^[131])). Similarly, evidence for the French seed industry suggests that the number of new varieties introduced each year is positively correlated with market size, although this correlation disappears for hybrid crops (Charlot et al., 2015^[132]).²⁴ The link between market size and innovation suggests that commercially less important crops indeed receive less attention from plant breeders, which in the long run could make these crops even less attractive to farmers.

Implications for consolidation

As the preceding discussion shows, the question of maintaining or improving genetic diversity in modern plant breeding is complex and depends in large part on the crop mix and on technological developments. To assess the potential effects of consolidation, a further conceptual distinction should be made. While there is clearly some link between the number of varieties introduced into the market and the degree of genetic diversity, the link is not clear. For instance, a large number of firms might be selling similar varieties, as could occur in systems where public R&D is responsible for the development of new varieties which are then commercialised by independent private firms. Conversely, a small number of suppliers could provide genetic diversity *over time* by ensuring rapid varietal turnover (thus avoiding the build-up of resistance among pests).

Hence, it is a mistake to automatically equate a smaller number of suppliers with a reduction in genetic diversity. As Louwaars et al. (2009^[133]) have pointed out, the results of Van de Wouw et al. (2010^[124]) show that genetic diversity increased between 1970 and 2000, a time of strong consolidation in the seed industry. Louwaars et al. (2009^[133]) credit technological developments for this observed increase. However, they also warn that other technological

developments, in particular the emergence of more precise breeding techniques, could reduce genetic diversity in the future.²⁵

Louwaars et al. (2009^[133]) also point out that a consolidated breeding programme which spans different regions could increase diversity in each region while reducing diversity at the global level. Less competition could reduce the breeding of specifically adapted varieties. However, it is not clear that a firm post-merger would find it profitable to close down specific breeding programmes. A larger firm could benefit from economies of scale such as investments in costly technology and could more easily focus on breeding for a crop with a smaller market, or for a specific geography or soil type.

These arguments apply not only to genetic diversity within a crop (e.g. plant breeders' incentives to tailor a new variety to specific agro-ecological conditions), but also to research efforts into crops with smaller markets. It is not clear whether a merged firm would find it profitable to shut down "niche" plant-breeding programmes.

In summary, the connection between consolidation and genetic diversity is ambiguous. While various mechanisms in theory could connect the number of firms to the overall level of genetic diversity, there is little empirical evidence to draw any strong conclusions in this regard.

4.4. Conclusion

This chapter reviewed literature on the potential effects of mergers on prices, innovation, and product choice. While information on product choice is limited, clear conclusions emerge concerning the potential effects on prices and innovation.

Similar "risk factors" determine potential harm in both cases. As a result, analysing when a merger has a negative impact on innovation corresponds closely to analysing when a merger may lead to higher prices. A reduction in contestability which allows a firm to charge higher prices would also allow it to reduce R&D efforts. However, if products are complementary, appropriability may increase as the firm now reaps the full benefits of innovations and has a greater incentive to innovate. Finally, synergies are most likely to occur when there are complementarities in technology.

Horizontal mergers in the seed industry are unlikely to lead to large appropriability or synergy effects on innovation, while they would eliminate parallel paths to R&D and may affect contestability. By contrast, non-horizontal mergers are more likely to lead to positive innovation outcomes (or to avoid negative outcomes) when there are complementarity effects. The central questions for the analysis of the current mergers are whether and in which markets the mergers are horizontal or non-horizontal; to what extent they eliminate a potential entrant; and whether there is sufficient evidence to expect efficiency gains through complementarities.

At a high level of aggregation, the recent mergers appear complementary. The merging firms have different profiles both in terms of their focus on seeds versus agrochemicals, and in terms of geographic footprint. At the same time, aggregate numbers may hide important horizontal effects in specific markets. The correct way of evaluating mergers is therefore to analyse outcomes market by market, using an appropriate market definition. Analysis at this level of granularity is what competition authorities do in the course of a merger review. During such a review, competition authorities can access confidential materials held by the merging firms, such as sales data, pricing information or estimates of market shares. This makes it possible to conduct a thorough review. For instance, in reviewing the Bayer-

Monsanto merger, the European Commission evaluated more than 2 000 product markets, and analysed 2.7 million internal documents of the companies (European Commission, 2018^[134]). Such a detailed analysis is clearly beyond the scope of the present report, but it is possible to go beyond highly aggregated numbers cited in the public debate by using market data from private providers, as is done in the next chapter.

Notes

- ¹ See, for example, the European Commission's guidelines on horizontal mergers (Official Journal C 31, 05.02.2004) and non-horizontal mergers (Official Journal C 265, 18.10.2008). Likewise, the Department of Justice and the Federal Trade Commission have published horizontal merger guidelines (the latest version dating from 2010) as well as guidelines on non-horizontal mergers (dating from 1984). The discussion of price effects here will broadly follow the treatment in the European and American merger guidelines. Merger guidelines set out in broad terms the reasoning and main analytical techniques and types of evidence used by competition authorities and offers a good introduction to the economic issues regarding mergers. However, analyses of actual mergers are always based on the specifics of the situation, and hence highly fact-intensive and context-dependent.
- ² Examples include situations where a merged firm would have control over patents or brands allowing it to make expansion or entry by rivals difficult. Likewise, in markets where *interoperability between platforms* is important (such as energy or telecommunications), the merged firm may be large enough to unilaterally set standards in the market in such a way as to raise the costs of its rivals. The merged firm may even be large enough to refuse to interconnect with rivals altogether.
- ³ To understand this, assume a firm with market power facing an inverse demand curve given by $p(q)$, constant marginal costs given by c and fixed costs given by F . Total profits are then given by $\pi(q) = p(q)q - cq - F$ where q is the output level of the firm. Maximising profits with respect to q leads to the optimal pricing rule $\frac{p-c}{p} = -\frac{1}{\eta}$, where η denotes the elasticity of demand. The optimal price thus depends on the marginal cost c and the elasticity of demand η , but not on the fixed cost F . A similar result holds for the standard Cournot-Nash oligopoly model, which takes into account strategic interactions between competitors. Reductions in fixed costs are hence less likely to be passed on to consumers in the form of lower prices, in contrast with a reduction in marginal costs.
- ⁴ *Official Journal of the European Union* 2008 C 265/07, point 49.
- ⁵ The discussion here focuses on effects on prices and efficiency, ignoring other effects such as those on employment studied by McGuckin and Nguyen (2001^[223]), Lehto and Böckerman (2008^[224]) and Siegel and Simons (2010^[225]). An older literature explored the price and efficiency effects of mergers and takeovers. Notable contributions include Ravenscraft and Scherer (1987^[226]), (1989^[229]); Scherer (1988^[230]), Lichtenberg (1992^[227]), and Kaplan (2000^[228]).
- ⁶ Winston et al. (2011^[217]) show that mergers of railroads in the western United States have not had a negative effect on the cost of transporting grain. These results suggest that efficiency gains offset the increased market power of the merging firms.
- ⁷ It is possible (although not analysed explicitly by Blonigen and Pierce (2016^[81])) that these market power effects explain the lower prices found by Sheen (2014^[80]). Mark-ups depend on the ratio between output price and marginal production cost. After a merger, a firm may use its buyer power to negotiate lower prices with its suppliers. Subsequently, it may pass on part (but not all) of this cost saving to consumers. This mechanism would imply lower prices for

- consumers and higher profitability (as found by Sheen (2014_[80])) combined with greater mark-ups and no evidence of efficiency gains (as found by Blonigen and Pierce (2016_[81])).
- ⁸ Ashenfelter and Hosken (2010_[78]) point out that these are short-run price effects and hence may not capture more long-term efficiency effects, such as those found by Sheen (2014_[80]).
- ⁹ A study on the effect of an individual merger typically compares the prices of products of the merging firms before and after the merger with those of competitors. A grouped-merger study, by contrast, would construct a larger dataset with observations of many firms, then compare price changes between groups of merging firms and all non-merging firms. Grouped-merger studies thus look at an “average” impact across different mergers.
- ¹⁰ Weinberg (2011_[216]) studied whether commonly used merger simulation techniques would have led to good predictions of the price effects of one of the mergers assessed by Ashenfelter and Hosken (2010_[78]). He shows that two commonly used techniques considerably underestimate the actual price effects. These results are in line with earlier work by Peters (2006_[218]), who showed that observed price changes in five airline mergers sometimes deviated considerably from what would be predicted *ex ante* (sometimes overstating and sometimes understating the actual price changes). Hence, while merger simulation is an important tool, caution is required in interpreting the results.
- ¹¹ In addition, the analysis by Bryant et al. (2016_[97]) uses the seed market share as its measure, which does not fully reflect the competitive situation. In 2014, Bayer did not have any soybean sales according to this measure, but Bayer was active in soybean markets through its LibertyLink (glufosinate-tolerant) trait. LibertyLink has grown strongly in popularity, from 6% market share in 2015 to a projected 20% in 2018 (Bayer, 2017_[221]), which includes traits in non-Bayer seed. Bayer soybean seed and LibertyLink traits are part of the business sold to BASF.
- ¹² This idea has been popularised in the management literature by Clayton Christensen as “the innovator’s dilemma” (Christensen, 1997_[222]). A large firm may have little incentive to innovate given the risk of cannibalisation, but competitors with a smaller market share have little risk of cannibalisation and are therefore more likely to introduce disruptive innovations. The incumbent firm therefore faces the dilemma to either innovate and cannibalise its own sales, or lose market share to competitors who innovate.
- ¹³ In fact, the endogenous sunk cost argument discussed earlier implies that a high degree of contestability can lead to high endogenous fixed costs for R&D and hence a high degree of market concentration – together with a high sustained rate of innovation.
- ¹⁴ In the context of seed markets, the practice of farm-saved seed limits the appropriability of the benefits of innovation. The introduction of hybrid maize in the 1930s dramatically changed appropriability, as the seed produced by F1 hybrids gives maize of poorer quality. With hybrid maize, farmers for the first time had a clear incentive to purchase new maize seed every year, thus greatly increasing the share of the benefits flowing to plant breeders even in the absence of intellectual property rights.
- ¹⁵ A working paper by Haucap and Stiebale (2016_[214]), focusing on the pharmaceutical industry in Europe, obtains similar results and finds that R&D expenditures of non-merging rivals decrease.
- ¹⁶ The Hirschman-Herfindahl Index is a standard measure of market concentration, calculated as the sum of the squares of the market shares of all firms. For a monopolist, the HHI therefore has a value of 10 000. In a market with 100 firms, each of which has 1% of the market, the HHI would have a value of 100. The HHI is often used by competition authorities. For instance, the Horizontal Merger Guidelines of the US Department of Justice and the Federal Trade Commission indicate that markets are generally considered ‘highly concentrated’ if the HHI is above 2 500, while markets are regarded as “unconcentrated” if the HHI is below 1 500.

- ¹⁷ “Approval” here means the approval to start field testing and not the final approval for commercial use. See Fernandez-Cornejo (2004_[72]) for a discussion of the regulatory procedures and the distinction between notifications and permits.
- ¹⁸ Oehmke and Naseem (2016_[65]) also look at the impact of mergers. When both firms are conducting field trials for the same crop, mergers do not impact the industry-wide number of field trials. When both firms are conducting field trials but in different crops, mergers appear to reduce the industry-wide number of field trials. Finally, when one of the firms is not conducting any field trials, mergers increase the industry-wide number of field trials. In contrast with the studies on mergers and R&D mentioned earlier, the analysis in their study is done by regressing industry-level outcomes on the cumulative number of mergers over time. This approach ignores the relative size of merging firms. Moreover, it is difficult to identify a causal relationship, as many other factors might explain the observed correlations.
- ¹⁹ A possible explanation is that innovation in plant breeding involves relatively long lags. In conventional plant breeding, for instance, it typically takes around ten years from the first crossing to the first commercial sales (KWS, 2017_[35]). With such long lags, firms may prefer to keep R&D programs in place, since it would be difficult to quickly ramp up innovation in response to unexpected moves by competitors.
- ²⁰ In the economic literature, the term “variety” is typically used in this context. To avoid confusion with plant varieties, this study will use the term “product choice” instead.
- ²¹ See in particular empirical research by Berry and Waldfogel (2001_[116]) and Sweeting (2010_[211]) on US radio stations and by Argentesi et al. (2016_[212]) on the merger of two Dutch supermarket chains; and theoretical contributions by Gandhi et al. (2008_[117]) and Mazzeo et al. (2012_[213]).
- ²² A spatial example may help illustrate these possibilities. If two grocery chains merge, they may re-evaluate the location of their stores. In some neighbourhoods, two stores may be located close together and it may be optimal to close one store. Another possibility is to relocate one of the stores to a different neighbourhood to attract new customers. However, if the two stores are then located too far apart, this may create an opportunity for a competitor to open a store halfway between the two, stealing business from both. Hence, it may be optimal to relocate one store, but not too far away. Such spatial analogies are common in the literature on horizontal differentiation.
- ²³ In the early 2000s, research on underutilised species was stimulated by the Global Facilitation Unit for Underutilized Species (www.underutilized-species.org), a joint initiative by FAO, IFAD, Bioversity International, the International Center for Underutilised Crops (ICUC), and the German Federal Ministry for Economic Cooperation and Development (BMZ). Since 2009, this initiative has been undertaken by Crops for the Future (www.cffresearch.org), based in Malaysia.
- ²⁴ Unpublished research by Sébastien Parenty (INRA) using data on French seed markets similarly finds a positive correlation between market size and the total number of varieties available for sale.
- ²⁵ Genetic modification and New Plant Breeding Techniques allow the precise introduction of a desired trait, and that trait alone, in an existing variety. In contrast, traditional plant breeding techniques rely on, for example, crossing with wild relatives or landraces, or on mutagenesis, both of which introduce a much wider “genetic load” than just the desired trait. While the new techniques improve precision, they also reduce the unintended increase in genetic diversity caused by the plant breeding process.

5. New evidence on market concentration

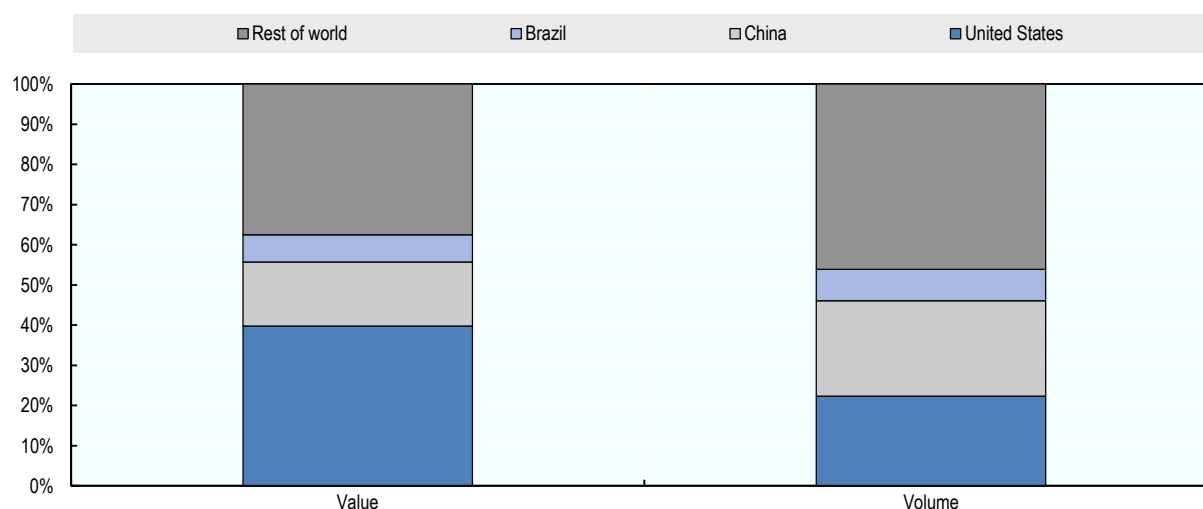
Using privately-held market research data, this chapter presents new estimates of concentration in seed markets covering a broad range of crops and countries, and analyses the determinants of market concentration levels in seed. In addition, this chapter provides evidence of “multimarket contact”, where the same firms face each other as competitors in several markets. The chapter concludes with a discussion of the available evidence on concentration in the market for GM technology.

Researchers working on market concentration in seed have often noted the difficulty of obtaining market share data at a sufficiently disaggregated level (Fernandez-Cornejo and Just (2007_[6]), Mammana (2014_[66])). For want of more detailed data, some analysts have used aggregate sales figures of firms and an estimate of the overall size of the global seed market to obtain estimates of global market concentration. Using this approach, Fuglie et al. (2011_[9]) estimated that the combined market share of the four largest firms increased globally from 21% in 1994 to 54% in 2009, while ETC Group (2013_[8]) puts this figure at 58% for 2011.

These aggregated approaches suffer from several shortcomings. First, as noted by Bonny (2014_[25]), (2017_[12])), estimates of the value of global seed sales tend to vary across different sources and methods, and some market research agencies tend to underestimate sales by small and medium-size enterprises. For instance, an estimate by Phillips McDougall of USD 35 billion in 2015 only appears to account for two-thirds of crops used in global agriculture. Estimates may differ in how they account for farm-saved seed; some estimates may only focus on commercial seed sales. When market concentration measures are calculated using such low estimates of total market size, the degree of market concentration is automatically overstated.

Moreover, any estimate of market concentration using global sales figures will automatically assign a greater weight to markets with a higher seed price. Correcting for differences in prices (for instance by using volume shares instead) can lead to very different results. To illustrate this, Figure 5.1 presents a rough estimate of the share of different geographies in global maize markets. The United States accounts for an estimated 40% of global maize markets in value terms (measured at average 2016 exchange rates). However, when measured in volume terms, the estimated share of the United States falls to below one-quarter of the global total, at about the same level as the People's Republic of China (hereafter "China"). It is clear that when value-based measures are used estimates of global market concentration in maize seed markets will assign a much greater weight to firms active in the United States.

An approach which aggregates across all countries and crops using sales in value terms may thus be misleading about concentration levels in specific markets. For instance, using data from before the current mergers would typically conclude that Monsanto is the leading firm, followed by DuPont, and with Syngenta a distant third (Ragonnaud (2013_[17]), Heisey and Fuglie (2011_[7]), ETC Group (2013_[8])). However, as noted earlier, about 60% of Monsanto's sales originate in the United States, and more than 80% come from the Americas. Monsanto's sales are limited in other regions, most notably Asia Pacific. Likewise, before its merger with Dow, agricultural sales of DuPont were overwhelmingly based in the Americas.¹ Calculations of global market shares reflect the disproportionate size and value of seed markets in North and South America (in particular the United States). It is not clear how such global calculations can inform policy makers about market concentration in specific crop seed markets in specific geographies.

Figure 5.1. Value versus volume in maize seed markets

Note: Estimated share in global maize markets in value (at average 2016 exchange rates) and volume.

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

This chapter takes an alternative approach. Rather than providing global, regional or national estimates of overall market concentration, this chapter provides new estimates of market concentration at the level of specific crops in specific countries. The focus is on major field crops such as maize, soybeans, wheat and barley, rapeseed, sunflower, and to a lesser extent on sugar beet, potato, and cotton. This chapter also provides information on market concentration in GM traits using a variety of sources.

5.1. Seed market data and methodology

The data on market concentration in seed relies on the amis®AgriGlobe® database of the Kleffmann Group. The AgriGlobe database uses annually-recurring farmer surveys, complemented with bi-annual recurring distributor surveys in some markets, as well as additional input from experts. As a result, the country and crop coverage varies depending on the level of detail; in general, more data is available on market size than on market shares of plant breeders. For our analysis, we rely on market share data for 2016 unless noted otherwise. More information regarding the Kleffmann database is provided in Annex 5A.

The Kleffmann database distinguishes between the commercial seed market and the overall seed market, including farm-saved seed (in both cases defined as the market for seed for final use within the country). A choice needs to be made whether to calculate market shares relative to the commercial seed market or to the overall seed market. In what follows, all market shares have been calculated using the *overall* seed market. The rationale behind this approach is that if seed saving is important, using the market shares of the commercial seed market would overstate the degree of market power. Commercial plant breeders in those markets are in fact competing with farm-saved seed; calculating only their share of the commercial seed market would be misleading.²

Market shares used in the calculations refer to the plant breeder, i.e. the owner of the variety.³ Public sector plant breeding institutes are active in a number of markets. The Kleffmann database treats these in the same way as private sector firms.⁴ In some cases, more than one public sector institute is active in the same market. These are considered here as different

suppliers in calculations of market concentration, as these institutes implicitly compete with each other. In some of the empirical analyses, an additional measure is included to control for the overall importance of public sector plant breeding in a market.

The choice of crops covered is based on data availability. In particular, detailed information on market shares is only available for maize, soybeans, wheat and barley, rapeseed, and sunflower. Additional information for a handful of countries is available for potato, sugar beet, and cotton. Data for some important markets are missing; where possible this has been complemented using estimates from the literature (Table 5.1).

This chapter presents the most detailed and complete estimates to date of market concentration in seed markets across crops and countries. Yet some gaps in coverage remain. The important market for vegetable seed is unfortunately not covered. Moreover, although the geographic coverage includes both OECD and non-OECD economies, much less is known about developing and least developed countries. Boxes 5.2 and 5.3 provide information on vegetable seed markets in Europe and market concentration in developing countries.

In the literature, two measures commonly used as indicators of market concentration are the four-firm concentration ratio (written as C4) and the Hirschman-Herfindahl Index (HHI). The C4 ratio is defined as the combined market share of the four largest firms in a particular market. This measure has the benefit of having an intuitive interpretation, but its main drawback is that it does not capture the relative size of different firms. For instance, a C4 ratio of 80% could reflect a market with four similar-sized firms, each with a market share of around 20%. However, this could equally reflect a market where the leading firm has nearly 80% of the market by itself, with the rest of the market shared among many smaller players.

The Hirschman-Herfindahl Index addresses this shortcoming. The HHI is defined as the sum of squared market shares. If a single firm has a 100% market share, the HHI would have a value of 10 000. By contrast, if the market was equally divided between 100 firms that each had 1% market share, the HHI would be 100; lower values are possible as the market becomes further fragmented. As the HHI is based on *squared* market shares, the index increases when a larger firm gains market share at the expense of a smaller firm.⁵

A typical challenge in analysing market concentration is *market definition*, i.e. correctly delineating the relevant market in which market shares of competitors can be analysed. The data available here implicitly defines the relevant market as the national market for seed of a specific crop.

Table 5.1. Overview of data availability

	Number of countries			Coverage (% of global market by value)		
	Kleffmann	Additional sources	Total	Kleffmann	Additional sources	Total
Maize	32		32	65%	0%	65%
Soybean	7		7	86%	0%	86%
Wheat and barley	15		15	23%	0%	23%
Rapeseed	16	1	17	27%	34%	62%
Sunflower	11		11	75%	0%	75%
Cotton	2	1	3	6%	29%	35%
Sugar beet	3	1	4	33%	10%	43%
Potato	1	1	2	2%	1%	4%

Note: Coverage of global seed market based on value of overall market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

In some cases, this geographic definition may be too broad, especially in large countries. For example, in the United States, there may be important differences in the maize markets between the central Corn Belt (the region in the Midwest of the United States where most maize production is situated), the neighbouring “fringe corn belt”, and the rest of the country. Agro-ecological characteristics will differ between such regions, meaning that what appears as a single market in the data (as presented in this study) may in reality represent separate markets. For other cases, however, the national definition of a market may be too narrow, especially in small countries. For example, in some EU Member States the agro-ecological conditions may be similar to those of neighbouring countries, in which case the relevant market may span an area greater than the national market.

Moreover, the crop dimension can also be called into question as it could be either too broad or too narrow. For example, the data available here groups together information on wheat and barley; but it could be argued that different types of wheat (e.g. hard red winter, durum) represent different seed markets. On the other hand, it could also be argued that from the point of view of the farmer different crops (e.g. maize, soybean) are to some extent substitutes, so that market concentration should be analysed in the context of a broader market which includes these substitutes.

These questions of market definition are important and central to much of the detailed analysis performed by competition authorities when evaluating mergers. In the context of the present study, the available data do not make it possible to go much beyond the national crop seed market definition, but it is important to keep in mind the limitations mentioned here. Despite these limitations, the data presented constitute a major improvement over what was previously available in the public domain.

5.2. Concentration in seed markets

Maize

Table 5.2 shows concentration measures for maize seed markets in 32 countries using the two most commonly used concentration measures (the Hirschman-Herfindahl Index, HHI, and the four-firm concentration ratio, C4), and using both volume and value measures. Figure 5.2 shows our preferred measure, the value-based HHI (hereafter referred to as the HHI).⁶ There is a considerable variation in concentration levels across countries in our sample, ranging from 933 in Belarus to almost 4 700 in Denmark. There is no obvious link between concentration and geography, or levels of development.⁷

There is a remarkable difference between the value-based and volume-based measures of market concentration in the Mexican maize seed market. As the centre of origin of maize, a large share of the seed market by volume (64%) is accounted for by farm-saved seed, with a low imputed value. By contrast, the commercial seed market is dominated by two multinational firms. This “dual” structure of the seed market explains the discrepancy between value- and volume-based measures.

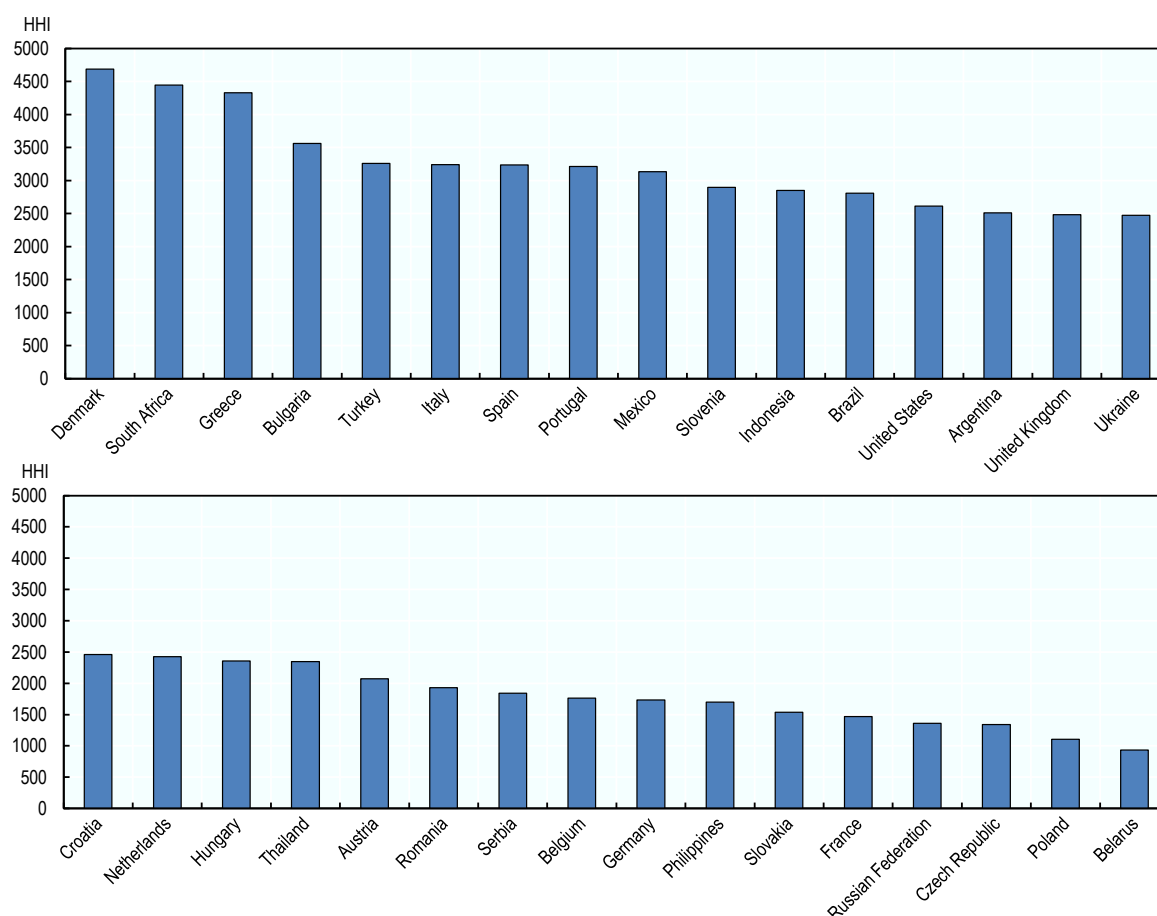
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Table 5.2. Concentration in the maize seed market, 2016

Country	Value		Volume	
	HHI	C4	HHI	C4
Argentina	2 510	73%	2 274	71%
Austria	2 071	77%	2 041	76%
Belarus	933	51%	1 278	65%
Belgium	1 761	72%	1 703	71%
Brazil	2 808	97%	2 579	94%
Bulgaria	3 563	91%	3 600	89%
Croatia	2 459	87%	2 296	85%
Czech Republic	1 342	63%	1 342	63%
Denmark	4 688	98%	4 560	97%
France	1 468	73%	1 426	71%
Germany	1 735	66%	1 652	65%
Greece	4 331	97%	4 134	97%
Hungary	2 355	81%	2 160	79%
Indonesia	2 850	95%	2 539	87%
Italy	3 242	93%	3 109	92%
Mexico	3 136	81%	470	32%
Netherlands	2 426	83%	2 473	83%
Philippines	1 700	72%	864	52%
Poland	1 105	57%	1 167	59%
Portugal	3 215	84%	3 049	83%
Romania	1 932	74%	1 067	59%
Russian Federation	1 358	67%	1 378	62%
Serbia	1 841	75%	1 662	73%
Slovakia	1 536	75%	1 536	75%
Slovenia	2 895	84%	2 696	82%
South Africa	4 448	99%	4 448	99%
Spain	3 235	89%	2 879	86%
Thailand	2 346	94%	2 244	91%
Turkey	3 261	89%	3 069	87%
United Kingdom	2 483	85%	2 354	84%
Ukraine	2 473	80%	1 741	68%
United States	2 614	82%	2 463	80%

Note: HHI is the Hirschman-Herfindahl Index; C4 is the four-firm concentration ratio. All calculations refer to the shares in the overall seed market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Figure 5.2. Concentration in the maize seed market, 2016

Note: HHI is the Hirschman-Herfindahl Index. All calculations refer to the shares in the overall seed market (including farm-saved seed) in value terms.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Soybeans

The database covers a much smaller number of countries for soybean seed (seven compared with 32 for maize). However, the countries covered here jointly account for an estimated 86% of the global soybean seed market by value. Data on market concentration are provided in Table 5.3 and Figure 5.3 Market concentration is lowest in the Ukrainian soybean seed market, and highest in Uruguay and South Africa. The highest observed concentration level for soybean seed is lower than that for maize markets. GM varieties for soybean are widely used in these countries. In Ukraine, the use of GM soybean is not permitted but glyphosate-tolerant varieties appear to be in use (Kleffmann Group, 2016[135]).

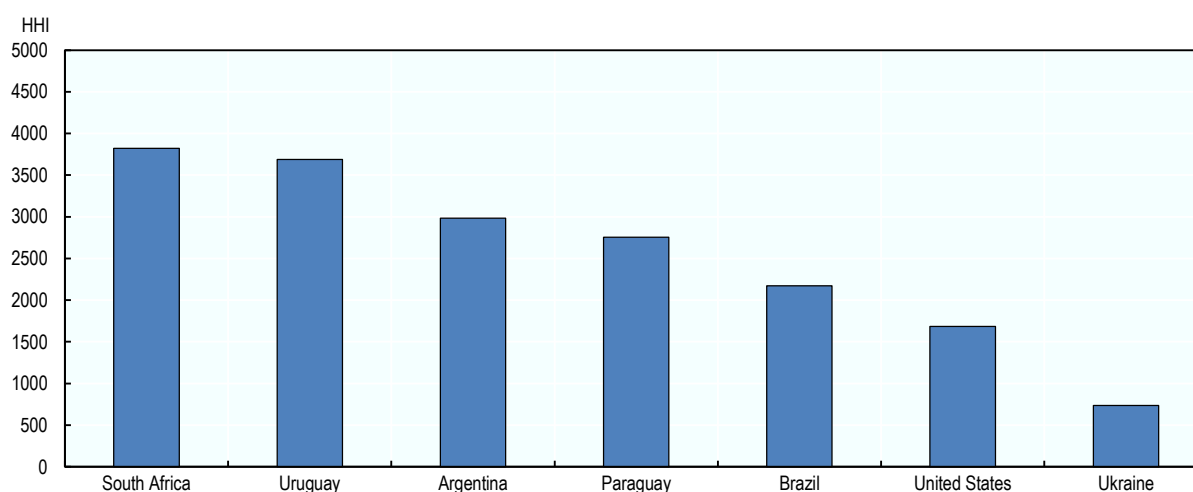
Compared with the other countries included in Table 5.3, a much greater share of soybean seeds in Ukraine derives from public research institutes and/or unknown sources (possibly farm-saved seed). Moreover, since several public research institutes are active, the market is quite fragmented.

Table 5.3. Concentration in the soybean seed market, 2016

Country	Value		Volume	
	HHI	C4	HHI	C4
Argentina	2 984	89%	3 178	88%
Brazil	2 173	82%	1 757	79%
Paraguay	2 756	96%	2 849	97%
South Africa	3 822	96%	3 821	96%
Ukraine	736	42%	736	42%
Uruguay	3 690	91%	3 390	88%
United States	1 683	69%	1 694	70%

Note: HHI is the Hirschman-Herfindahl Index; C4 is the four-firm concentration ratio. All calculations refer to the shares in the overall seed market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

Figure 5.3. Concentration in the soybean seed market, 2016

Note: HHI is the Hirschman-Herfindahl Index. All calculations refer to the shares in the overall seed market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

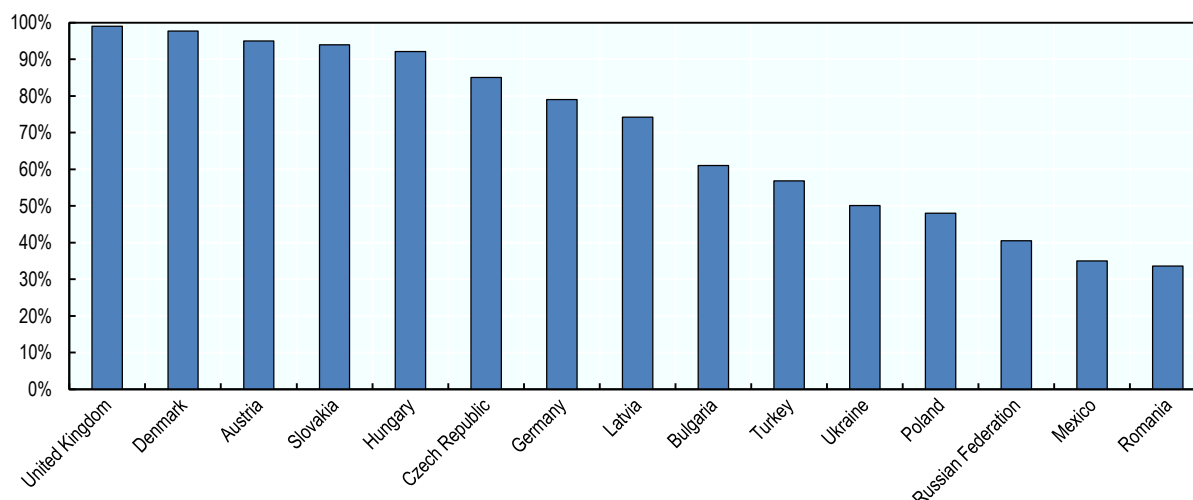
Wheat and barley

Public institutes play a greater role for wheat and barley as compared to other crops.⁸ They are important sources of cereal varieties in Bulgaria, Latvia, Mexico, Romania, the Russian Federation, Turkey, and Ukraine where they contribute 20% or more to total volumes. In addition, a large share of wheat and barley seed by volume could not be allocated to a plant breeder in several markets, indicating a reliance on farm-saved seed. In Romania, Latvia, Hungary and Poland this share was between 14% and 39% of the overall market by volume. Together, the presence of farm-saved seed and the role of public institutes imply that the share of seed accounted for by the commercial sector varies considerably between countries, as shown in Figure 5.4 for the 15 countries for which data is available in the Kleffmann database.

The commercial market dominates in the United Kingdom, Denmark, Austria and Slovakia. By contrast, the role of the commercial sector is relatively small in the Russian Federation, Mexico and Romania, among other countries.

Table 5.4 and Figure 5.5 present estimates of market concentration in wheat and barley seed markets.⁹ Overall, the levels of market concentration appear low, with the HHI index ranging from less than 600 in the Russian Federation to more than 4 000 in Mexico. As a comparison of Figure 5.4 and Figure 5.5 indicates, there is no clear link between the measured level of market concentration and the role of the commercial sector, as in some countries a single public institute dominates (e.g. Mexico) while in other countries several smaller public institutes are active (e.g. Belarus).¹⁰

Figure 5.4. Share of commercial sales in total wheat and barley seed market (in volume), 2016



Note: Estimated share of commercial sales in total, by volume; remainder of the market is either supplied by public institute or farm-saved seed. Data for Mexico refers to winter wheat only.

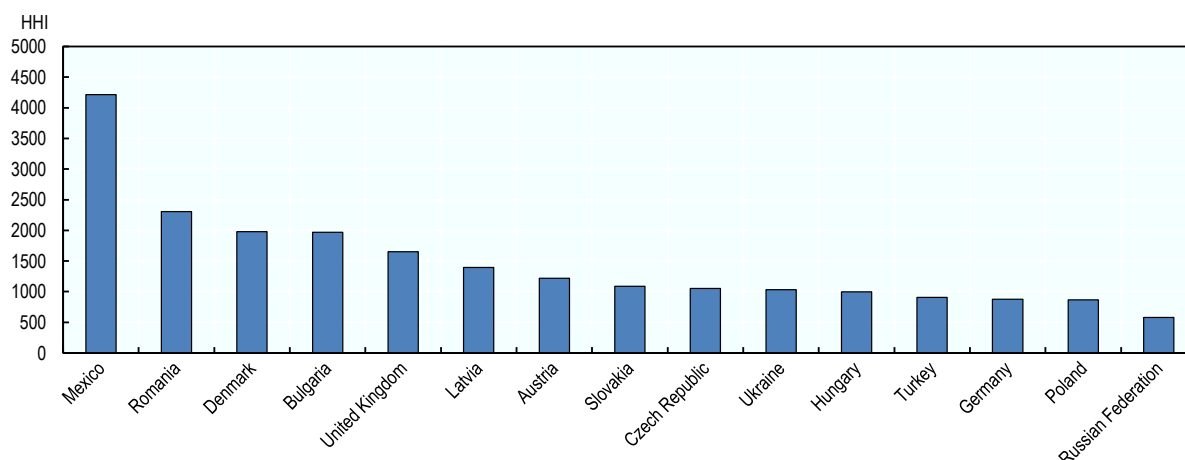
Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

Table 5.4. Concentration in the wheat and barley seed market, 2016

Country	Value		Volume	
	HHI	C4	HHI	C4
Austria	1 218	59%	1 199	58%
Bulgaria	1 970	71%	1 994	71%
Czech Republic	1 052	55%	1 096	56%
Denmark	1 979	83%	1 940	82%
Germany	877	44%	804	45%
Hungary	999	58%	1 002	58%
Latvia	1 396	68%	1 297	66%
Mexico	4 217	98%	4 416	98%
Poland	865	47%	758	43%
Romania	2 307	60%	2 211	59%
Russian Federation	581	38%	555	36%
Slovakia	1 087	57%	1 075	56%
Turkey	909	51%	974	52%
United Kingdom	1 653	74%	1 648	74%
Ukraine	1 030	53%	1 056	52%

Note: HHI is the Hirschman-Herfindahl Index; C4 is the four-firm concentration ratio. All calculations refer to the shares in the overall seed market (including farm-saved seed). Data for Mexico refers to winter wheat only.

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

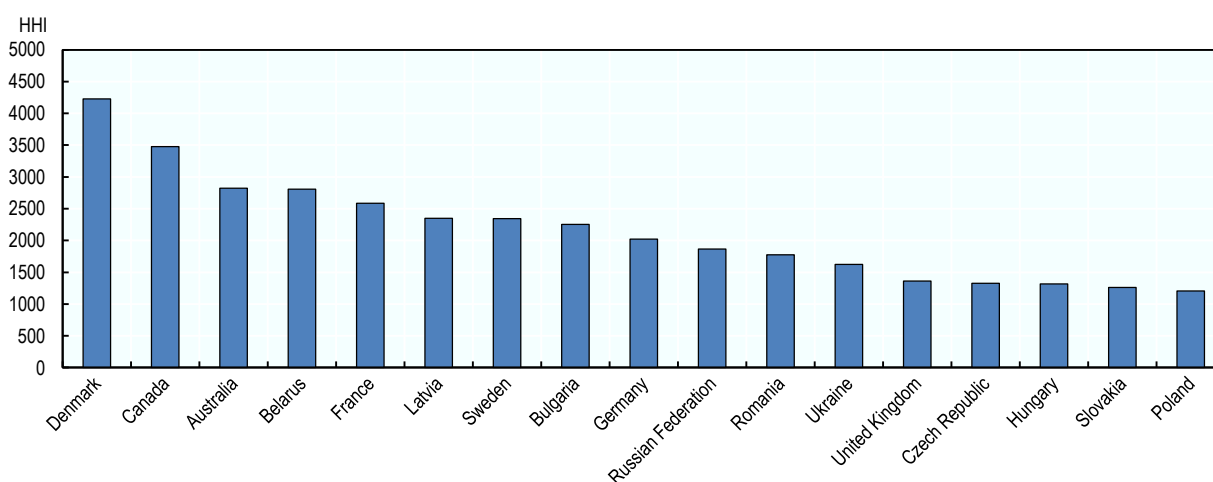
Figure 5.5. Concentration in the wheat and barley seed market, 2016

Note: HHI is the Hirschman-Herfindahl Index. All calculations refer to the shares in the overall seed market (including farm-saved seed). Data for Mexico refers to winter wheat only.

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

Rapeseed/canola

The database covers 16 markets for rapeseed, although it does not include information on Canada, the largest market for rapeseed. Instead, estimates for Canada have been calculated using data from the Canadian Grain Commission on the acreage of insured varieties. The Canadian rapeseed (canola) seed market is by far the largest in the world, and developments in this market are discussed in more detail in Box 5.1. Measures of market concentration are shown in Figure 5.6 and in Table 5.5

Figure 5.6. Concentration in the rapeseed seed market, 2016

Note: HHI is the Hirschman-Herfindahl Index. All calculations refer to the shares in the overall seed market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database except Canada based on Canadian Grain Commission, “Grain varieties by acreage insured,” www.grainscanada.gc.ca (consulted 4 July 2018).

Table 5.5. Concentration in the rapeseed seed market, 2016

Country	Value		Volume	
	HHI	C4	HHI	C4
Australia	2 820	94%	3 240	90%
Belarus	2 810	78%	7 672	94%
Bulgaria	2 252	75%	1 901	71%
Canada	3 475	86%	3 475	86%
Czech Republic	1 327	64%	1 167	58%
Denmark	4 225	95%	4 272	95%
France	2 586	81%	2 337	79%
Germany	2 022	72%	1 889	70%
Hungary	1 316	67%	1 287	66%
Latvia	2 347	79%	1 905	75%
Poland	1 208	62%	1 034	56%
Romania	1 775	71%	1 688	70%
Russian Federation	1 864	70%	1 340	60%
Slovakia	1 262	59%	1 176	54%
Sweden	2 344	85%	2 019	78%
United Kingdom	1 363	66%	1 302	65%
Ukraine	1 622	72%	810	50%

Note: HHI is the Hirschman-Herfindahl Index; C4 is the four-firm concentration ratio. All calculations refer to the shares in the overall seed market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database except Canada based on acreage data from Canadian Grain Commission, “Grain varieties by acreage insured,” www.grainscanada.gc.ca (consulted 4 July 2018).

Observed levels of market concentration vary from around 1 200 in Poland to more than 4 200 in Denmark, where the market leader serves more than half of the market. Other markets seem to have more moderate levels of market concentration. In the case of Belarus and the Russian Federation, public research institutes provide a large share of the seed by volume. In Belarus, this also translates into a high market share by value, and hence a high level of market concentration as measured here.

Box 5.1. Market concentration in canola seed

Until the 1960s, rapeseed played a minor role in Canadian agriculture. Less than half a million hectares were planted in 1968 (representing less than 5% of Canadian cropland). Since 1970, however, this area has grown strongly and by 2014 more than 8 million hectares were planted with rapeseed (more than 30% of cropland), as the industry was stimulated by several important developments.

In the late 1970s, publicly-funded research led to the introduction of canola – a specific type of rapeseed with lower levels of erucic acid and glucosinolates. In the following years, the introduction of intellectual property rights in the form of plant breeders’ rights and patents on traits for genetically-modified canola led to a dramatic increase in private R&D efforts. While public R&D spending had dominated historically, the private sector took the lead in the early 1990s, and by the mid-1990s most canola varieties originated in the private sector. Incentives for the private sector were further strengthened by the development of hybrid canola which reduced the role of farm-saved seed.

A by-product of these developments has been the increasing market concentration of seed and biotech firms. Table 5.6 shows estimated market shares of main plant breeders in canola seed for 2008, 2013 and 2017. In 2008, Bayer accounted for more than half the total canola area; the area seeded with Bayer’s most popular variety, InVigor 5020, was roughly equal to the combined area of the next three firms. While market shares fluctuate over time, Bayer remained the leading firm in 2017.

These numbers only capture market concentration in seed (germplasm), but market concentration is also high in GM traits. Figure 2.4 shows the shares of different types of herbicide tolerance traits in canola. Over time, Bayer’s LibertyLink technology has captured the majority of the market for such traits. In 2014, LibertyLink traits had 65% of

the market (as measured in hectares); followed by 25% for Monsanto's Roundup Ready and 10% for BASF's Clearfield (a non-GM herbicide tolerance trait). These numbers imply a four-firm concentration ratio of around 100% and an HHI of almost 4 900 for genetic traits, considerably higher than the corresponding measures for seed itself.

It is clear that a combination of Bayer and Monsanto would have led to a near-monopoly in traits and a dominant position in seeds. As part of its global divestitures to secure regulatory approval for the merger, Bayer has transferred its canola hybrid business and LibertyLink portfolio to BASF.

The merger of Dow and DuPont, approved by the Canadian Competition Bureau in June 2017, did not involve any remedies in the canola market. As shown in Table 5.6, Dow and DuPont's combined market share in 2017 was considerably below Bayer's, while neither company has a presence in the market for canola traits.

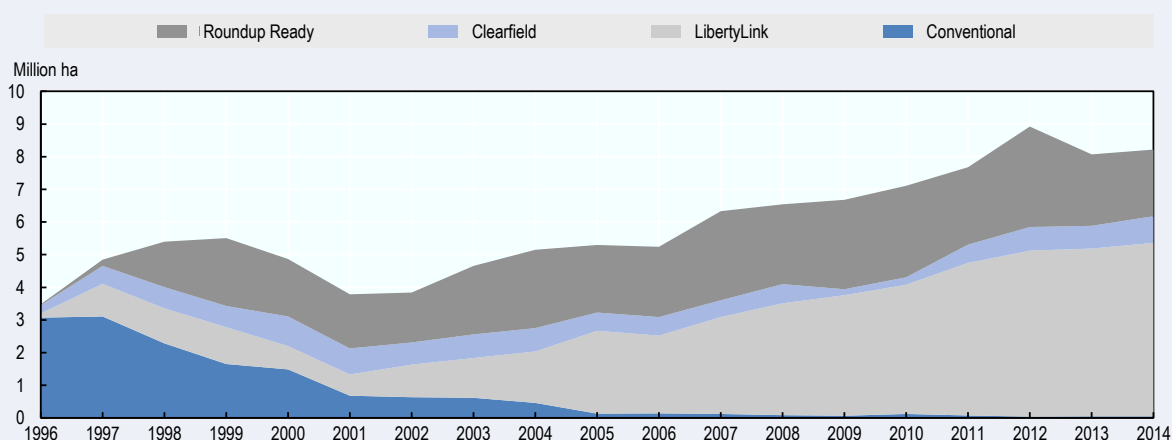
Table 5.6. Market concentration in canola seed, 2008-2017

Plant breeder	2008	2013	2017
Bayer	55%	47%	56%
DuPont Pioneer	11%	14%	12%
Monsanto	10%	12%	12%
Dow	9%	9%	6%
Cargill	7%	3%	2%
Viterra / Agrium	4%	7%	5%
Canterra	2%	0%	2%
Brett-Young	1%	3%	3%
Other	1%	3%	2%
Total	100%	100%	100%
HHI Index	3408	2750	3475
C4 ratio	85%	83%	86%

Note: Market share estimates based on area seeded. Data refers to varieties (i.e. not GM traits) by plant breeder. Data for 2013 and 2017 are estimates based on data of insured canola acreage only. For 2013, data covers 15.7 million acres out of 20 million planted acres (79%); for 2017, data covers 18.5 million acres out of 22.6 million planted acres (82%). Market shares for 2013 and 2017 refer to acreage where varieties were reported (in 2017, 8% of insured canola acreage did not specify the planted variety; in 2013, this was 1%). As the DowDuPont merger was approved only in June 2017, both firms are shown separately.

Source: Brewin and Malla (2012) and personal communication with the authors; Canadian Grain Commission, "Grain varieties by acreage insured", www.grainscanada.gc.ca (consulted 4 July 2018).

Figure 5.7. Herbicide tolerance traits in canola, 1996-2014



Note: Seeded area in millions of hectares by herbicide tolerance traits: conventional (non-GM) canola, Bayer's LibertyLink, BASF's Clearfield, and Monsanto's Roundup Ready.

Source: Brewin and Malla (2017).

* This box is based on Brewin and Malla (2012^[135]), (2017^[136]) and Malla and Brewin (2015^[137]), as well as on data from the Canadian Grain Commission (www.grainscanada.gc.ca).

** A factor that may help explain the popularity of LibertyLink relates to the process by which hybrid canola seed is produced. Although several methods exist, one procedure relies on a genetically modified line which is both male-sterile and herbicide-tolerant, and which is crossed with a second line which is neither male-sterile nor herbicide-tolerant. The two lines are planted near each other. As the first line is male-sterile, it is pollinated exclusively by the second line. The second line is then eliminated by spraying the whole field with herbicide. Only plants of the first line remain, producing herbicide-tolerant seed which is a hybrid of the two lines. Hence, herbicide tolerance facilitates the production of hybrid seed. Bayer's InVigor with LibertyLink (now owned by BASF) is a prime example of this method (Hawkes et al., 2011^[138]). The OECD wishes to thank Robert Duncan and Derek Brewin of the University of Manitoba for clarifying this point.

Sunflower

Table 5.7 and Figure 5.8 contain data on market concentration in sunflower seed in the 11 countries included in the database. These countries jointly account for three-quarters of the global market for sunflower seed (by value). Ukraine and the Russian Federation together account for almost half of the global total.

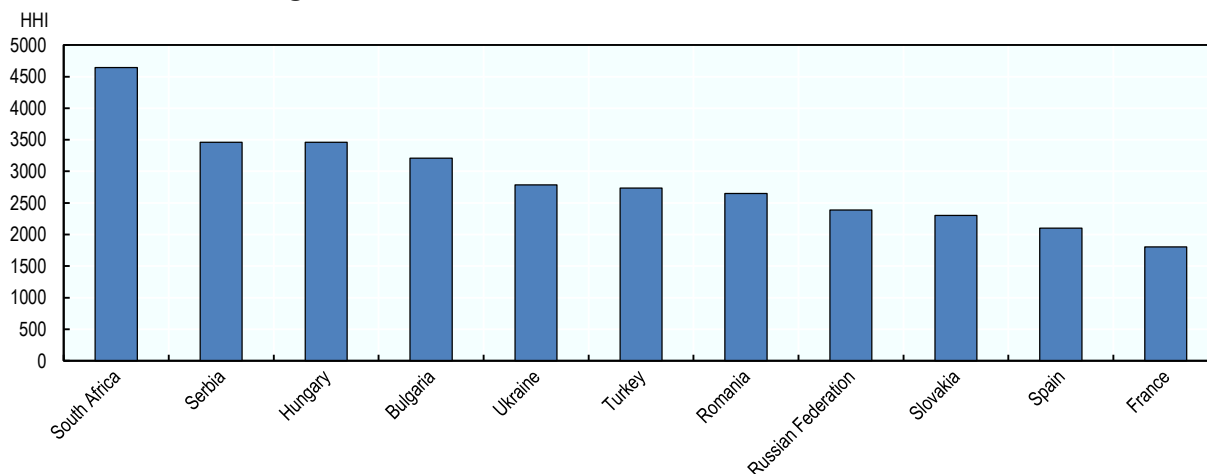
Table 5.7. Concentration in sunflower seed markets, 2016

Country	Value		Volume	
	HHI	C4	HHI	C4
Bulgaria	3 211	92%	3 126	92%
France	1 802	77%	1 776	77%
Hungary	3 459	88%	3 359	87%
Romania	2 652	85%	2 624	84%
Russian Federation	2 389	78%	1 224	58%
Serbia	3 461	89%	3 461	89%
Slovakia	2 302	85%	2 302	85%
South Africa	4 645	99%	4 643	99%
Spain	2 103	90%	2 023	88%
Turkey	2 737	93%	2 388	91%
Ukraine	2 786	88%	1 922	75%

Note: HHI is the Hirschman-Herfindahl Index; C4 is the four-firm concentration ratio. All calculations refer to the shares in the overall seed market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Figure 5.8. Concentration in sunflower seed markets, 2016



Note: HHI is the Hirschman-Herfindahl Index. All calculations refer to the shares in the overall seed market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

The lowest level of market concentration in the sample is found in France and the highest in South Africa. In South Africa, only a limited number of firms are active, with two firms accounting for nearly the entire sunflower seed market.

Sugar beet, potato, and cotton

There is only limited information available in the Kleffmann database regarding concentration in seed markets of sugar beet, cotton seed, and potatoes.¹¹ This information, along with three additional data points from the available literature, is shown in Table 5.8 and Figure 5.9.

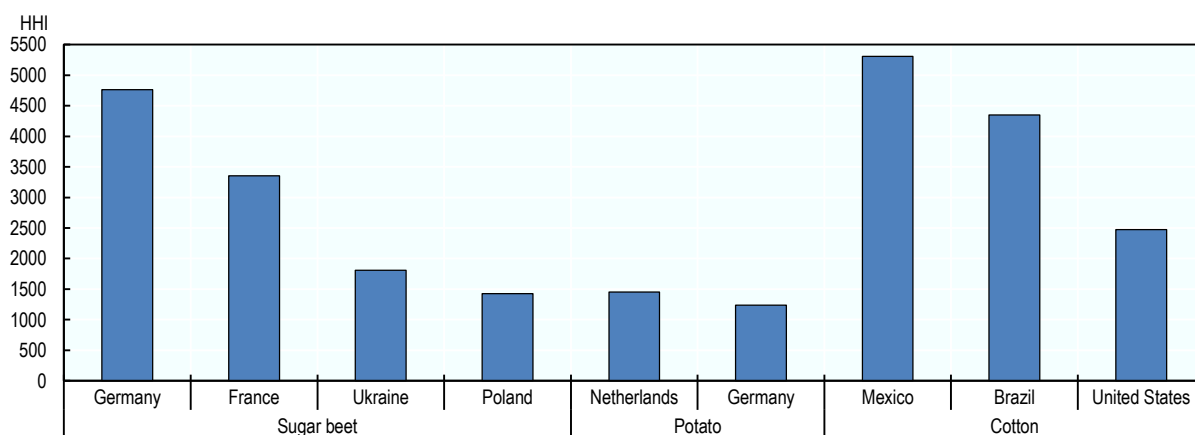
Table 5.8. Concentration in sugar beet, potato, and cotton seed markets, 2016

Country	Crop	Value		Volume	
		HHI	C4	HHI	C4
Germany	Sugar beet	4 762	100%	4 617	100%
France ⁽¹⁾	Sugar beet	3 353	<i>n.a.</i>	3 353	<i>n.a.</i>
Ukraine	Sugar beet	1 811	82%	1 811	82%
Poland	Sugar beet	1 425	69%	1 425	69%
Netherlands ⁽²⁾	Potato	1 454	60%	1 454	60%
Germany	Potato	1 240	59%	1 240	59%
Mexico	Cotton	5 308	100%	5 245	100%
Brazil	Cotton	4 348	100%	4 873	99%
United States ⁽³⁾	Cotton	2 474	91%	2 474	91%

Note: HHI is the Hirschman-Herfindahl Index; C4 is the four-firm concentration ratio. All calculations refer to the shares in the overall seed market (including farm-saved seed). Additional data from literature: (1) Data from Fugerey-Scarbel and Lemarié (2013^[139]) for 2011 (Table 5). (2) Data from Kocsis et al. (2013^[140]) for 2011 using area planted (Table 11). (3) Data from USDA (2017^[141]) for 2017.

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database except where noted.

Figure 5.9. Concentration in sugar beet, potato, and cotton seed markets, 2016



Note: HHI is the Hirschman-Herfindahl Index. All calculations refer to the shares in the overall seed market (including farm-saved seed).

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database except as noted in Table 5.8.

Market concentration appears especially high in cotton seed. The level of market concentration in Mexico is the highest level observed in the database (across all crops), and the level in Brazil is similarly high. Concentration in US cotton seed is lower than in Brazil and Mexico, but still fairly high. In all three cases, the market is dominated by GM cotton.

Market concentration for seed potatoes is low in the Netherlands and Germany. In Ukraine and Poland, market concentration for sugar beet seed is also low. However, the market concentration for sugar beet seed in Germany is exceptionally high. The leading firm in this country has more than half of the market, and the two leading firms account for around 90% of the market. Data for France similarly seem to show a high market concentration in sugar beet seed.

Box 5.2. Market concentration in vegetable seed in Europe

With sales of USD 4.7 billion, the market for vegetable seed accounts for some 10% of the global seed market by value (Figure 2.6). The database used in this study does not contain market share information on vegetable seed, but some insights can be obtained from data on plant breeders' rights in Europe. The analysis here uses the PLUTO database (Chapter 6).

Table 5.9 shows the ownership of EU-wide plant breeders' rights for cucumber, carrot, lettuce, and tomato, respectively, as well as the four-firm concentration ratio. In all segments, the four largest firms account for most plant breeders' rights: 72% in tomato, 79% in lettuce, 94% in cucumber, and 95% in carrot. Monsanto holds a strong position in cucumber (46%), while Bayer (through its Nunhems brand) holds a strong position in carrots (52%). Interestingly, several specialised firms have strong positions in vegetable seed, such as Rijk Zwaan and Enza Zaden, both privately held family-owned businesses from the Netherlands.

In its decision on the Bayer-Monsanto merger, the European Commission noted that Monsanto is the largest global supplier of vegetable seeds, and Bayer the fourth-largest player. To secure approval for the merger, Bayer divested its global vegetable seeds business to BASF. A combined Bayer-Monsanto vegetable seeds business would have held around 80% of plant breeders' rights in cucumber in the European market and 71% in carrot, with a strong position in tomato (39%).

However, plant breeders' rights are not a perfect measure of market shares. A single "star" variety may have a disproportionate market share while many other varieties may have little or no sales. Many successful varieties were introduced before the period under consideration (2013-2017), including some no longer covered by a plant breeders' right. Moreover, firms may differ in their strategy regarding protection of their varieties. For these reasons, the correlation between market shares and plant breeders' rights is far from perfect.

Table 5.9. Ownership of plant breeders' rights for vegetables in Europe

EU-wide plant breeders' rights only, 2013-2017

	Cucumber		Carrot		Lettuce		Tomato	
Rijk Zwaan	9	11%	-	-	130	32%	63	20%
Monsanto	39	46%	4	0	25	6%	77	24%
Enza Zaden	5	6%	-	-	106	26%	18	6%
Nunhems (Bayer)	27	32%	11	1	26	6%	47	15%
Syngenta	5	6%	-	-	47	11%	43	14%
Limagrain	-	0%	3	0	44	11%	44	14%
Bejo	-	0%	2	0	12	3%	-	0%
Other	-	0%	1	0	19	5%	26	8%
Total	85	100%	21	1	409	100%	318	100%
Four-firm concentration ratio	94%		95%		80%		73%	

Note: Table shows total number of approved EU-wide plant breeders' rights applied for in the period 2013-2017 by applying party using the following uc-codes in the PLUTO database: CUCUM_SAT (Cucumber), DAUCU_CAR (Carrot), LACTU_SAT (Lettuce) and SOLAN_LYC (Tomato).

Source: OECD analysis using the UPOV PLUTO database (version 16 February 2018).

5.3. Determinants of concentration in seed markets

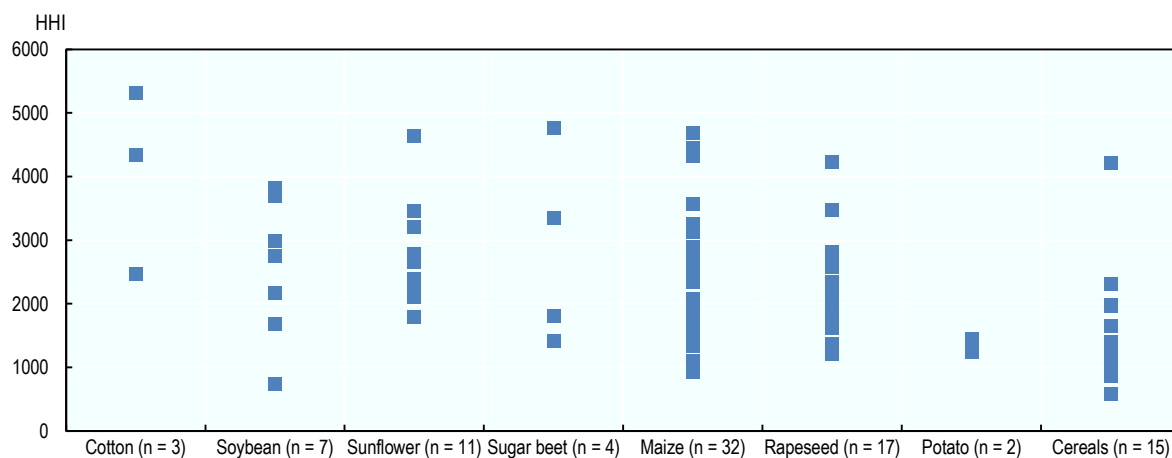
As the database varies in coverage across countries and crops, it is not easy to provide a clear assessment of overall trends. For some countries and crops, only a small number of observations exist. Some patterns can nevertheless be discerned.

Figure 5.10 plots all observations of market concentration for the different crop seed markets. Using the median observation per crop seed market, markets have been ranked from high to low market concentration levels. Despite the limited number of observations available, cotton appears to have the highest levels of market concentration, followed by several crops with intermediate levels (soybean, sunflower, sugar beet, maize). Rapeseed, potato, and wheat and barley appear to have much lower levels of market concentration.

Figure 5.11 plots these data points for the different countries and indicates with which crop each data point corresponds. Fewer observations are available per country than are available per crop. For 14 of the 38 countries there is only one observation; for seven countries, there are only two observations; for eight countries, there are three observations; and for the remaining nine countries, there are at least four observations. Hence, the ranking of countries needs to be interpreted with caution.

Figure 5.10 and Figure 5.11 show data without correcting for composition effects. For instance, the high score for cotton in Figure 5.10 could be due to biological or technological characteristics of cotton, or to the fact that data is only available from countries with higher levels of market concentration overall. Conversely, in Figure 5.11 the high score for South Africa could be due either to the country's institutional characteristics or to the higher concentration levels overall for soybean, maize and sunflower. In other words, it is important to disentangle “crop-specific” and “country-specific” effects. Given the limitations of the dataset, it will not be possible to perfectly distinguish between the two here, but an attempt can be made through a regression of market concentration levels on crop and country indicator variables and a number of other control variables (Table 5.10).

Figure 5.10. Market concentration across crop seed markets, 2016



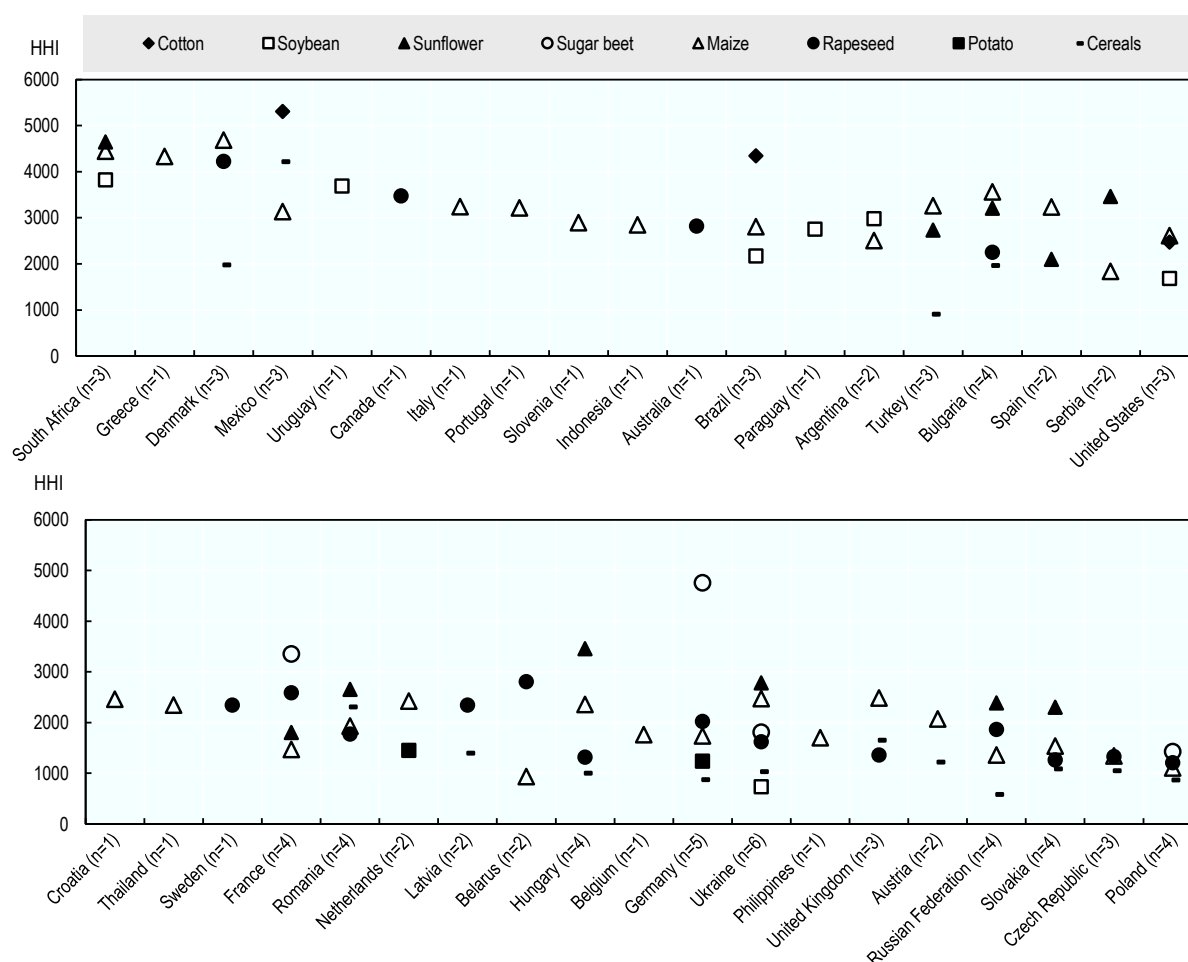
Note: Each data point corresponds to an observation of the (value-based) HHI index as detailed in Table 5.1 to Table 5.8.

Source: OECD analysis using the Kleffmann amis®/AgriGlobe® database except as noted in Table 5.8.

Strong differences are found between crops. Compared to the reference category of wheat and barley, markets for sugar beet, sunflower and cotton seed on average have an HHI index which is more than 1 000 points higher, a sizeable difference. Similarly, maize and rapeseed have, on average, higher market concentration than wheat and barley. By contrast, the markets for potato and soybean seed do not appear to be systematically more concentrated than wheat and barley, after correcting for other factors including country-specific effects. These crop differences are visualised in Figure 5.12 (using the estimates in the third column of Table 5.10).

In addition, the regression analysis controls for other factors which could in theory affect market concentration, although none of these show a clear effect. In theory a smaller market could lead to higher concentration (as fewer firms are willing to enter the market), a market where GM technology is present could be more concentrated (because of economies of scale and complementarity effects), and a large role for public breeders or a large share of farm-saved seed could intensify competition among commercial firms. The data, however, do not support any of these hypotheses.¹²

Figure 5.11. Market concentration across countries, 2016



Note: Each data point corresponds to an observation of the (value-based) HHI index as detailed in Table 5.1 to Table 5.8.

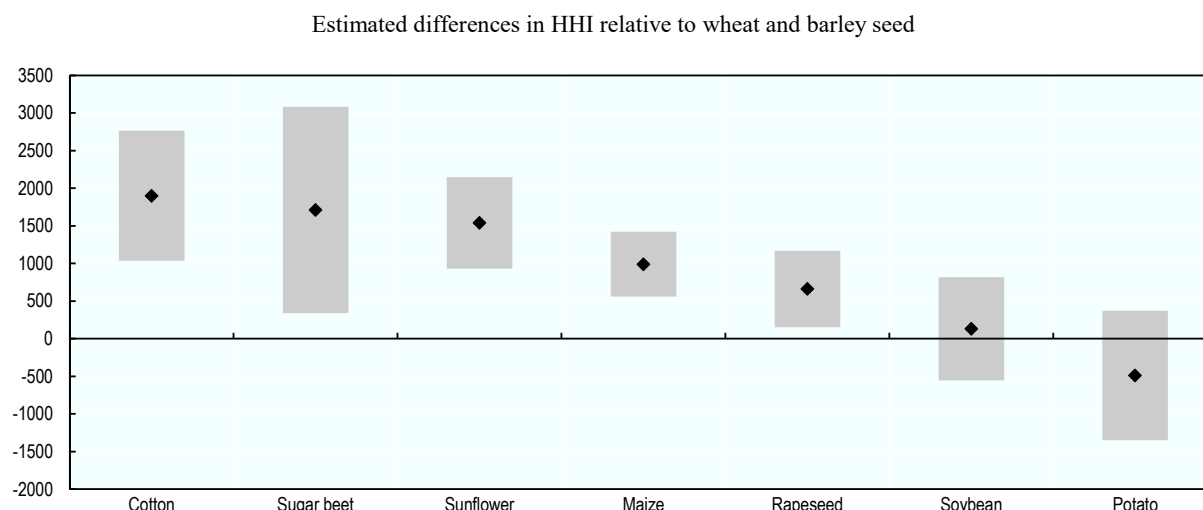
Source: OECD analysis using the Kleffmann amis® AgriGlobe® database except as noted in Table 5.8.

Table 5.10. Determinants of market concentration

Dependent variable: Value-based HHI			
Explanatory variables	(1)	(2)	(3)
Log(Market size in mln USD)	-0.016 (0.011)	-0.016 (0.011)	-0.013 (0.011)
GM used? (Yes = 1, No = 0)		0.053 (0.041)	0.038 (0.044)
Volume share of public breeders			0.087 (0.068)
Volume share of farm-saved seed			-0.048 (0.085)
<i>Crop fixed effects</i>	<i>(Reference category: wheat and barley)</i>		
Cotton	0.147*** (0.039)	0.118** (0.047)	0.190*** (0.044)
Maize	0.087*** (0.019)	0.082*** (0.019)	0.099*** (0.022)
Potato	-0.042 (0.031)	-0.045 (0.031)	-0.049 (0.044)
Rapeseed	0.050** (0.022)	0.049** (0.022)	0.066** (0.026)
Soybean	0.024 (0.027)	-0.002 (0.034)	0.013 (0.035)
Sugar beet	0.167*** (0.057)	0.167*** (0.056)	0.171** (0.07)
Sunflower	0.125*** (0.023)	0.130*** (0.022)	0.154*** (0.031)
<i>Country fixed effects</i>	Yes	Yes	Yes
Constant	0.324*** (0.081)	0.290*** (0.085)	0.267*** (0.086)
Observations	91	91	87
Adjusted R ²	0.59	0.59	0.58
F Statistic	3.834*** (df = 45; 45)	3.764*** (df = 46; 44)	3.479*** (df = 47; 39)

Note: Output of OLS regressions with crop and country fixed effects. Numbers in brackets denote heteroscedasticity-robust standard errors. Significance levels: *p<0.1; **p<0.05; ***p<0.01. Dependent variable is the value-based HHI index, scaled between 0 and 1.

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

Figure 5.12. Crop differences in market concentration levels

Note: Shaded area refers to the 95% confidence interval around the estimated crop effect. Estimates shown are based on specification (3) in Table 5.10.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

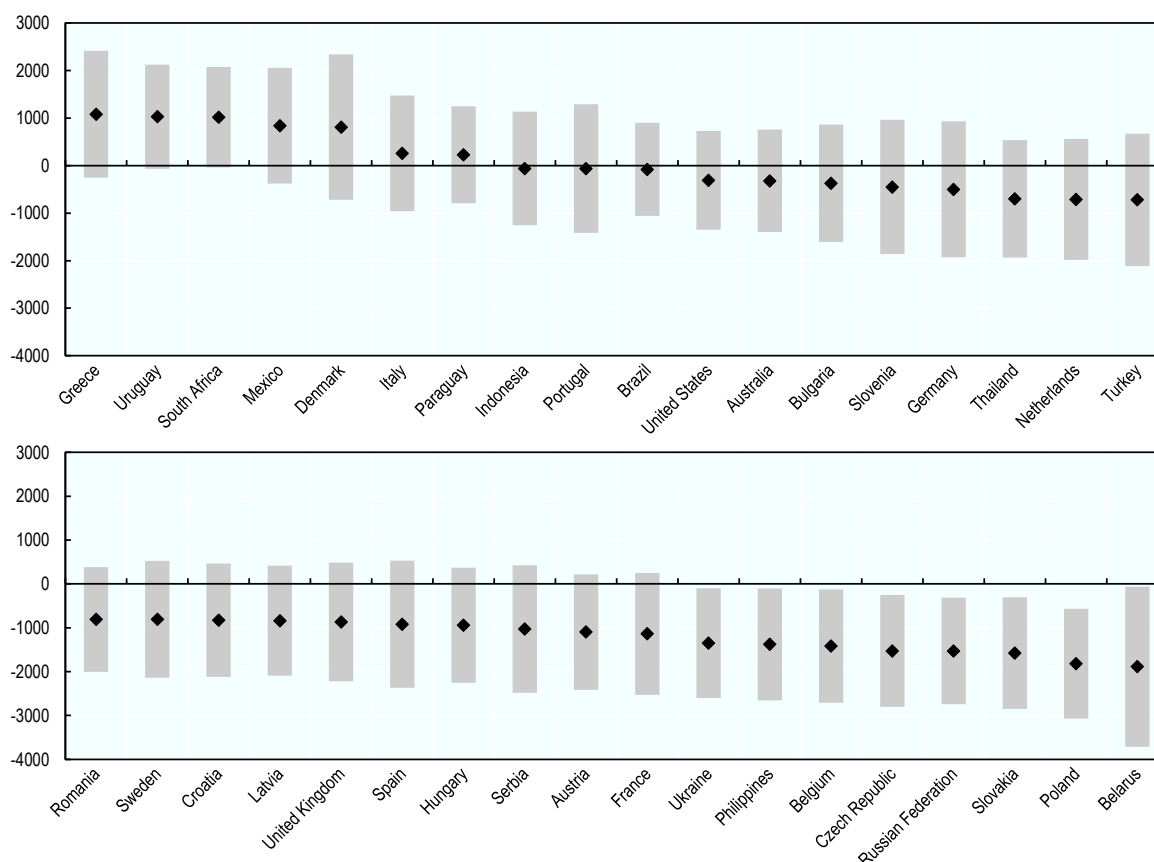
Figure 5.13 and Table 5.11 show the country effects corresponding to the specification in the last column of Table 5.10. In this case, country effects are expressed as differences in the HHI compared with the reference category, Argentina. For most countries there is no clear evidence of systematic differences, but for some countries the estimated effects tend to be large, with HHI differences of 1 000 points or more compared to Argentina.

It appears from this exercise that Greece, Uruguay and South Africa have systematically higher levels of market concentration whereas countries such as Slovakia, Poland and Belarus appear more competitive across different crop seed markets.

These results need to be interpreted with caution given the low number of observations in the database. For instance, the United States appears to have relatively competitive seed markets in part because the US market for soybean and cotton seed is more competitive than in the other countries in the dataset. If additional markets were included, rankings might look different. Moreover, high levels of market concentration as measured here do not necessarily mean a high level of concentration in the commercial seed sector; in Mexico, for instance, the market for wheat and barley seed appears highly concentrated due to the important role played by public institutes.

Figure 5.13. Country differences in market concentration levels

Estimated differences in HHI relative to the reference category (Argentina)



Note: Estimates for Canada not available due to small number of observations. Shaded area refers to the 95% confidence interval around the estimated country effect. Estimates shown are based on specification (3) in Table 5.10.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Table 5.11. Country differences in market concentration levels

Estimated differences in HHI relative to Argentina				
	Estimated country effect	Lower bound	Upper bound	Significance level of estimated country effect
Australia	-320	-1398	758	
Austria	-1100	-2413	213	
Belarus	-1890	-3713	-67	**
Belgium	-1420	-2714	-126	**
Brazil	-80	-1060	900	
Bulgaria	-370	-1605	865	
Canada	n.a.	n.a.	n.a.	
Croatia	-830	-2124	464	
Czech Republic	-1530	-2804	-256	**
Denmark	810	-719	2339	
France	-1140	-2532	252	
Germany	-500	-1931	931	
Greece	1080	-253	2413	
Hungary	-940	-2253	373	
Indonesia	-60	-1256	1136	
Italy	260	-955	1475	
Latvia	-840	-2094	414	
Mexico	840	-375	2055	
Netherlands	-710	-1984	564	
Paraguay	230	-789	1249	
Philippines	-1380	-2654	-106	**
Poland	-1820	-3074	-566	***
Portugal	-60	-1412	1292	
Romania	-810	-2006	386	
Russian Federation	-1530	-2745	-315	**
Serbia	-1030	-2480	420	
Slovakia	-1580	-2854	-306	**
Slovenia	-450	-1861	961	
South Africa	1020	-38	2078	*
Spain	-920	-2370	530	
Sweden	-810	-2143	523	
Thailand	-700	-1935	535	
Turkey	-720	-2112	672	
Ukraine	-1350	-2604	-96	**
United Kingdom	-870	-2222	482	
United States	-310	-1349	729	
Uruguay	1030	-68	2128	*

Note: Estimates shown are based on specification (3) in Table 5.10. Estimates for Canada not available due to small number of observations. Lower bound and upper bound refer to the 95% confidence interval around the estimated country effect. Final column shows significance levels of estimated country effects against the null hypothesis of no difference compared with the reference country (Argentina); levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

5.4. Multimarket contact

Seed firms are typically active in several geographies and several crops. For this reason, it is important to study the degree of multimarket contact or overlap between the set of players in different markets. A high degree of overlap in the firms active in different markets could increase the likelihood of collusion between firms as well as reduce the contestability of markets by diminishing the likelihood of entry by outsider firms.

Table 5.12 shows the presence of major maize firms across different countries in the database. The maize firms were selected as they were the ten firms present in the greatest number of countries. For each country, a company is indicated as being active if it is one of the top ten firms in that market. Of the 32 countries for which data on the maize seed market is available, Syngenta and DuPont are active in 31 countries, Monsanto is active in 29, and KWS and Limagrain in 25 countries. The degree of overlap is considerable.

This degree of overlap reflects both the presence of truly multinational firms such as Syngenta, DuPont and Monsanto, as well as firms with a strong European presence, such as Caussade or RAGT. As the Kleffmann database focuses on European countries, by construction firms with a strong European presence appear in the table as major firms; a database with a different geographical focus would presumably identify a different set of major firms. Hence, it is difficult to generalise to all seed markets, but for the markets covered in the Kleffmann database the degree of multimarket contact appears considerable. Even in non-European maize markets such as Argentina, Indonesia, Mexico, the Philippines, Thailand and the United States, there is clear evidence of multimarket contact as Syngenta, DuPont and Monsanto are present in all these markets.

The same pattern is found for the other crop seed markets. For soybean seed (Table 5.13), four firms (Monsanto, Syngenta, Nidera, and Asociados Don Mario) are active in at least five of the seven seed markets in the database. For wheat and barley (Table 5.14), KWS, Nordsaat and Limagrain are competing against each other in more than half of the countries in the database. Similar situations are found for rapeseed (Table 5.15) and sunflower (Table 5.16).¹³

However, significant differences can be found across markets too. For instance, the degree of multimarket contact seems to be greatest for maize, rapeseed, and sunflower seed but lower for wheat and barley. The set of firms tends to differ by crop. For instance, NPZ is active in a large number of countries, but focuses on rapeseed and is not a major multinational player in other seed markets. Other firms such as RAGT and Euralis are active across several countries and crops, although not necessarily to the same extent as the major firms. There are some notable absences. For instance, despite a strong position in rapeseed in European countries, neither NPZ nor DSV are active in the Canadian market (where GM technology is used, in contrast to the European market), nor is Monsanto a major player in European seed markets for wheat and barley or sunflower. Monsanto sold its European wheat and barley assets to RAGT in 2004 and its global sunflower assets to Syngenta in 2010.

As the database does not have complete coverage of geographies and crops, the findings here almost certainly underestimate the degree of multimarket contact. In general, then, there does appear to be a considerable degree of multimarket contact, both across geographies and across crops.

Table 5.12. Multimarket contact: Maize

Maize	Syngenta	DuPont	Monsanto	KWS	Limagrain	Maisadour	Caussade	RAGT	Dow	Euralis
Argentina	X	X	X	X					X	
Austria	X	X	X	X	X	X		X		X
Belarus	X			X		X	X			X
Belgium	X	X	X	X	X	X	X	X		X
Brazil	X	X	X						X	
Bulgaria	X	X	X	X	X	X	X	X		X
Croatia	X	X	X	X	X			X		
Czech Republic	X	X	X	X	X	X	X	X	X	
Denmark	X	X		X	X	X	X	X		
France	X	X	X	X	X	X	X	X		X
Germany	X	X	X	X	X	X	X	X		X
Greece	X	X	X	X	X	X	X			
Hungary	X	X	X	X	X	X		X	X	
Indonesia	X	X	X		X					
Italy	X	X	X	X	X	X	X			
Mexico	X	X	X						X	
Netherlands	X	X	X	X	X	X	X			
Philippines	X	X	X							
Poland	X	X	X	X	X	X	X	X		X
Portugal	X	X	X	X	X	X	X		X	
Romania	X	X	X	X	X	X	X	X		
Russian Federation	X	X	X	X	X	X		X		X
Serbia	X	X	X	X	X					
Slovakia	X	X	X	X	X		X	X	X	
Slovenia	X	X	X	X	X			X		X
South Africa		X	X		X					
Spain	X	X	X	X	X	X	X	X	X	
Thailand	X	X	X							
Turkey	X	X	X	X	X		X			
Ukraine	X	X	X	X	X	X		X	X	X
United Kingdom	X	X		X	X	X	X	X	X	X
United States	X	X	X						X	
Total (out of 32)	31	31	29	25	25	19	17	17	11	11

Note: Firms shown are the ten maize breeders with the largest country presence in the database; data is from 2016.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Table 5.13. Multimarket contact: Soybean

	Monsanto	Syngenta	Nidera	Asociados Don Mario	DuPont	TMG
Argentina	X	X	X	X		
Brazil	X	X	X	X	X	X
Paraguay	X	X	X	X		X
South Africa	X		X	X	X	
Ukraine						
United States	X	X			X	
Uruguay	X	X	X	X		X
Total (out of 7)	6	5	5	5	3	3

Note: Firms shown are soybean breeders active in at least three countries in the database; data is from 2016. In 2017, Syngenta acquired Nidera's seeds business.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Table 5.14. Multimarket contact: Wheat and barley

	KWS	Nordsaat	Limagrain	RAGT	Syngenta	DSV	Lantmännen	Saatzucht Donau
Austria	X	X		X		X	X	X
Bulgaria	X	X	X		X			X
Czech Republic	X	X	X	X		X	X	X
Denmark	X	X	X	X	X			
Germany	X	X	X	X	X	X	X	
Hungary	X	X	X		X			
Latvia	X	X			X	X	X	
Mexico								
Poland	X			X		X	X	
Romania		X	X					X
Russian Federation								
Slovakia	X	X	X	X				X
Turkey					X			
Ukraine						X		
United Kingdom	X		X	X	X			
Total (out of 15)	10	9	8	7	7	6	5	5

Note: Firms shown are wheat and barley breeders active in at least five countries in the database; data is from 2016.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Table 5.15. Multimarket contact: Rapeseed

	Monsanto	DSV	NPZ	DuPont	Syngenta	Limagrain	KWS	Bayer	RAGT	Euralis
Australia			X	X				X		
Belarus	X	X	X		X		X	X		X
Bulgaria	X	X	X	X	X	X	X	X		X
Canada	X			X				X		
Czech Republic	X	X	X	X	X	X	X		X	X
Denmark	X	X	X		X	X	X		X	
France	X	X		X	X	X	X		X	X
Germany	X	X	X	X	X	X		X	X	X
Hungary	X	X	X	X	X	X	X	X	X	
Latvia	X	X	X	X		X	X	X	X	
Poland	X	X	X	X	X	X	X		X	
Romania	X	X	X	X	X	X	X	X		X
Russian Federation	X	X	X	X			X	X		
Slovakia	X	X	X	X	X	X	X		X	
Sweden	X	X	X	X	X					X
Ukraine	X	X	X	X	X	X		X	X	X
United Kingdom	X	X	X		X	X	X	X	X	
Total (out of 17)	16	15	15	14	13	12	12	11	10	8

Note: Firms shown are the ten rapeseed breeders with the largest country presence in the database; data is from 2016.

Source: OECD analysis using the Kleffmann amis@AgriGlobe® database.

Table 5.16. Multimarket contact: Sunflower

	DuPont	Syngenta	Limagrain	Euralis	RAGT	Maisadour	Caussade	Dow	UPL	May Seed Group	Nidera
Bulgaria	X	X	X	X		X	X		X	X	X
France	X	X	X	X	X	X	X	X			
Hungary	X	X	X	X	X		X		X	X	X
Romania	X	X	X	X	X	X	X	X	X		X
Russian Federation	X	X	X	X	X	X		X			
Serbia	X	X	X	X	X	X	X		X		
Slovakia	X	X	X	X	X		X			X	X
South Africa	X	X									
Spain	X	X	X	X	X	X					
Turkey	X	X	X	X	X					X	
Ukraine	X	X	X	X	X	X	X	X			
Total (out of 11)	11	11	10	10	9	7	7	4	4	4	4

Note: Firms shown are the ten sunflower breeders with at least 4 country presences in the database; data is from 2016.

Source: OECD analysis using the Kleffmann amis@AgriGlobe® database.

5.5. Concentration in the market for GM traits

The preceding sections have focused on market concentration in seed (germplasm). This section presents available information on market concentration in markets for GM traits, using a variety of sources. Data on concentration in GM traits can be found in publicly available information for US cotton and Canadian canola markets. For some other markets, the Kleffmann amis®AgriGlobe® database can provide indirect information on market concentration in GM traits. For some markets, the Kleffmann database lists not only sales by firm but includes data on the ten best-selling varieties. Technical documentation (e.g. on company websites) can be used to infer which GM traits are incorporated in these varieties. The resulting view of market concentration in GM traits is incomplete, as only data for the top ten varieties is available. For some markets, these account for the majority of sales; for others, the share of the market covered by the best-selling varieties can be as low as 10% (Table 5.17). Even in these markets, however, the data can provide some useful insights.

Table 5.17. Overview of GM markets covered

Country	Crop	Share of market covered by data	Area cultivated ('000 of ha)	Adoption of GM	GM area ('000 of ha)
United States	Maize	10%	38 041	92%	34 998
Brazil	Maize	21%	14 577	88%	12 828
Argentina	Maize	39%	3 300	95%	3 135
South Africa	Maize	45%	1 942	85%	1 651
Brazil	Soybean	35%	32 300	97%	31 169
Argentina	Soybean	52%	20 704	100%	20 704
Paraguay	Soybean	87%	3 813	96%	3 661
Uruguay	Soybean	69%	1 161	98%	1 138
South Africa	Soybean	68%	497	95%	472
United States	Cotton	100%	4 061	96%	3 899
Brazil	Cotton	84%	894	78%	700
Mexico	Cotton	97%	123	98%	121
Canada	Canola	100%	9 146	95%	8 689

Note: All data 2016 except Canada canola (2017). “Share of market covered by data” refers to the share of the market accounted for by the top-10 varieties covered by the Kleffmann database, except for Canadian canola (from Brewin and Malla (2017^[136])) and US cotton (based on USDA AMS reports). In both cases the data represents the full market.

Source: Kleffmann amis®AgriGlobe® database except GM adoption rates from United States Department of Agriculture (for US maize and cotton), argenbio.org (for Argentine maize and soybean), AgroPages.com (for Brazilian cotton, maize and soybean), and ISAAA.org (all others).

The markets covered here represent some of the most important GM markets worldwide and cover two-thirds of the global GM area (Table 5.18). Coverage is greatest for canola (where Canada by itself accounts for most of global GM canola) and maize (where the United States accounts for more than half). Coverage is lowest for cotton as the data does not include major GM cotton producers such as India and Pakistan.

Analysis of market concentration in GM traits raises a conceptual problem because of the frequent practice of combining several GM traits in stacks. For instance, the AcreMax stack for maize (popular in the United States) contains Monsanto’s YieldGard and Dow’s Herculex HX1 as insect resistance traits, as well as Bayer’s LibertyLink and Monsanto’s Roundup Ready 2 herbicide tolerance traits. In a hypothetical scenario where 100% of the market used this stack, it is not clear whether LibertyLink and Roundup Ready should be seen as each simultaneously having 100% of the market for herbicide tolerance traits (since each trait is

present in all seeds in this scenario) or as each having 50% of the market. The conceptual problem also exists for insect resistance traits, where different traits may also target different pests while not all pests are present in every sub-region of the market.¹⁴ A pragmatic approach is used here: rather than calculating explicit concentration measures, the following paragraphs provide a description of the competitive situation in GM traits.

Table 5.18. Importance of markets covered

	GM area of countries covered (million hectares)	Global GM area (million hectares)	Coverage (%)
Maize	52.61	60.6	87%
Soybean	57.14	91.4	63%
Cotton	4.72	22.3	21%
Canola	8.69	10.2	85%
Total	123.16	185.1	67%

Note: All data refers to 2016 except canola (2017).

Source: ISAAA (2017^[18]) and (2016^[16]).

Maize

The US maize market is the largest GM market in terms of acreage across all crops. The ten best-selling varieties only cover around 10% of the total market for US maize varieties, which makes it difficult to draw strong conclusions about overall market shares for GM traits. Nevertheless, the clear pattern that emerges is that stacks combining several herbicide-tolerant and/or insect resistance traits play an important role in the market. Two popular systems are AcreMax (including variants such as AcreMax Xtra and AcreMax XTreme) and SmartStax. All of these stacks combine traits of several firms, and all of the best-selling varieties include Monsanto's Roundup Ready and insect resistance traits by Dow. Most varieties also include Bayer's LibertyLink and Monsanto insect resistance traits; some varieties also include Syngenta's Agrisure insect resistance trait.

Based on this information, the competitive situation in maize traits appears complex. A small number of stacks dominate the best-selling varieties, and just four firms supplied all the traits included in these stacks. At the same time, the stacks combine traits by competitors. Some of these traits are complementary (e.g. insect resistance traits for different pests) but the combination of two competing herbicide tolerance traits is also common. The merger between Bayer and Monsanto would have removed competition on herbicide tolerance traits, as none of the best-selling varieties included traits by other firms (as noted, Bayer sold its LibertyLink assets to BASF to obtain regulatory approval). The analysis also shows that the DowDuPont merger did not affect the situation in the market for GM traits as DuPont did not have a strong position in GM traits.¹⁵

In Brazil, the top-selling maize varieties similarly contain stacked traits such as Dow's PowerCore, which combines insect resistance traits of Monsanto and Dow, as well as Roundup Ready and LibertyLink herbicide tolerance traits. At the same time, single-firm offerings were also present, such as Monsanto's VT PRO and Syngenta's Viptera. As in the United States, Monsanto traits appear to be ubiquitous, whether alone or in combination with Dow traits.

In Argentina, most of the top-ten varieties included Monsanto's VT Triple Pro technology (a stack which combines insect resistance traits with Roundup Ready herbicide tolerance). Dow's PowerCore trait stack was also present.

In South Africa, eight of the ten top-selling varieties are GM, and all of these include Monsanto traits, including non-Monsanto maize seed varieties.

The four maize markets covered here jointly account for 87% of the global GM maize area. Stacked traits are used widely. In the United States and Brazil, these stacks often combine traits by competing firms, including competing herbicide tolerance traits. In all markets, GM traits by Monsanto are ubiquitous, either in single-firm stacks or in combination with traits of other firms.

Soybeans

The available data for Brazil, Paraguay and Uruguay show that all of the top-ten soybean varieties in these countries incorporated a Monsanto-only GM trait stack. Both Monsanto's Roundup Ready stack and the newer Intacta Roundup Ready 2 PRO stack were present. Monsanto's GM traits also played an important role in Argentina. Trait stacks from other firms were available, in the form of Syngenta's Plenus system and DuPont's STS herbicide tolerance trait; these captured a smaller share of the market, however.

Other sources confirm Monsanto's strong position in soybean traits in Latin America. During the 2013-14 season, Roundup Ready traits were present on an estimated 84% of the Brazilian soybean acreage (Bonato, 2016^[142]). Intacta, a newer Monsanto offering, was planted on 24% of the planted area in Brazil, Argentina, Paraguay and Uruguay in the 2015-16 season and was expected to capture 31 to 38% of the area in the 2016-17 season. However, Monsanto did not expect Intacta to gain the same prominence as Roundup Ready had previously, as competing offers would soon become available (Bonato, 2016^[142]).

In South Africa, all of the best-selling varieties used Monsanto's Roundup Ready technology as this is the only soybean GM trait approved in the country (see further for an overview of GM approvals by crop and by country).

The soybean markets covered here jointly account for 63% of the global GM soybean area. As with maize traits, Monsanto's GM technology appears widespread. In contrast with maize, where stacks sometimes included traits by competitors, the data suggests most soybeans have single-firm trait stacks, with Monsanto capturing most of the market.

Cotton

The Kleffmann database covers the cotton seed markets of Brazil and Mexico, while data from the United States Department of Agriculture is available on the US cotton seed market (Chapter 3.4). Together, these countries only cover some 4.7 million hectares out of an estimated 22 million hectares of global GM cotton area.

For the United States, Monsanto's Roundup Ready and BollGard traits dominate the market. In 2011, 94% of cotton acreage included a variant of Monsanto's Roundup Ready technology, while 73% included Monsanto's BollGard insect resistance traits. Until 2007, nearly all GM technology in the cotton sector was Monsanto-only. After the Department of Justice required Monsanto to allow stacking Monsanto traits with those of competing firms in 2007, mixed stacks grew strongly and accounted for some 35% of total cotton acreage in 2014 and 2015. In parallel, the growth in sales of PhytoGen and Americot cotton varieties also allowed for a greater market share of Bayer (LibertyLink, TwinLink and GlyTol) and Dow (WideStrike) traits, although these remain much smaller than Monsanto.

The Brazilian and Mexican cotton seed market show contrasting patterns. In Brazil, several competing trait stacks are available in the market; the top-selling varieties include trait stacks such as Dow's Widestrike, Bayer's GLT (GlyTol, LibertyLink, TwinLink) and Monsanto's BollGard2 RoundupFlex; Monsanto's market share is smaller than that of its competitors. In Mexico, however, Monsanto appeared to be the only provider of cotton GM traits, with even Bayer's cotton seed offerings relying on Monsanto GM traits.

The markets covered here only account for 21% of global GM cotton area, as no data is available for large producers such as India, China, and Pakistan. However, indirect information suggests Monsanto provides nearly all cotton GM traits in India, the largest GM cotton market in the world with 11 million hectares of GM cotton in 2017. Between 2002 and 2006, the only traits approved for commercialisation were Monsanto-owned (Pray and Nagarajan, 2012^[143]). Expert estimates put Monsanto's share of Bt cotton at 90-95% in 2009-10, and Monsanto's share may have grown even further thanks to the success of its BollGard II varieties (Carl Pray, personal communication).

Rapeseed/canola

As discussed above, the available data for Canada shows that the market for GM traits in canola is considerably more concentrated than the market for seed (Figure 5.7). In 2014, around two-thirds of the canola area in Canada contained Bayer's LibertyLink traits, while 25% contained Monsanto's Roundup Ready, and 10% contained BASF's Clearfield (a non-GM herbicide tolerance trait).

Indirect evidence from GM approvals

The International Service for the Acquisition of Agri-biotech Applications (ISAAA) maintains a global database of GM approvals, which includes information on crop type, developer, trait type, and approval type. Information on approvals of GM events for cultivation can provide an indirect view of concentration on GM trait markets, since without approval no sale can take place. A company's share of GM approvals should therefore provide a rough indication of its potential share of the GM traits market.¹⁶

For maize, the number of GM events approved for cultivation is similar in the United States, Brazil, and Argentina (Table 5.19). Despite these similarities, the concentration of GM events follows somewhat different patterns. In the United States, Monsanto holds 14 of the 42 approved events (33%), with another two developed in collaboration with others. Syngenta, which is in second place, only holds eight approvals (19%). By contrast, in Argentina Syngenta has a considerably larger share of GM approvals than Monsanto, while in Brazil the two firms have the same number of approvals (once Monsanto's jointly developed events are taken into account). The number of approved GM events for maize is lower in South Africa; Monsanto holds the majority of approvals. Canada has approved the highest number of maize GM events; although Bayer-Monsanto holds the highest number of approved events, Syngenta and DowDuPont hold a considerable share of the total.

A smaller number of events have been approved for soybeans (Table 5.20). Across all markets, Monsanto holds the highest number of approved GM events. Its relative share is highest in South Africa (where Roundup Ready is the only approved GM event for soybeans), Paraguay and Uruguay. In the United States, Brazil, Canada, and Argentina other firms such as Bayer, Dow and DuPont also hold an important share of approved events.

Table 5.19. Maize GM events approved for cultivation

Firm	Argentina	Brazil	Canada	South Africa	United States
Syngenta	21	14	18	2	8
Monsanto	9	11	20	6	14
DuPont	8	7	7	1	6
Dow	2	5	7	0	2
Dow & DuPont	3	3	4	2	2
Bayer	1	1	3	0	5
Monsanto & Dow	1	2	1	0	0
Monsanto & BASF	0	1	1	0	1
Genective	0	0	1	0	1
Monsanto & DuPont	0	0	1	0	1
Renessen	0	0	1	0	1
Stine Seed	0	0	1	0	1
Syngenta & Monsanto	0	0	1	0	0
Total	45	44	66	11	42

Note: is table shows the cumulative number of GM events (both stacked and single traits) approved for cultivation from 1992 to 9 July 2018. Firm is the developer of the event as listed by ISAAA's GM approval database.

Source: OECD analysis using International Service for the Acquisition of Agri-biotech Applications (ISAAA)'s GM Approval Database, <http://www.isaaa.org/gmapprovaldatabase/default.asp> (accessed 9 July 2018).

Table 5.20. Soybean GM events approved for cultivation

Firm	Argentina	Brazil	Canada	Paraguay	South Africa	United States	Uruguay
Monsanto	4	6	8	2	1	8	4
Bayer	3	3	2	0	0	7	2
Dow	3	4	4	0	0	3	0
DuPont	1	0	4	0	0	3	0
BASF	1	1	1	1	0	1	1
Bayer & MS Technologies	0	1	1	0	0	1	0
Bayer & Syngenta	1	0	1	0	0	1	0
Verdeca	1	0	0	0	0	0	0
Total	14	15	21	3	1	24	7

Note: This table shows the cumulative number of GM events (both stacked and single traits) approved for cultivation from 1992 to 9 July 2018. Firm is the developer of the event as listed by ISAAA's GM approval database.

Source: OECD analysis using International Service for the Acquisition of Agri-biotech Applications (ISAAA)'s GM Approval Database, <http://www.isaaa.org/gmapprovaldatabase/default.asp> (accessed 9 July 2018).

Table 5.21 shows the number of approved GM events in cotton. Across the four markets, Monsanto again has the largest share of GM events. Notably, Monsanto's share of approved events is smallest in India, where several local players have developed GM events. As mentioned previously, however, Monsanto's BollGard and BollGard II insect resistance traits are by far the most used in the Indian market. In the other markets, Monsanto holds more than half of all GM events, while Bayer is the second-largest firm in the United States and Brazil.

Table 5.21. Cotton GM events approved for cultivation

Firm	United States	Brazil	Mexico	India
Monsanto	14	8	7	2
Bayer	5	6	0	0
Dow	3	1	3	0
Syngenta	2	0	1	0
Nath Seeds/Global Transgenes	0	0	0	1
Monsanto & Dow	0	0	1	0
Public sector - India	0	0	0	1
JK Agri Genetics	0	0	0	1
DuPont	1	0	0	0
Metahelix Life Sciences	0	0	0	1
Total	25	15	12	6

Note: This table shows the cumulative number of GM events (both stacked and single traits) approved for cultivation from 1992 to 9 July 2018. Firm is the developer of the event as listed by ISAAA's GM approval database.

Source: OECD analysis using International Service for the Acquisition of Agri-biotech Applications (ISAAA)'s GM Approval Database, <http://www.isaaa.org/gmapprovaldatabase/default.asp> (accessed 9 July 2018).

Finally, for canola in Canada, 19 GM events have been approved for cultivation.¹⁷ Of these, twelve are from Bayer, five from Monsanto, and two from DuPont. As noted earlier, BASF's Clearfield technology is a non-GM herbicide tolerance trait and is therefore not included in these numbers.

Across the different markets, some regularities stand out. First, the total number of approved GM events is relatively low, considering that ISAAA's database contains all approvals since the 1990s (which means several approved events have probably been superseded by newer technology or have become obsolete because of resistance build-up). A small number of approved events naturally limits the amount of competition that can be expected in a market. Second, markets with smaller numbers of approved events tend to show a greater prominence of Monsanto, which probably reflects Monsanto's first-mover advantage in developing GM technology. Third, a comparison with the market share data presented earlier shows that the GM events database understates in many cases the degree of concentration.¹⁸ For instance, in US cotton, only 10-20% of total area planted does *not* contain Monsanto traits (a figure which includes non-GM cotton). Yet Table 5.21 shows that Monsanto holds 56% of GM events. Likewise, Monsanto holds two of the six approved GM events in India, but reportedly nearly all of the GM traits market. The available data for other markets similarly suggests that the true degree of market concentration is higher than what is implied by GM event approvals.

Indirect evidence from patents

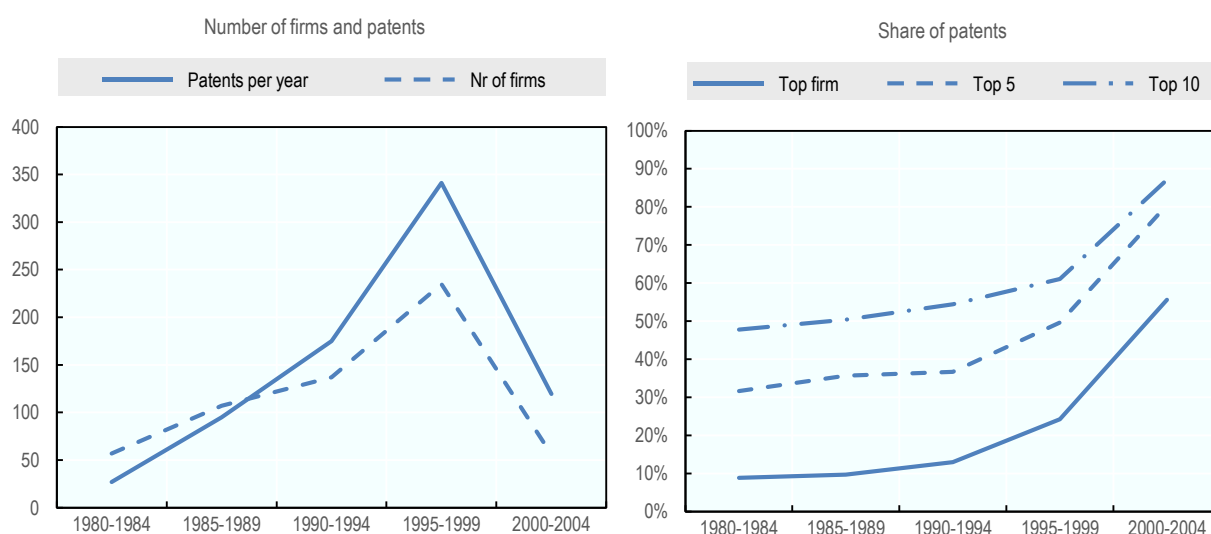
Another indirect way of evaluating concentration comes from assessing the concentration in ownership of intellectual property rights on biotechnology traits and tools.¹⁹

Heisey and Fuglie (2011^[7]) estimated that DuPont was responsible for 20.7% of US patents for agricultural biotechnology issued between 1976 and 2000, followed by Monsanto at 16.8%, Dow at 9.9%, and Syngenta at 9.8%. These four firms accounted for 57% of patents.²⁰ These numbers include patents on plants and biotechnologies.

Graff et al. (2003^[144]) analysed data on US agricultural biotechnology patents granted between 1982 and 2000. They found that Monsanto (14%), DuPont (13%), and Syngenta (7%) were the main private-sector firms holding such patents.²¹

Louwaars et al. (2009^[133]) provide data for both the United States and the European Union, focusing on private-sector patents on biotechnology processes and technologies. Figure 5.14 shows the evolution for the United States from 1980 to 2004. Both the number of firms and the number of patents granted per year showed a strong increase in the 1980s and 1990s, but with an apparent drop in the early 2000s.²² The share of patents granted to the top firm increased from around 10% of the total during the 1980s to 56% in the early 2000s, while the share of the top ten firms increased from around 50% to almost 90%.

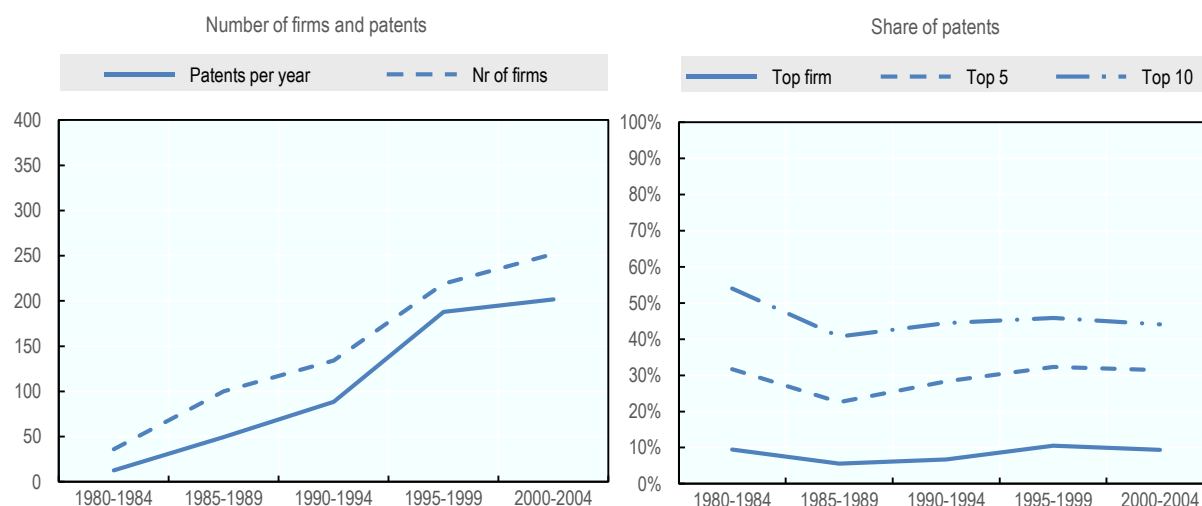
Figure 5.14. US patents on biotechnology, 1980-2004



Note: Data refers to patents granted by USPTO for IPC classes A01H1 to A01H4 (which includes processes for changing genotypes and phenotypes, as well as plant reproduction via tissue culture techniques) and C12N15/82, 83 and 84 (which includes recombinant DNA/RNA and other technologies used for the genetic modification of plants), for which full information was available about the identity of the patent holder/applicant. Data excludes patents for products (such as plant varieties), as well as patents from the public or non-profit sector or from individual patent holders.

Source: Analysis by Louwaars et al. (2009^[133]) using data from US Patents and Trademark Office (USPTO).

Figure 5.15 shows similar data for the European Union, where trends are somewhat different. The number of firms and patents shows strong growth in the 1990s before reaching a plateau in the early 2000s. The European data show lower and more stable levels of concentration of patents.²³

Figure 5.15. European patents on biotechnology, 1980-2004

Note: Data refers to EPO patent applications for IPC classes A01H1 to A01H4 (which includes processes for changing genotypes and phenotypes, as well as plant reproduction via tissue culture techniques) and C12N15/82, 83 and 84 (which includes recombinant DNA/RNA and other technologies used for the genetic modification of plants), for which full information was available about the identity of the patent holder/applicant. Data excludes patents for products (such as plant varieties), as well as patents from the public or non-profit sector or from individual patent holders.

Source: Analysis by Louwaars et al. (2009^[133]) using data from European Patent Office (EPO).

Louwaars et al. (2009^[133]) also present the main firms applying for biotechnology patents in the 2003-2007 period in the United States and Europe (Table 5.22). In contrast to Monsanto's strong position in GM traits and approved GM events, the firm with the largest number of patent applications in both the United States and the European Union was DuPont Pioneer. The data confirms the higher level of concentration in the United States, where DuPont and Monsanto jointly accounted for more than half of patent applications. In the European Union, the three leading firms (DuPont, BASF and Monsanto) each accounted for only 8-9% of patent applications.

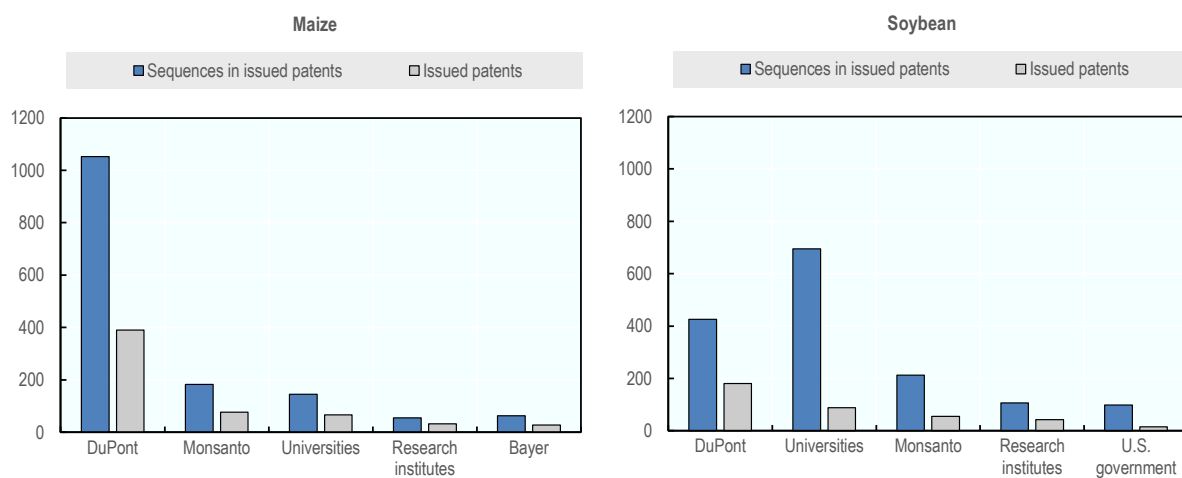
More recent data on ownership concentration of biotechnology patents is provided by Jefferson et al. (2015^[145]), who constructed a unique database of genetic sequences of maize, rice, and soybean referenced in the claims of patents issued globally from 1993 to 2014.²⁴ Their data on sequences and patents for maize and soybean are shown in Figure 5.16.²⁵

For maize, DuPont holds around 400 patents, with Monsanto holding less than 100. For soybean, DuPont holds almost 200 patents while Monsanto holds less than 100. In both cases, DuPont appears to hold a larger gene patent portfolio. Data on the sequences referenced in issued patent claims show an even greater degree of concentration for maize, with DuPont holding more than 1 000 sequences and Monsanto less than 200.²⁶ For both maize and soybean, it is clear that DuPont and Monsanto have a considerable lead over other multinational firms in terms of ownership of biotechnology-related patents.²⁷

Table 5.22. Top 10 firms applying for biotechnology patents, United States and the European Union

US patent applications, 2003-2007			EU patent applications, 2003-2007		
Firm	Number	Share	Firm	Number	Share
DuPont Pioneer	843	28%	DuPont Pioneer	107	9%
Monsanto	728	24%	BASF	105	9%
Syngenta	167	6%	Monsanto	101	8%
BASF	128	4%	Bayer	57	5%
Bayer	89	3%	Crop Design	36	3%
Ceres	74	2%	Syngenta	28	2%
Mertec	58	2%	Unilever	23	2%
Anix	49	2%	Icon Genetics	22	2%
Dow	48	2%	Novartis	21	2%
Delta and Pine Land	39	1%	Mendel Biotechnology	18	1%
Others	769	26%	Others	702	58%
Total	2992	100%	Total	1220	100%
Top 5	1955	65%	Top 5	406	33%
Top 10	2223	74%	Top 10	518	42%

Source: Analysis by Louwaars et al. (2009^[133]) using data from US Patent and Trademark Office (USPTO) and European Patent Office (EPO).

Figure 5.16. Ownership of patents and sequences

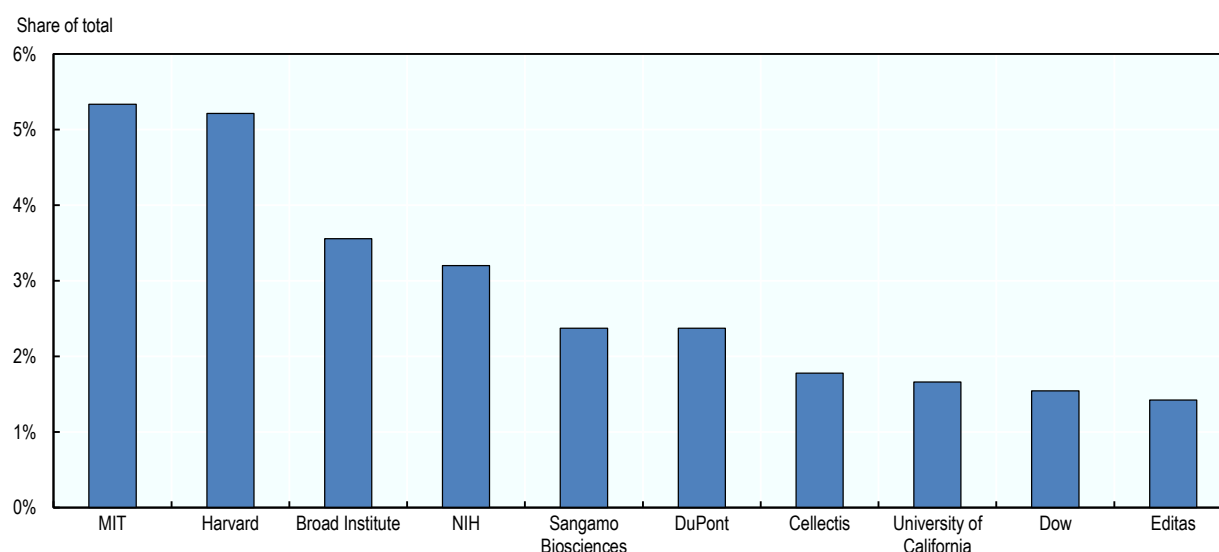
Note: Figures show the holdings of plant-related patents issued globally during the period 1993-2014 and of the genetic sequences referenced in the claims of these patents.

Source: Jefferson et al. (2015^[145])

Recent technological developments, in particular CRISPR-Cas gene editing technology, could considerably change which patents are relevant to biotechnology. It is therefore important to understand the ownership pattern of these patents. A recent analysis by Egelie et al. (2016^[146]) identified all patents filed around the world referring to any aspect of CRISPR and Cas9 technologies, removing double-counting of equivalent patents filed around the world. Figure 5.17 shows the top ten patent holders.

Of 604 inventions, MIT accounted for the greatest share (45, or 5.3%) followed by Harvard (44, 5.2%) and the Broad Institute (30, 3.6%). These three institutes collaborate intensively on CRISPR-Cas9. Moreover, Editas is a commercial spin-off from MIT and the Broad Institute. Aggregating these four organisations puts their total at 131 inventions, or 16% of the total. When the numbers for Dow and DuPont are combined, this firm becomes the second largest holder, with 33 inventions (4%). The University of California has only a small share of the inventions (14, or 2%), but these may include some essential aspects of the technology. Remarkably, other firms such as Bayer, Monsanto or Syngenta do not have a strong position in these patents.

Figure 5.17. Top 10 patent holders on CRISPR-Cas9, 2000-2015



Note: Patents counted in terms of “inventions” (i.e. removing double-counting of equivalent patent applications worldwide). Top ten holders account for 28% of total inventions.

Source: Egelie et al. (2016) using data from Thomson Innovation

Patent holdings on CRISPR-Cas9 thus appear considerably less concentrated than is the case for agricultural biotechnology, and academic institutes dominate the patent portfolio. A more detailed analysis by Egelie et al. (2016^[146]) shows that industry players such as Dow and DuPont seem to be more active in agricultural and food applications. At the same time, the prominent role of academic institutions does not guarantee easy access to the intellectual property underlying CRISPR-Cas9. While most academic institutions allow free use of their technologies for academic research purposes, they do not necessarily commit to providing broad and non-exclusive commercial licensing to make technology widely available for commercial applications.

Concluding remarks

Assessing market concentration in GM traits is difficult both because of the limited availability of data and because of conceptual difficulties. Yet, the evidence reviewed here strongly suggests that the degree of market concentration in GM traits is higher than that of seeds across the different markets surveyed.

Whereas independent local or regional firms often play a role in specific seed markets (e.g. Americot in US cotton; Don Mario in soybean seed in Latin America), only the major

firms (Monsanto, Bayer, Syngenta, Dow, DuPont) are generally active in the markets for GM traits. In maize markets, trait stacks often include traits from competing firms, but this seems to be less common in other markets. Overall, traits by Monsanto appear to be ubiquitous. By contrast, patents for CRISPR-Cas9 appear much less concentrated and are mostly held by academic institutes. While DowDuPont holds several patents, other firms such as Bayer-Monsanto or Syngenta were notably absent from the list of top 10 patent holders of this new technology.

The analysis here also suggests that indirect methods of assessing market concentration may give a misleading picture. First, a comparison of data on best-selling varieties with data on approved GM events suggests that the latter tends to understate the true extent of concentration in the GM traits market. At the same time, the data on patents consistently shows DuPont as either the leading firm in terms of patents on agricultural biotechnology or a close second after Monsanto. Yet DuPont is not a major player in terms of either approved GM events or market share of GM traits. Indirect measures of market concentration based on approved GM events or patent ownership are hence imperfect proxies for actual market concentration in sales.

5.6. Conclusion

This chapter has reviewed a large amount of new empirical evidence on market concentration in seed and GM traits, covering a broad set of countries and crops. Several insights emerge from the data.

First, seed markets show a large variation in market concentration. The Hirschman-Herfindahl Index varies from values below 1 000 (equivalent to a market with ten equally-sized firms) to values above 5 000 (equivalent to a market with two equally-sized firms).

Second, within this heterogeneity there are clear patterns. Seed markets for sugar beet, cotton, sunflower, maize, and rapeseed are typically more concentrated, while seed markets for potato, soybean and wheat and barley appear much less concentrated. There is also evidence of differences between countries, as some have systematically higher degrees of market concentration across different crop seed markets. However, the statistical analysis did not show a clear relationship between market concentration and market size, the presence of GM technology, the volume share of public breeders, or the volume share of farm-saved seed.

Third, there is a considerable degree of multimarket contact across seed markets, with similar firms competing against each other in different geographies and different crops. Not surprisingly, the large multinational firms are found in many markets. However, there are important differences between markets. There is more multimarket contact for maize, rapeseed, and sunflower, and less for wheat and barley. The set of firms also differs: some firms are active across geographies in a limited number of crops (e.g. NPZ in rapeseed), while large firms may be absent in some markets (e.g. Monsanto in European markets for wheat and barley, and sunflower).

For GM traits, market concentration appears much higher than for seed markets. While several medium-sized regional players are active in seed markets, the market for GM traits is dominated almost exclusively by large multinational firms (Monsanto, Bayer, Syngenta, DowDuPont). Traits by Monsanto appear particularly prominent, especially in markets where a smaller number of events has been approved. Data on patents for CRISPR-Cas9, however, suggest that this new technology is mostly dominated by academic institutes, with some presence of DowDuPont, but no strong position for Bayer-Monsanto or Syngenta.

An overarching conclusion from the analysis in this chapter is the need for precise data on market concentration issues, and an understanding of the context of specific markets. In the case of GM traits, data on patents or approvals appear to understate the real degree of market concentration. As noted earlier, discussions of market concentration in seed and GM traits have often relied on aggregate data, such as the four-firm concentration ratio for the global seed and GM traits market as a whole. Such measures are not very useful for policy makers. For instance, the commercial seed market is less important as a source of seed in developing regions, and within the commercial seed market some regions and crops dominate in terms of market size. Global figures will therefore tend to reflect the situation in the largest commercial seed markets. Furthermore, as the detailed analysis here has shown, there are important differences by crop and by country. Using aggregate figures can therefore result in misleading conclusions. By contrast, disaggregated data make it possible to conduct more precise analyses on the effects of market concentration, as shown in Chapter 6.

Box 5.3. Market concentration in developing countries

The data presented in this chapter covers mostly developed countries and some emerging economies. For most developing and least developed countries, little to no information is available regarding market concentration or the potential impact of recent mergers.

In many of these countries, farmers rely on informal systems (e.g. farm-saved seed, seed exchanged with neighbours and informal local markets) rather than on the commercial seed sector. In a survey of farmers in five Sub-Saharan African countries and Haiti, McGuire and Sperling (2016^[147]) found that 90% of seed was sourced through such informal channels (mostly informal local markets). Likewise, the formal commercial sector in India is estimated to account for only a quarter of all seed (see Spielman et al. (2014^[148]), (2014^[149])). Small, resource-poor farmers in particular tend to rely on informal channels. In turn, this means that mergers and market concentration are likely to have only a limited impact on these farmers.

Yet the commercial sector appears to be growing in many developing countries. In India, the commercial seed sector is growing more than 10% per year (Spielman et al., 2014^[148]), while in Sub-Saharan Africa the number of private seed firms has been increasing in recent years. In addition to local and regional seed firms, many of the leading multinationals are active in the emerging commercial seed markets in Africa (African Centre for Biodiversity, 2015^[150]).

In addition to local and regional firms, many of the large global firms are active in these developing countries. In 2013, DuPont acquired Pannar, a South African seed company with a presence in 24 countries in Sub-Saharan Africa. Prior to this acquisition, DuPont had already established a presence in the region. Monsanto has a strong presence in South Africa, with an estimated market share of 45% for field crops through its ownership of Sensako (acquired in the 1990s); it is also present in several other eastern and southern African countries, although with much smaller market shares. Syngenta is similarly active in the region; in 2013, for instance, it acquired MRI, the largest private seed company in Zambia (African Centre for Biodiversity, 2015^[150]).

In developing countries, the commercial sector tends to be prominent in maize, in part because hybrid maize offers a biological means to protect intellectual property. In India, private-sector investment has focused on cotton, maize, pearl millet, sorghum, and horticulture crops where hybrids are possible (Spielman et al., 2014^[148]). Data on market concentration among these commercial firms is scarce. For India, Pray and Nagarajan (2014^[151]) report a four-firm concentration ratio of 34% in 2009 for the private seed firms in their sample, down from 77% in 2000. Similarly, Murugkar et al. (2007^[152]) estimate that the top five firms selling proprietary hybrid seed in India saw their share decline from 84% in 1996-7 to 59% in 2004-5, although the market for GM traits is more concentrated. Spielman and Kennedy (2016^[153]) report data for Nepal in 2012, finding a four-firm concentration ratio of 64% for rice, 82% for wheat, and 91% for maize. For other countries and seed markets, public data is generally lacking, although proprietary data may exist in the private sector.

Given the growing importance of commercial seed sectors in the developing world, there is a clear need for more public data on concentration in these markets, in addition to several other indicators necessary to enable better policymaking (Spielman and Kennedy, 2016^[153]).

Notes

- ¹ Approximately 54% of DuPont's 2016 agricultural sales originated in North America, with an additional 16% coming from Latin America. These figures refer to overall agricultural sales including crop protection chemicals (which accounted for 30% of total revenues).
- ² The importance of farm-saved seed varies across countries and across crops. Farm-saved seed is less common for crops where hybrid varieties are used, as is notably the case for maize. In the dataset used here, farm-saved seed is especially important for cereals (wheat and barley), as discussed below. The Kleffmann database lists farm-saved seed as seed with an "unknown" plant breeder. In the calculations of market concentration, rather than interpreting farm-saved seed as a single "supplier", the total share of farm-saved seed is interpreted as if it consisted of a large number of small firms, which is a better representation of the actual situation.
- ³ The owner of the variety is not necessarily the firm responsible for multiplication, distribution or sales of the seed. Owners of varieties often let other firms take care of these tasks in return for royalty payments; these firms tend to be more numerous and less concentrated than those engaging in plant breeding. In Argentina, for instance, the four-firm concentration ratio for soybean seed is 88% by volume using the final owner of the variety. For the actual production of seed, the corresponding figure is only 29% (Pedro Lavignolle, INASE, personal communication).
- ⁴ Market shares are based on ownership of varieties, even if multiplication and distribution are organised through private firms.
- ⁵ A drawback of the HHI is that the index is less intuitive than the C4 ratio. To help with interpretation, it is useful to keep in mind that with n equally-sized firms, the HHI index is $(10\,000/n)$. For instance, if four firms each had 25% of the market, the HHI would be 2 500; if two firms each had 50% of the market, the HHI would be 5 000.
- ⁶ The value-based HHI correlates strongly with the volume-based HHI and the C4-ratios. We use the value-based HHI here as it is the measure used in economic analysis.
- ⁷ A comparison with similar market share data for 2013 for 30 countries shows no clear pattern of increasing or decreasing market concentration. Across these countries, the median change in the HHI index (in value terms) is a modest decrease of 118 points; the median change in the C4 ratio (in value terms) is an increase of 1%. In terms of the HHI, 47% of the countries registered an increase versus 57% when using the C4 ratio.
- ⁸ The Kleffmann database refers to "cereals," a category which does not include maize and hence refers mainly to wheat and barley. In the case of Mexico, the Kleffmann database normally includes sorghum under cereals. As this market has different characteristics, the analysis here uses separate estimates by Kleffmann for winter wheat only.
- ⁹ In calculating these figures, no distinction has been made between market shares of public institutes and of commercial firms. Seed with "unknown" plant breeder (typically referring to farm-saved seed) has been treated in the same way as unallocated sales more generally; the assumption used is that these sales are provided by a number of small firms with market shares equal to the smallest market share observed in the data. (See Annex 5.B). This is the common approach used in the literature to calculate the HHI index when some sales are unallocated. This approach tends to overstate the degree of market concentration, although the impact is likely to be small in the sample used here. In the wheat and barley seed data, the smallest market share by country is typically between 1% and 2.5%.

- ¹⁰ The concentration measures used here consider each public institute separately. In the statistical analysis presented later, the total share of seed coming from public institutes is used as an additional control variable.
- ¹¹ In contrast with the other crops mentioned here, potatoes are not grown from seed but from tubers (which are, however, referred to as “seed potatoes”). Nevertheless, the terminology of seed markets will be applied to potatoes here.
- ¹² The volume share of public breeders is the sum of the volume shares of all public sector plant breeders in a market. Using their combined market share in volume terms rather than in value terms gives a better representation of the importance of public sector breeders, as these sometimes sell seed at lower prices.
- ¹³ Data for sugar beet, potato and cotton are not presented given the limited number of countries in the database.
- ¹⁴ The approach of “trait acres” used by Heisey and Fuglie (2011^[7]) measures the area sown to GM crops where stacked GM traits are counted multiple times based on the number of traits stacked. This measure gives an indication of the relative importance of firms in overall GM activity in a market. However, it does not necessarily provide an appropriate measure of market share. For instance, if an insect resistance trait is the only trait on the market protecting against a specific pest, it should logically have 100% market share. If stacked traits are the norm and if the firm supplying this trait does not supply many other traits, however, the trait acres approach could show a much smaller market share for the firm.
- ¹⁵ For this reason, the National Corn Growers Association pointed out that the Dow-DuPont merger could benefit farmers as “[t]he Dow-DuPont combination brings together Dow’s trait development expertise with Pioneer’s germplasm and distribution network – making the new company a far stronger competitor with the current industry leader [Monsanto]” (National Corn Growers Association, 2016^[235]).
- ¹⁶ The number of approvals was used, for instance, as an indicator of GM trait market concentration in a joint statement on the Bayer-Monsanto merger by the American Antitrust Institute, Food & Water Watch and the National Farmers Union (2017^[236]).
- ¹⁷ The discussion here focuses on Argentine canola (*Brassica napus*), the most commonly used variety. Four GM events have been approved for Polish canola (*Brassica rapa*), of which one by Bayer and three by the University of Florida.
- ¹⁸ A similar result was found by Heisey and Fuglie (2011^[7]), who found that Monsanto accounted for around half of global approvals (1982-2007) but about 85% of global trait-acres in 2007. (“Trait-acres” represent the area sown to GM crops where stacked GM traits are counted as multiple acres).
- ¹⁹ The discussion here focuses on intellectual property for GM and other biotechnology (including recent techniques such as gene editing). For a review of broader questions of intellectual property in agriculture, see Clancy and Moschini (2017^[238]).
- ²⁰ The measure used here is based on the narrow definition of agricultural biotechnology in Heisey and Fuglie (2011^[7]), focusing on patents “pertaining specifically to crops and to the suite of modern biotechnology techniques.”
- ²¹ Interestingly, 24% of US agricultural biotechnology patents were granted to public sector actors such as universities. Graff et al. (2003^[145]) report the public sector also played a large role in Europe (25%) and Japan (14%). There were qualitative differences between the types of patents granted to public and private organisations, with public research focusing more on plant developmental processes and private research on specific applications.
- ²² It is not clear whether this decline reflects an actual decrease or whether it is due to a change in reporting or other data issues. When combining information on firms’ shares of the total, it

appears that the decline in patents occurred across all firms, including the top firm. This would suggest either a widespread structural change or a change in reporting.

- 23 Louwaars et al. (2009^[133]) also provide data for 2005-2006. The period shown here is restricted to 2004 to allow for a better comparability with the US data. Moreover, results for this two-year period are more likely to be skewed by exceptional results in a single year. The 2005-2006 data in Europe do appear to show a reduction in the number of patents per year, although much less than what the US data show for 2000-2004 compared to the preceding period. The 2005-2006 data show higher concentration levels for the top firm, top 5, and top 10 firms. These higher shares may simply be due to the shorter period: some smaller firms may not apply for a patent every year and thus not appear in the data for 2005-2006 while they would show up when a longer period was used.
- 24 The data underlying the paper by Jefferson et al. (2015^[146]) are based on work by The Lens (www.lens.org), a project to provide free access to global data on scholarly works and patents, and gene and genome-based patents in particular. The Lens contains more than 110 million patent records from 95 jurisdictions. Its PatSeq platform for genetic sequences referenced in patents includes more than 294 million patent sequences linked to patent information and scholarly research. See Jefferson et al. (2015^[244]) and (2015^[245]) for a description of data and methods. The collection of issued patents in Figure 5.16 is available at <https://www.lens.org/lens/collection/5464>.
- 25 Data for rice, not included here, shows less concentration in patent ownership, but also less patenting overall compared to maize and soybean.
- 26 The data in Jefferson et al. (2015^[146]) further confirm the findings of Graff et al. (2003^[145]) on the important role of the public sector, reporting that the public sector accounted for 40-50% of plant gene patenting before 2000 and around 25% since.
- 27 In some jurisdictions (notably the United States), patents can be issued for new plant varieties obtained with or without genetic modification. By contrast, the data here refers to patents referencing genetic sequences in their claims, which implies the data are a good proxy for biotechnology-related patents.

Annex 5.A. Pro forma effects of recent mergers

The available data allows for a “pro forma” assessment of how the recent mergers of Dow and DuPont and of Bayer and Monsanto would have affected market concentration in the absence of any divestitures.

For the countries covered here, the mergers would have no effect on wheat and barley. In 2016, Bayer did not have any wheat or barley varieties on the market.¹ Monsanto likewise had little presence in wheat and barley. In 2004, the firm sold its European wheat and barley breeding programmes to the French firm RAGT as part of a global reorganisation. In other markets included in the dataset, Monsanto’s role in wheat and barley is negligible. Dow had an active presence in wheat in Australia, but limited activity in other markets; DuPont sells wheat seed in the United States, but has a limited presence in Turkey (as well as in Italy, Greece and Portugal, which are not included in the database).

Likewise, the mergers would have no effect on markets for seed potatoes and sugar beet seed, as none of the four firms (Bayer, Monsanto, Dow, DuPont) were active in these markets.² In sunflower seed, the dataset shows that mergers would affect some of the countries covered, although the effect on market shares would be small.³

Maize

Table 5.A.1 shows the impact of the mergers on relevant maize seed markets using a “pro forma” approach, i.e. combining the market shares of 2016 without taking into account divestitures. As Bayer was not active in maize, the impacts reflect the merger between Dow and DuPont.

As a guide to interpreting the results, the Horizontal Merger Guidelines of the US Department of Justice indicate that mergers “potentially raise significant competitive concerns” when they change the HHI by at least 100 points and result in a HHI of more than 1 500 points. Mergers which raise the HHI by more than 200 points and lead to a highly concentrated market (with a HHI above 2 500 points) are “presumed to be likely to enhance market power.”

By far the largest impact would have been in Brazil, with an increase in the HHI of more than 1 000 points, leading to a post-merger HHI of 3 900. The mergers would also have led to a large increase in the HHI in the United States and Slovakia. In the United States, the impact of the merger was apparently not considered a concern by the competition authorities; while DuPont was only required to divest certain crop protection chemicals, no divestitures were required in seed markets.

Annex Table 5.A.1. Pro forma impact of mergers on maize seed markets

	Pre-merger HHI	Post-merger HHI (pro forma)	Change in HHI
Argentina	2 510	2 579	70
Brazil	2 808	3 892	1 083
Czech Republic	1 342	1 406	64
Hungary	2 355	2 440	84
Portugal	3 215	3 259	44
Slovakia	1 536	1 761	226
Spain	3 235	3 281	46
Ukraine	2 473	2 517	44
United Kingdom	2 483	2 497	14
United States	2 614	2 875	261

Note: Using data for 2016. Pro forma analysis does not take into account divestitures.

Source: OECD analysis using the Kleffmann amis®/AgriGlobe® database

Given the large potential effects in the Brazilian maize seed market, the Brazilian Competition Authority (CADE) imposed a set of measures as a precondition for allowing the DowDuPont merger. Dow was required to transfer a copy of its germplasm bank, part of its maize hybrid varieties (including some still under development), some production and research facilities as well as associated brands and employees. These assets were acquired by the Chinese investment fund CITIC for USD 1.1 billion in 2017 and renamed LP Sementes.

Several maize seed markets are included in the database but not shown in Table 5.A.1 as the mergers would not affect the market. This is the case for Austria, Belarus, Belgium, Bulgaria, Croatia, Denmark, France, Germany, Greece, Indonesia, Italy, Mexico, the Netherlands, the Philippines, Poland, Romania, the Russian Federation, Serbia, Slovenia, South Africa, Thailand, and Turkey. DuPont is active in all these markets (except Belarus) but Dow is not, or has only a minor presence. Similarly, although Monsanto is present in some of these markets, Bayer is not active in any. Hence, a large number of maize seed markets are not affected by the mergers.

Soybean

For soybean seed, the available data points to a noticeable impact of the mergers in the United States, where the HHI would increase from 1 683 to 2 041, an increase of 358 points. However, the resulting HHI is fairly low, which probably explains why again no remedies were requested from Dow and DuPont in this regard.

For Brazil, available market data for 2016 seems to show little to no impact of the Bayer-Monsanto merger. Bayer had sold its soybean activities in Brazil to the Dutch firm Nidera in 2005 (which in turn was sold to Syngenta in 2017). However, in this case historical market shares understate the potential role Bayer might have played in soybean seed markets without a merger. Bayer had been following a deliberate strategy of increasing its investments in the Brazilian soybean seed industry to challenge Monsanto's strong market position. In 2013, Bayer acquired the soybean seed company Wehrtec, as well as the soybean seed business of Agricola Wehrmann and a soy germplasm bank of Melhoramento Agropastoril-Cascavel (Birkett, 2013^[154]). In 2015, Bayer acquired the seed business of CCGL-Cruz Alta (which included soybean seeds) (Birkett, 2015^[155]). Bayer also acquired firms active in soybean seeds in Paraguay (Granar) and Argentina (FN Semillas), and in its 2015 Annual Report explicitly announced its intention to “establish competitive positions in soybeans and wheat”

(Bayer, 2015, p. 60_[156]). In 2016, Bayer announced plans to introduce genetically modified soybean seeds (Freitas, 2016_[157]). In other words, a merger with Monsanto would have eliminated a strong potential competitor in the industry. For this reason, the Brazilian competition authorities required the divestiture of Bayer's soybean seed assets (among others).

Rapeseed/canola

Table 5.A.2 shows the pro forma impact of mergers on the rapeseed seed market.

Annex Table 5.A.2. Pro forma impact of mergers on rapeseed seed markets

	Pre-merger HHI	Post-merger HHI (pro forma)	Change in HHI
Bulgaria	2 252	2 538	286
Canada	3 475	4 818	1 343
Germany	2 022	2 104	82
Hungary	1 316	1 433	118
Latvia	2 347	2 623	276
Romania	1 775	1 985	210
Russian Federation	1 864	1 933	69
Ukraine	1 622	1 949	327
United Kingdom	1 363	1 471	108

Note: Using data for 2016. Pro forma analysis does not take into account divestitures.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Monsanto is an important supplier of rapeseed seed for Bulgaria, the Czech Republic, Denmark, France, Germany, Hungary, Latvia, Poland, Romania, Slovakia, Sweden, the United Kingdom, as well as the Russian Federation and Ukraine. In some of these countries, Bayer is also active, although typically with a smaller presence. As Table 5.A.2 shows, in some countries the merger would increase the HHI considerably (in several of these countries, the HHI would increase by more than 100 points). Generally, the post-merger HHI would remain relatively low based on 2016 data. Nevertheless, the European Commission was of the opinion that the Bayer-Monsanto merger “would have eliminated competition in Europe between the largest supplier in Europe – Monsanto – and the largest supplier globally, Bayer, which is currently expanding into Europe” (European Commission, 2018_[134]). Bayer's global rapeseed plant breeding activities form part of the assets sold to BASF.

The largest impact by far, however, would have occurred in Canada. In 2017, Bayer had an estimated market share of 56% and Monsanto 12% (Box 5.1). A merger would have increased the HHI from an already-high value of almost 3 500 to more than 4 800, a level practically equivalent to a market dominated by two equal-sized firms.

Cotton

The available data shows a large potential impact of the mergers in cotton seed markets (Table 5.A.3). For the three countries for which data is available, the mergers would have led to a strong increase in competition; in the case of Mexico even leading to a near-monopoly, with a post-merger HHI practically equal to the theoretical maximum of 10 000. In none of these markets did DuPont have a presence; hence, the effects are due to the Bayer-Monsanto merger.⁴

Annex Table 5.A.3. Pro forma impact of mergers on cotton seed markets

	Pre-merger HHI	Post-merger HHI (pro forma)	Change in HHI
Brazil	4 348	5 109	761
Mexico	5 308	9 988	4 680
United States	2 474	3 492	1 018

Note: Using data for 2016. Pro forma analysis does not take into account divestitures.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

In Mexico, competition authorities required the divestiture of Bayer's cotton assets as a precondition for approving the Bayer-Monsanto merger (among other divestitures in vegetable seeds and crop protection chemicals). Bayer divested these assets to BASF. In Brazil, the divestiture of Bayer's cotton seed business was one of the prerequisites for approving the Bayer-Monsanto merger.

While the dataset does not cover European countries, it is worth noting that the European Commission also indicated that a Bayer-Monsanto merger (without any divestitures) could have reduced competition in the market for cotton seed licensing in Europe.

Notes

- ¹ Bayer did invest to develop new wheat varieties, for instance by opening a wheat breeding station near Paris (France) in 2013 and through a partnership with the Dutch biotech firm KeyGene.
- ² In sugar beet, Monsanto has developed Roundup Ready GM sugar beet traits, but does not sell sugar beet seed. Rather, these traits are used in the North American market by other firms such as Betaseed, owned by KWS.
- ³ In none of the sunflower seed markets included here would the HHI increase by more than 100 points. The US Horizontal Merger Guidelines indicate that mergers are "unlikely to have adverse competitive effects" if the change in HHI is below this level.
- ⁴ DuPont's cotton activities were concentrated in two countries: India and Greece.

Annex 5.B. The Kleffmann AgriGlobe database

In preparing this study, the OECD contacted three market research firms specialising in agricultural input markets: Kynetec, Informa – Phillips McDougall, and Kleffmann. After comparing the available information and pricing, the OECD chose Kleffmann as the data provider. This annex discusses the methodology behind the Kleffmann database, provides some validation checks of the data against external sources, and gives further methodological notes regarding the calculation of market concentration measures.

Methodology of the Kleffmann AgriGlobe database

The main data source in this report is the Kleffmann Group's amis®AgriGlobe® database. The Kleffmann Group specialises in agricultural market research on seed, crop protection, agricultural machinery, livestock and animal health, and related markets.

Kleffmann data on seed markets covers 75 countries, corresponding to an estimated 95% of the global seed market. However, data coverage does not go into the same level of detail in every country. Data on market shares are available only for selected crops in a smaller number of countries. Market share data is obtained by Kleffmann through annual interviews with more than 100 000 farmers worldwide, covering over 60% of the data in value terms. Standardised questionnaires are used to ensure comparability of the data across years and across countries. Where such detailed farmer panels are not conducted, data are obtained through bi-annual distributor surveys in emerging markets and information from consultants and experts to obtain estimates of market size by crop. All Kleffmann data refers to 2016 unless noted otherwise.

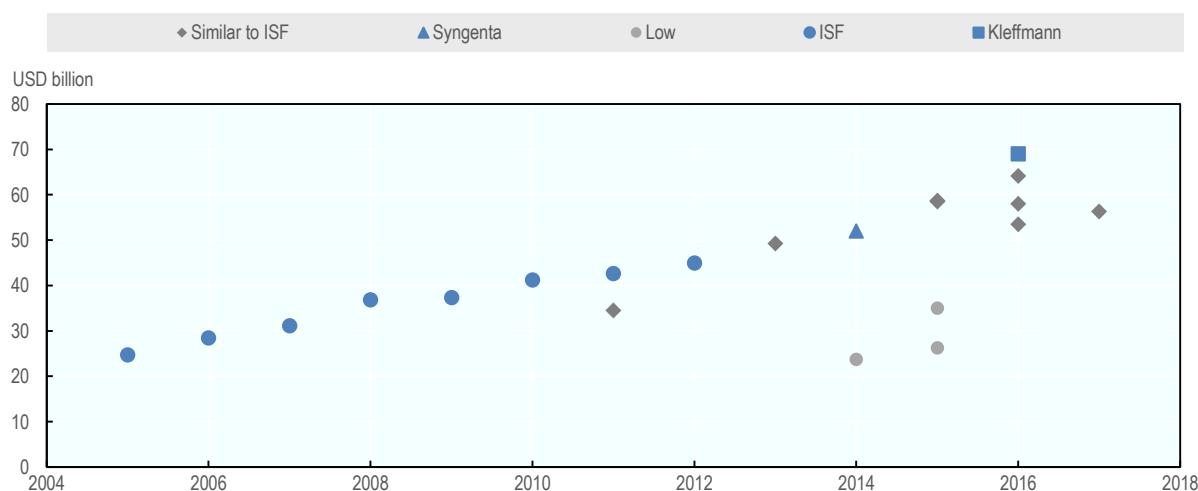
Cross-validation with other data sources

The Kleffmann data is consistent with data obtained from other sources, as seen from a number of validation exercises. First, it is possible to compare Kleffmann's overall estimate of the size of the global seed market with other estimates as presented in Bonny (2017^[12]), as well as the estimate by Syngenta (2016^[15]) and ISF estimates presented in Ragonnaud (2013^[17]). As shown in Figure 5.B.1 below, Kleffmann's estimate for the size of the global seed market is between 65 and 70 billion for 2016. Although somewhat on the higher end of the range of the available estimates, this is in line with the ISF and Syngenta estimates of the preceding years. (In addition to ISF and Syngenta estimates, the figure shows estimates from eleven other market research firms, collected by Bonny (2017^[12]); several are similar to ISF estimates but some estimates are considerably lower).

A more detailed assessment is possible by comparing the Kleffmann data with the data in Syngenta (2016^[15]), which were used to construct Figure 2.4. The Syngenta data represent estimates of the size of specific crop seed markets (e.g. maize seed) in broadly defined regions (e.g. Europe, the Middle East and Africa; Asia Pacific). To compare the two data sources, the Kleffmann data were aggregated bottom-up to a similar regional grouping. One challenge here is that definitions do not match exactly. For instance, it is not clear which

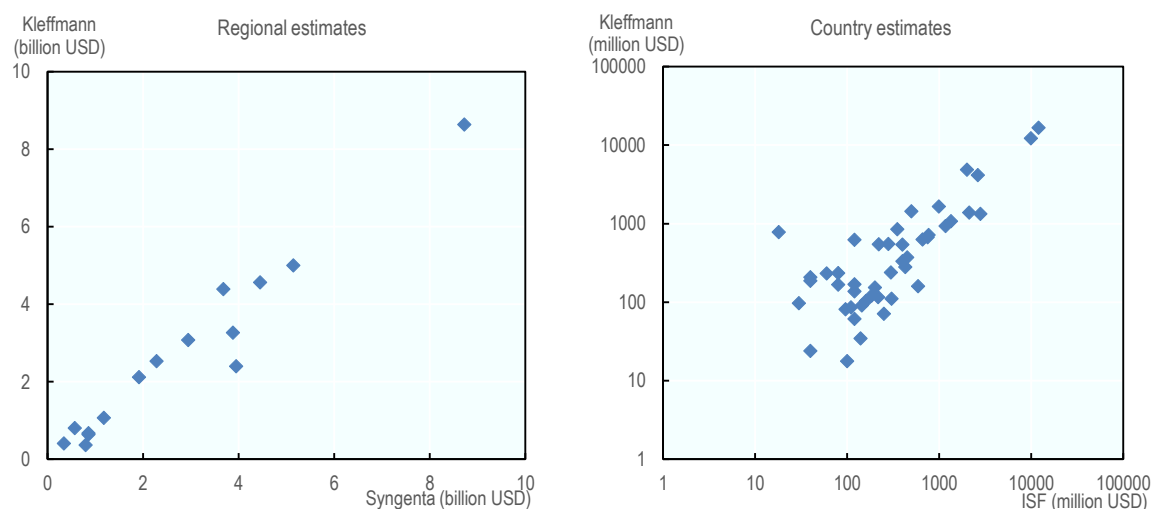
countries are included in Syngenta's regions, and the Kleffmann database includes data for "cereals", i.e. wheat and barley, whereas Syngenta only shows data for wheat. Despite these discrepancies, the numbers from the two sources are broadly consistent, with the exception of estimates for the size of maize seed markets in Latin America and in Europe, the Middle East and Africa, where the Kleffmann numbers are lower. Part of this discrepancy is likely due to the fact that a bottom-up calculation was used for Kleffmann, while not all countries are represented in the Kleffmann dataset; part of this may also be due to definitional differences (e.g. some datasets may define "maize" to also include other coarse grains). The two data sources nevertheless seem to match fairly closely.

Annex Figure 5.B.1. Estimates of global seed market value



Source: Bonny (2017), Syngenta (2016), Ragonnaud (2013).

Annex Figure 5.B.2. Comparison of regional and country estimates



Note: In the first panel, each point corresponds with a regional market for a specific crop, e.g. maize in Latin America. In the second panel, each point corresponds with a country, e.g. the total seed market in France.

Source: OECD analysis using the Kleffmann database and Syngenta (2016) (first panel) and ISFA data cited in ISAAA (2016) (second panel).

ISAAA (2016^[16]) cites ISF estimates of the value of seed markets at the national level for 2012. These data are compared with the corresponding Kleffmann data for 2016 in the figure below. Despite the different years, there is a high correlation between the two datasets, with a correlation coefficient of 0.98. The main outlier is the Philippines, where the discrepancy seems due to a fairly low ISF estimate of USD 18 million. In other words, the Kleffmann estimates at national level again seem to be validated by other sources.

A final quality check on the Kleffmann data was conducted for the markets included in the empirical analysis of market concentration. The Kleffmann data reports market shares and total market sizes not only in volume (tonnes of seed) and value, but also in terms of hectares. These numbers were compared with publicly available data on the total area devoted to the corresponding crop, using a variety of data sources (including FAOSTAT, Eurostat, USDA GAIN reports, and websites of national statistical agencies). For most markets there was a close fit between these different data sources; where numbers deviated by more than 20%, the precise definitions were verified with Kleffmann to ensure a correct interpretation of results.

Example

For each market included in the analysis of market concentration, the Kleffmann database reports the ten leading suppliers of seed, with their corresponding volume, sales value, acreage, and overall size of the market, as shown in Table 5.B.1 using fictional data.

“Company” here denotes the ultimate global owner of the varieties, i.e. the plant breeders. For instance, when a plant breeder licenses out the multiplication or distribution of varieties to other firms, the company listed here will be the plant breeder, not the distributor. Similarly, the Kleffmann data uses the ultimate global owner; hence, a local subsidiary of Monsanto will be listed as Monsanto in the database. Public institutes are not identified as such in the Kleffmann data; private and public sector breeders are distinguished by manually verifying the names of the breeders.

Farm-saved seed is typically included as seed with “unknown” plant breeder. The monetary value of farm-saved seed is calculated by assigning an average price to a volume estimate. This average price tends to be lower than the prevailing average price in the market. The “Grand Total” refers to the overall market size, including the non-commercial part of the market (i.e. including farm-saved seed).

Annex Table 5.B.1. Example of Kleffmann data

Country X Crop Y	Area cultivated (000 ha)	Volume (000 kg)	Value (USD m)
Company 1	1 036.96	191 973.84	30.40
Company 2	917.70	163 401.35	26.05
Company 3	432.56	76 745.89	12.21
...	...	...	...
Unknown	337.93	60 756.10	9.71
...	...	...	...
Company 10	269.08	47 437.45	7.78
Top Ten Total	4 711.96	845 960.44	135.00
Grand Total	5 324.51	947 475.70	148.50
Top Ten in %	88%	89%	91%

Note: Fictional data only.

Calculating market concentration

The main measures of market concentration used in this chapter are the four-firm concentration ratio and the Hirschman-Herfindahl Index. The four-firm concentration ratio was found simply by adding up the market shares of the four largest firms. In case one of the top four firms was listed as “unknown” (i.e. farm-saved seed), the next largest firm was used.

The Hirschman-Herfindahl Index is defined as the sum of the squared market shares of all firms in a market. In theory, calculating the HHI requires information on the market shares of *all* firms in a market, while the Kleffmann data only includes information for the ten largest firms. The calculation of the HHI here uses an approximation for the unobserved firms. As is common in the industrial organisation literature, the assumption is that the unobserved firms are all as large as the smallest firm in the top ten. In other words, if the tenth-largest firm has a market share of 5%, and if the top ten firms together account for 85% of the market, the assumption is that there are three other firms with 5% each ($3 \times 5\% = 15\%$, the remaining part of the market). This approximation slightly overstates the HHI (as it assumes all remaining firms are equally large), but the effect tends to be negligible.

As mentioned in the main text, this study chooses to calculate market concentration relative to the *overall* seed market, including farm-saved seed, rather than only the *commercial* seed market. In calculating the HHI, farm-saved seed is considered part of the market accounted for by firms outside of the top ten, and is thus subject to the same approximation.

6. New evidence on the effects of concentration in seed markets

The new data presented in the previous chapter allow for an empirical analysis of the effects of concentration in seed markets. An analysis of determinants of seed prices does not find strong evidence of a harmful impact of market concentration. Using data for the European Union on the introduction of new varieties, an empirical analysis similarly does not find strong evidence of a harmful effect of concentration on innovation.

Chapter 5 presented disaggregated data on market concentration in seed for different crops and countries. This dataset allows an empirical exploration of the effects of market concentration in seed on prices and innovation.

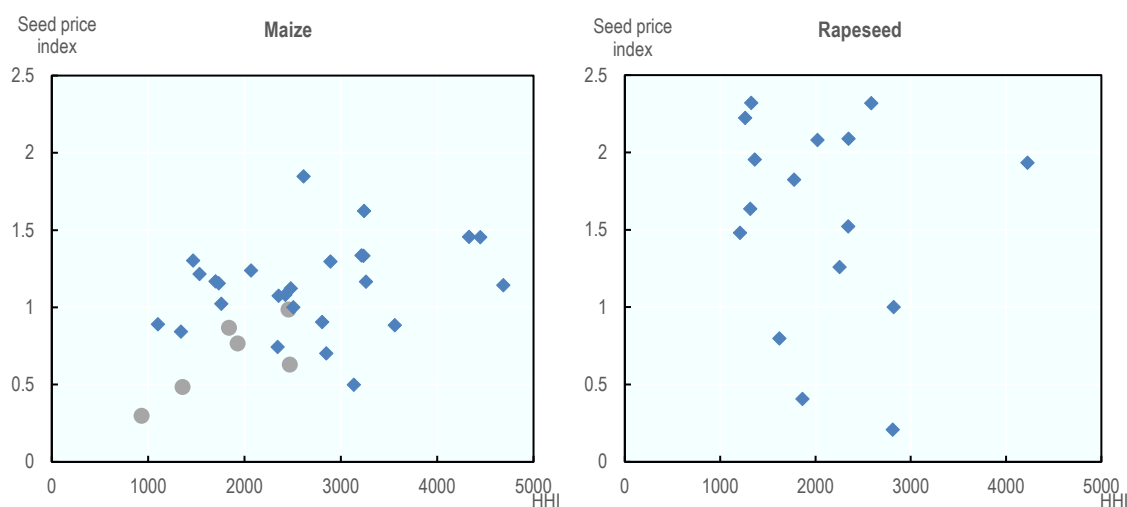
6.1. Market concentration and seed prices

Does market concentration lead to higher prices? At first sight, the data seems to suggest this is the case. Figure 6.1 shows average maize seed prices and market concentration levels for maize seed. There indeed appears to be a positive correlation, with more concentrated markets showing a higher seed price. In addition, price levels appear to be systematically lower in countries where public sector plant breeding institutes are active (Belarus, the Russian Federation, Serbia, and, to a lesser extent, Romania, Ukraine, and Croatia).¹

However, when looking at other crops, the picture is more complicated. For rapeseed, there is no clear link between market concentration and seed prices (Figure 6.1). Among the other markets, there is also no clear link between market concentration levels and average prices. This example demonstrates that prices and market concentration do not necessarily correlate in all markets.

A more rigorous analysis is possible through a regression of seed prices on different possible determinants, including market concentration. Table 6.1 shows the outcome of six linear specifications where the average seed price in each market is regressed on measures of market size, market concentration, and a set of other characteristics. All specifications include crop and country fixed effects, which filter out any price effects common to a crop or country (only the crop effects are shown explicitly).

Figure 6.1. Market concentration and seed prices



Note: Countries with public research institutes active in the maize seed market (Belarus, Russian Federation, Serbia, Romania, Ukraine, Croatia) highlighted in grey. The seed price index measures the relative price of seed (per kg) converted at average 2016 exchange rates. Because of data confidentiality, seed prices have been rescaled by a random factor. Hence, absolute levels are not meaningful, but relative comparisons (within a crop) can be made.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Table 6.1. Determinants of seed prices (linear specification)

Dependent variable: average seed price (USD per kg)

Explanatory variables	(1)	(2)	(3)	(4)	(5)	(6)
Market size (USD mln)	0.001*** (0.0003)	0.001*** (0.0003)	0.001** (0.0003)	0.001** (0.0002)	0.0003 (0.0003)	0.0003 (0.0003)
HHI (Value)	3.335 (6.745)		-42.952** (19.08)		-39.757** (19.579)	
C4 (Value)		-2.56 (4.786)		-75.952*** (18.092)		-69.082*** (21.835)
(HHI) ²			88.269*** (34.057)		79.052** (34.907)	
(C4) ²				52.447*** (12.238)		47.154*** (14.216)
GM used? (Yes = 1, No = 0)					3.740** (1.535)	2.706* (1.579)
Volume share of public breeders					1.646 (2.93)	0.687 (3.339)
Volume share of farm-saved seed					-0.328 (2.35)	-2.53 (2.896)
<i>Crop fixed effects (Reference category: wheat and barley)</i>						
Cotton	11.444*** (1.78)	12.669*** (1.468)	8.000*** (2.132)	10.455*** (1.105)	6.303*** (2.431)	8.506*** (1.984)
Maize	5.350*** (1.006)	6.006*** (1.066)	6.172*** (0.921)	6.615*** (0.931)	6.233*** (0.946)	6.556*** (0.971)
Potato	-3.386** (1.708)	-3.396* (1.964)	-2.651* (1.565)	-1.617 (1.804)	-2.696* (1.63)	-1.854 (1.889)
Rapeseed	15.912*** (1.111)	16.500*** (1.058)	16.864*** (0.971)	17.552*** (0.937)	17.089*** (1.103)	17.499*** (1.041)
Soybean	2.579** (1.261)	2.776** (1.2)	2.802** (1.158)	2.779** (1.135)	1.09 (1.129)	1.524 (1.291)
Sugar beet	62.360*** (2.615)	63.771*** (2.92)	62.590*** (2.145)	63.832*** (2.384)	63.199*** (2.127)	63.994*** (2.282)
Sunflower	11.753*** (1.283)	12.858*** (1.539)	12.948*** (1.302)	12.776*** (1.387)	13.863*** (1.443)	13.301*** (1.524)
<i>Country fixed effects</i>						
Constant	Yes -2.509 (1.984)	Yes 0.058 (3.606)	Yes 3.043 (2.971)	Yes 24.589*** (6.861)	Yes 0.216 (3.541)	Yes 20.689** (9.186)
Observations	87	87	87	87	87	87
Adjusted R2	0.92	0.92	0.93	0.94	0.93	0.93
F Statistic	24.346*** (df = 45; 41)	24.348*** (df = 45; 41)	25.912*** (df = 46; 40)	27.884*** (df = 46; 40)	23.742*** (df = 49; 37)	25.124*** (df = 49; 37)

Note: Output of OLS regressions with crop and country fixed effects. Numbers in brackets denote heteroscedasticity-robust standard errors. Significance levels: *p<0.1; **p<0.05; ***p<0.01. HHI (Value), C4 Value, Volume share of public breeders, and Volume share of farm-saved seed all range from 0 to 1.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

The first and second column of Table 6.1 use two different measures of market concentration: the HHI and the C4, which are both defined here in value terms. Alternative specifications with volume-based measures gave practically identical results and are not shown. In the first two specifications, neither of the two concentration measures is statistically significant, and the sign is inconsistent (positive in column 1, negative in column 2). The crop fixed effects, however, do pick up important differences between crops. For instance, these results show that seed prices for cotton are on average USD 9.9 per kg higher than for wheat and barley seed (the reference category used here). Within the country fixed effects (not shown here), most results were small and not statistically significant.

Columns 3 and 4 try to account for potential non-linear effects of market concentration by including a squared term of respectively the HHI and C4 measure. In both cases, both the linear (first-order) and squared (second-order) effect are statistically significant. For the HHI measure, the coefficients imply that moving from a market with five equally large firms (corresponding to a HHI of 0.2) to a market with three equally large firms (corresponding to a HHI of 0.33) would increase the average price by only USD 0.5/kg. However, in more concentrated markets the price effect accelerates: moving from a HHI of 0.33 to a HHI of 0.5 would increase the average price by USD 5.1/kg, all else equal, and the effects accelerate for higher levels. For the C4 measure, the coefficients imply that an increase in the market share held by the four largest firms would *decrease* the average price as long as the C4 ratio remains below approximately 80%; above that threshold, higher ratios increase prices, although the estimated coefficients imply that the price increases would be modest. Moving from a C4 ratio of 80% to 100% would only increase the average price by around USD 3.5/kg according to these estimates. In other words, these estimates provide contradictory results.

Columns 5 and 6 add an indicator showing whether GM technology is used in the market and the volume shares of public plant breeders and of farm-saved seed, respectively. By themselves, these variables do not appear to exert a major impact on prices; and other coefficients are not affected by the inclusion of these additional controls.

A shortcoming of the analysis in Table 6.1 is that, by construction, the linear specification expects variables to exert the same effect on all crop seed markets, regardless of the initial price level. For instance, the linear specification expects an increase in the volume share of public breeders to have the same price effect in USD/kg regardless of the crop. For several explanatory variables it seems more plausible that the impact would be a *proportional* increase or decrease of the price, rather than such an absolute change. To analyse this, Table 6.2 presents results of a logarithmic specification.

As the dependent variable is in logarithmic form, the interpretation of the coefficients presented in Table 6.2 requires some care. For explanatory variables which are in logarithmic form (such as market size), the estimated coefficients are elasticities. For instance, a coefficient of 0.12 would imply that an increase by 1% in the explanatory variable leads to an increase of prices by 0.12%. For variables which are expressed as a share (such as the volume share of public breeders), a similar interpretation holds: for an estimated coefficient of -0.76, a one percentage point increase in the volume share of public breeders would decrease prices by around 0.76%. The interpretation is somewhat more complicated for indicator variables which can only take a value of zero or one, as is the case for the GM indicator and the crop and country fixed effects; these are discussed in more detail below.

Table 6.2. Determinants of seed prices (logarithmic specification)

Dependent variable: log (average seed price)

Explanatory variables:	(1)	(2)	(3)	(4)	(5)	(6)
Log(Market size in mln USD)	0.122** (0.058)	0.129** (0.054)			0.140*** (0.049)	0.136*** (0.05)
Log(Market volume in tons)			-0.096* (0.052)	-0.088* (0.053)		
Log(HHI (Value))	0.017 (0.137)		-0.062 (0.131)			
Log(C4 (Value))		0.252 (0.34)		0.062 (0.358)	0.052 (0.252)	-0.49 (0.515)
Log ² (C4 (Value))						-0.589 (0.432)
GM used? (Yes = 1, No = 0)					0.121 (0.193)	0.164 (0.186)
Volume share of public breeders					-0.756*** (0.289)	-0.711** (0.291)
Volume share of farm-saved seed					-1.191*** (0.332)	-1.167*** (0.352)
<i>Crop fixed effects (Reference category: wheat and barley)</i>						
Cotton	4.796*** (0.193)	4.756*** (0.178)	4.054*** (0.349)	4.042*** (0.365)	4.336*** (0.196)	4.370*** (0.2)
Maize	3.654*** (0.107)	3.598*** (0.12)	3.438*** (0.165)	3.419*** (0.173)	3.485*** (0.107)	3.492*** (0.108)
Potato	-0.966*** (0.176)	-0.974*** (0.172)	-1.332*** (0.093)	-1.330*** (0.099)	-1.072*** (0.14)	-1.122*** (0.151)
Rapeseed	4.905*** (0.096)	4.864*** (0.097)	4.214*** (0.292)	4.219*** (0.299)	4.750*** (0.116)	4.740*** (0.118)
Soybean	1.929*** (0.229)	1.912*** (0.216)	1.743*** (0.258)	1.747*** (0.253)	1.788*** (0.19)	1.784*** (0.182)
Sugar beet	6.416*** (0.165)	6.316*** (0.188)	5.593*** (0.38)	5.569*** (0.392)	6.188*** (0.169)	6.218*** (0.176)
Sunflower	4.581*** (0.135)	4.502*** (0.164)	4.090*** (0.296)	4.060*** (0.306)	4.346*** (0.178)	4.387*** (0.179)
<i>Country fixed effects</i>						
Constant	-3.046*** (0.434)	-3.026*** (0.425)	-0.904 (0.746)	-0.904 (0.792)	-3.136*** (0.415)	-3.238*** (0.415)
Observations	87	87	87	87	87	87
Adjusted R2	0.97	0.97	0.97	0.97	0.98	0.98
F Statistic	69.705*** (df = 45; 41)	70.655*** (df = 45; 41)	67.673*** (df = 45; 41)	67.431*** (df = 45; 41)	78.065*** (df = 48; 38)	75.617*** (df = 49; 37)

Note: Log(.) denotes the natural logarithm. Output of OLS regressions with crop and country fixed effects. Numbers in brackets denote heteroscedasticity-robust standard errors. Significance levels: *p<0.1; **p<0.05; ***p<0.01. HHI (Value), C4 Value, Volume share of public breeders, and Volume share of farm-saved seed all range from 0 to 1.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

The first two columns in Table 6.2 show that market concentration measures are not statistically significant. In columns 3 and 4, market volume is used as an alternative measure of market size, to capture the potential effect of economies of scale; however, this change in variable does not seem to affect the estimates of other variables. Column 5 adds variables for GM, public breeding and farm-saved seed. The coefficient on the GM indicator is discussed in more detail below. The estimates imply that a one percentage point increase in the volume share of public plant breeding results in a decrease in prices by around 0.76%, all else equal, while a one percentage point increase in the share of farm-saved seed would reduce prices by 1.2%.

Finally, column 6 adds the square of the log of the C4 indicator, analogously to the inclusion of the squared term in Table 6.1. Neither the linear nor the squared C4 indicator are statistically significant, indicating no clear effect of market concentration on prices. Moreover, the sign and magnitude of the effects is puzzling, as these coefficients would imply that higher market concentration leads to increases in prices as long as the four largest firms have a combined market share below 60%, but that prices would decrease if market concentration rises above this level. Other coefficients remain largely unchanged.

Given a logarithmic formulation, the correct interpretation of coefficients on indicator variables (variables which can only take a value of zero or one) is not trivial. The calculation of the implied percentage change in average seed prices for such variables is detailed in a footnote.²

For the GM indicator, the estimated coefficient is small and has a large standard error, which means the data provides no clear evidence that GM seed is more expensive than non-GM seed. The estimated percentage change in the final specification is +16%, but with a range from -20% to +67%, indicating considerable uncertainty around the estimate.

Table 6.3 shows how prices of seed differ across crops (compared to the reference category of wheat and barley seed), after controlling for all other factors included in the analysis. Estimates are based on the estimated coefficients in the final column of Table 6.2 and reveal large differences in average seed prices between crops, with sugar beet seed almost five hundred times as expensive (per kg) as seed for wheat and barley.

Table 6.3. Crop effects on average seed prices (relative to wheat and barley seed prices)

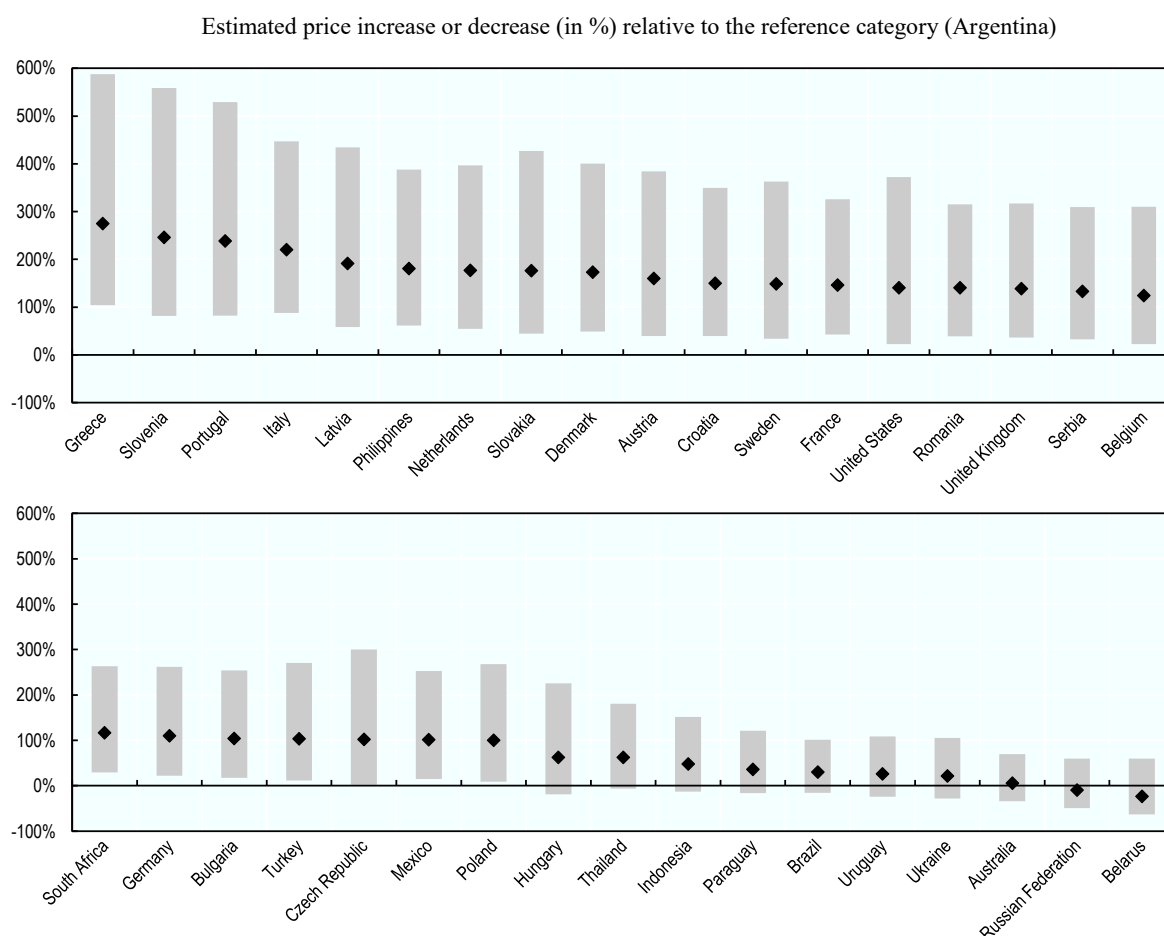
	Multiple at estimated value	Multiple at lower bound	Multiple at upper bound	Significance level of estimated coefficient
Cotton	77.5	52.4	114.7	***
Maize	32.7	26.4	40.4	***
Potato	0.3	0.2	0.4	***
Rapeseed	113.6	90.2	143.2	***
Soybean	5.9	4.1	8.4	***
Sugar beet	494.0	349.9	697.5	***
Sunflower	79.1	55.7	112.4	***

Note: This table shows by what multiple the average seed price of crops differ from prices for wheat and barley seed. Estimates derived from the coefficient estimates in the last column of Table 6.2 using the Kennedy transform as detailed in footnote 2. Given their magnitude, effects are shown as multiples, i.e. the price of sunflower seed is on average 75 times higher than that of wheat and barley. Final column shows significance levels of corresponding coefficients in the last column of Table 6.2: *p<0.1; **p<0.05; ***p<0.01.

Source: OECD analysis using the Kleffmann amis®/AgriGlobe® database.

Likewise, Figure 6.2 and Table 6.3 show how seed prices differ across countries (compared to Argentina, the reference category), after controlling for all other factors included in the analysis. These estimates are derived from the country effects of the specification in the final column of Table 6.2. As the confidence intervals in Figure 6.2 show, there tends to be considerable uncertainty around the estimated country effects, which means that country rankings are probably not very robust. However, comparing the extremes of the rankings, it does appear that Greece, Slovenia and Portugal, among others, have higher seed prices on average than Australia, the Russian Federation or Belarus. One important limitation in interpreting these country effects is that the analysis does not control for the quality of seed; the country-specific differences in price found here may reflect such quality differences.

Figure 6.2. Country differences in average seed prices



Note: Estimates for Canada not available due to small number of observations. Shaded area shows estimated percentage impact between the boundaries of the 95% confidence interval around the estimated country effect (see main text for methodological notes).

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

Table 6.4. Country differences in average seed prices (relative to Argentina)

	Percentage change at estimated value	Percentage change at lower bound	Percentage change at upper bound	Significance level of estimated coefficient
Australia	6%	-34%	70%	
Austria	160%	40%	384%	***
Belarus	-23%	-63%	59%	
Belgium	124%	23%	310%	***
Brazil	30%	-16%	101%	
Bulgaria	104%	17%	254%	***
Croatia	150%	39%	350%	***
Czech Republic	102%	2%	300%	**
Denmark	173%	49%	401%	***
France	146%	43%	326%	***
Germany	110%	22%	262%	***
Greece	275%	104%	588%	***
Hungary	62%	-19%	225%	
Indonesia	48%	-13%	151%	
Italy	221%	88%	447%	***
Latvia	191%	59%	435%	***
Mexico	101%	14%	253%	***
Netherlands	177%	55%	397%	***
Paraguay	36%	-16%	121%	
Philippines	181%	62%	388%	***
Poland	100%	9%	268%	**
Portugal	239%	82%	529%	***
Romania	140%	39%	315%	***
Russian Federation	-10%	-49%	60%	
Serbia	133%	32%	310%	***
Slovakia	176%	45%	427%	***
Slovenia	246%	81%	559%	***
South Africa	116%	29%	263%	***
Spain	120%	35%	260%	***
Sweden	149%	34%	363%	***
Thailand	62%	-6%	181%	*
Turkey	103%	11%	270%	**
Ukraine	21%	-28%	105%	
United Kingdom	139%	36%	317%	***
United States	141%	23%	373%	***
Uruguay	26%	-24%	108%	

Note: Table shows estimated price differences for each country compared to Argentina. Estimates derived from the country fixed effects corresponding to the last column of Table 6.2, using the Kennedy transform as detailed in footnote 2. Final column shows significance levels of corresponding coefficients in the last column of Table 6.2: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

A greater presence of public plant breeding seems to reduce average prices according to the estimates in Table 6.2. This effect could reflect competitive pressure from public plant breeders, but it could also reflect a “composition effect” whereby public plant breeders themselves sell seed at lower prices (thus lowering the average seed price in the market) without affecting the prices of private firms.

Summarising the various specifications, the data do not provide clear evidence of a connection between market concentration and seed prices. Table 6.1 found some evidence that above a certain threshold more concentrated markets have higher prices, although the effects appear modest in magnitude; the effect is not found in the alternative specifications of Table 6.2 however, and is even reversed in some specifications.

Overall, the findings of the regression analysis provide no strong evidence of a link between market concentration and average seed prices in the markets studied here.³

6.2. Market concentration and innovation in the European Union

The Kleffmann database by itself does not allow for an analysis of how market concentration affects innovation. In this section, a measure of the rate of innovation in European crop seed markets is constructed to allow for such an analysis.

Data on innovation

Innovation is defined here as the *annual number of new varieties introduced in a market*, where a market is a combination of a country and a crop (e.g. the French maize seed market), consistent with the definition used earlier in studying market concentration.

There is more than one way to measure the number of new varieties. One possibility would be to use the number of new plant breeders' rights or patents issued. However, differences between jurisdictions make it hard to compare these numbers. To obtain a comparable measure, the analysis here focuses on the European Union. In the European Union, marketing of seed requires that varieties are registered in the National List of one EU Member State. Hence, the number of new entries on the National List can be used as a measure of innovation. While this approach is not without its shortcomings, it provides a reasonable proxy for innovation, as discussed in more detail in Annex 6.A.⁴

Table 6.5 shows the median number of new varieties for which registration in the National List was granted between 2013 and 2017.⁵ Using a median instead of an average avoids distortions in the data caused by years with exceptionally high or low numbers of approved entries to the National List. The table does not include data for cotton, as plant breeding on cotton is relatively rare in the European Union.⁶ The final two rows of the table compare the EU total for National List entries with EU-wide plant breeders' rights; the two figures have a strong correlation.

Figure 6.3 and Figure 6.4 visualise these data by crop and by country, respectively. By far the largest number of new varieties is introduced for maize, with more than 700 new varieties per year. Wheat, at slightly above 300 new varieties per year, is a distant second, closely followed by rapeseed and sugar beet. Among the crops included here, the lowest number of new varieties is introduced for soybean, at around 40 per year.⁷

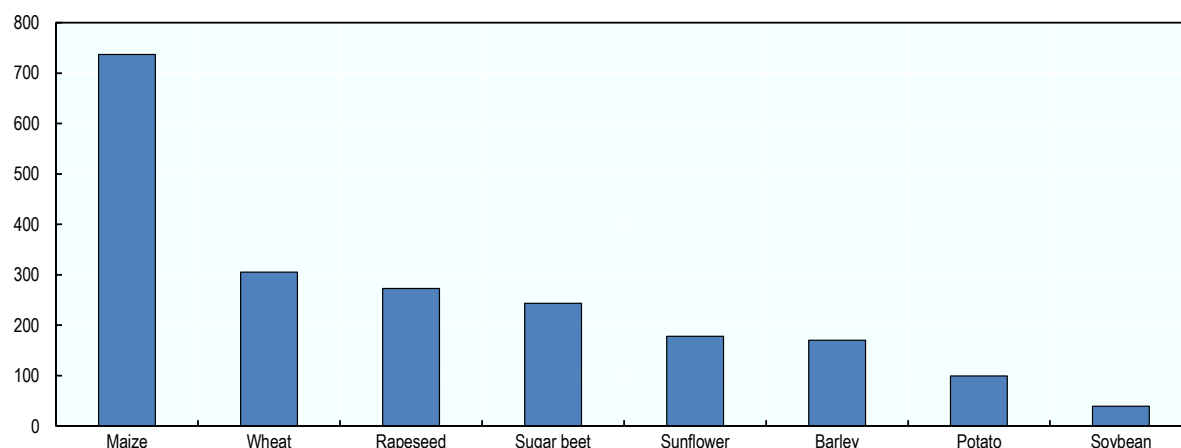
Italy and France have the highest number of new variety introductions per year (Figure 6.4), driven in particular by high numbers of new maize and wheat varieties. Another crop where specific countries dominate is sugar beet, where Germany, France and Spain together account for about half of new varieties.

Table 6.5. Median number of new varieties in the European Union, 2013-2017

Country	Measure	Maize	Soybean	Wheat	Barley	Rapeseed	Sunflower	Potato	Sugar beet	Total
Austria	NLI	20.5	6.0	11.0	9.5	5.0	3.0	2.0	-	60.5
Belgium	NLI	11.0	-	4.0	1.5	-	-	1.0	15.0	32.5
Bulgaria	NLI	30.5	1.0	10.5	3.5	8.5	27.0	1.0	-	85.5
Croatia	NLI	19.0	1.0	10.0	2.0	4.0	3.0	2.0	9.0	54.0
Czech Rep.	NLI	36.0	1.0	15.0	11.0	13.0	3.0	4.0	14.0	101.0
Denmark	NLI	5.0	-	11.0	14.0	26.0	-	2.0	16.0	74.0
Estonia	NLI	2.5	1.0	7.0	9.0	10.0	-	1.0	-	31.5
Finland	NLI	-	-	3.5	6.0	3.0	-	1.0	-	13.5
France	NLI	122.0	6.0	50.0	22.0	27.0	21.0	12.0	42.0	339.0
Germany	NLI	36.0	1.5	21.0	17.0	23.0	-	9.0	51.0	163.5
Hungary	NLI	16.0	4.0	15.0	4.0	32.0	5.0	1.5	12.0	124.0
Ireland	NLI	2.0	-	2.5	3.0	-	-	4.0	-	11.5
Italy	NLI	188.0	6.0	36.0	3.5	14.0	63.0	1.0	6.5	342.0
Latvia	NLI	1.0	-	3.0	3.0	5.0	-	4.0	-	16.0
Lithuania	NLI	12.0	1.0	12.0	9.0	14.0	-	-	13.0	61.0
Netherlands	NLI	34.0	-	5.0	2.0	-	-	35.0	-	173.0
Poland	NLI	21.0	1.5	12.0	12.0	18.0	-	5.0	15.0	89.5
Portugal	NLI	22.0	-	-	-	-	10.0	1.0	-	41.0
Romania	NLI	42.0	5.0	8.0	2.0	6.0	22.0	2.0	2.0	93.0
Slovakia	NLI	65.0	1.5	16.0	7.0	21.0	18.0	1.0	-	131.5
Slovenia	NLI	11.0	1.0	5.5	-	3.0	-	1.0	-	24.0
Spain	NLI	25.0	-	17.0	6.0	1.0	2.0	1.5	30.0	110.5
Sweden	NLI	1.5	-	7.0	3.0	3.0	-	1.0	10.0	25.5
European Union	Total NLI	737.0	39.5	305.0	170.0	272.5	178.0	99.0	243.5	2 311.0
European Union	PBR	213.0	12.0	149.0	75.0	91.0	66.0	69.0	13.0	766.0

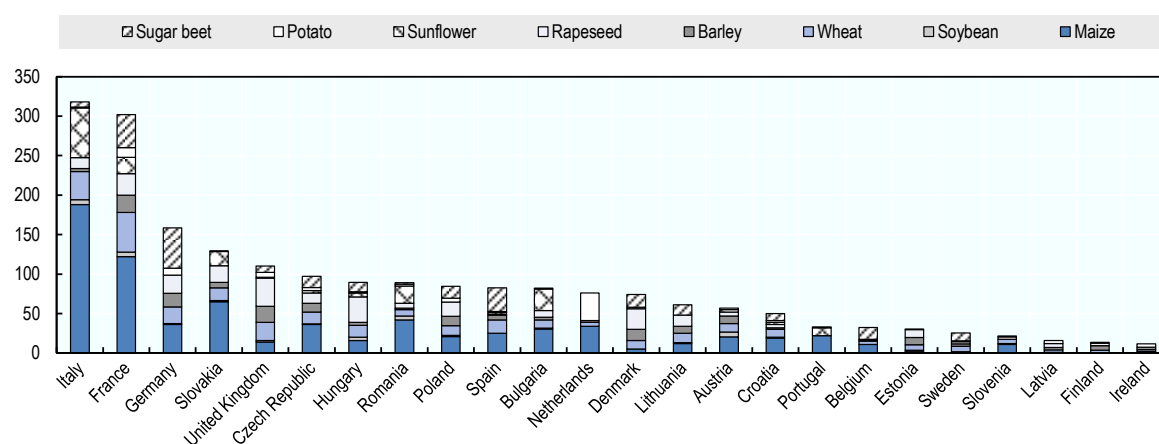
Note: NLI is National List; PBR is Plant breeders' right. Country data is the median number of annual approved applications to the National List, 2013-2017 (based on grant start date). EU PBR data shows the median number of plant breeders' rights granted at EU-level over the same period.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

Figure 6.3. Annual number of new varieties in the European Union by crop, 2013-2017

Note: Data shows the sum across EU member states of the median number of annual approved applications to the National List, 2013-2017 (based on grant start date).

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

Figure 6.4. Median number of new varieties in the European Union, by country, 2013-2017

Note: Median number of annual approved applications to the National List, 2013-2017 (based on grant start date).

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

Market concentration and innovation

Combining the data in Table 6.5 with market data from Kleffmann makes it possible to explore the determinants of the rate of innovation in the EU plant breeding sector, including the potential impact of market concentration. Table 6.6 presents results of a regression analysis where the dependent variable is the logarithm of the median number of new entries on the national list (a logarithmic specification was chosen as it provided the best fit for the data).

Table 6.6. Determinants of innovation

Dependent variable: Log (median number of new entries on the National List, 2013-2017)

Explanatory variables:	(1)	(2)	(3)	(4)	(5)	(6)
Log(Market size in mln USD)	0.484*** (0.122)	0.473*** (0.128)	0.481*** (0.119)	0.470*** (0.131)	0.446*** (0.172)	0.432** (0.184)
Log(HHI (Value))	-0.476 (0.35)		0.822 (1.485)		0.334 (1.543)	
Log(C4 (Value))		-0.409 (0.662)		-0.035 (1.449)		-0.556 (1.663)
Log ² (HHI (Value))			0.425 (0.438)		0.199 (0.478)	
Log ² (C4 (Value))				0.452 (1.518)		-0.657 (1.71)
Volume share of public breeders					-1.585 (1.013)	-2.083** (0.839)
Volume share of farm-saved seed					0.391 (1.118)	0.669 (1.123)
<i>Crop fixed effects</i>	<i>(Reference category: wheat and barley)</i>					
Maize	0.253 (0.208)	0.125 (0.27)	0.335 (0.246)	0.126 (0.274)	0.065 (0.355)	-0.132 (0.308)
Potato	-0.185 (0.196)	-0.171 (0.211)	-0.134 (0.2)	-0.149 (0.235)	-0.443 (0.357)	-0.582 (0.413)
Rapeseed	0.388 (0.244)	0.283 (0.236)	0.464* (0.244)	0.288 (0.238)	0.16 (0.315)	-0.029 (0.277)
Sugar beet	1.195*** (0.425)	1.001** (0.4)	1.243*** (0.392)	0.985** (0.401)	0.924* (0.501)	0.594 (0.518)
Sunflower	-0.063 (0.393)	-0.24 (0.399)	0.03 (0.377)	-0.258 (0.395)	-0.378 (0.481)	-0.62 (0.445)
<i>Country fixed effects</i>	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.461 (0.817)	1.275** (0.528)	1.35 (1.399)	1.353** (0.609)	1.478 (1.368)	1.592** (0.741)
Observations	52	51	52	51	50	50
Adjusted R2	0.42	0.38	0.41	0.35	0.34	0.33
F Statistic	2.428** (df = 26; 25)	2.172** (df = 26; 24)	2.312** (df = 27; 24)	2.008** (df = 27; 23)	1.859* (df = 29; 20)	1.824* (df = 29; 20)

Note: Log(.) denotes the natural logarithm. Output of OLS regressions with crop and country fixed effects. Numbers in brackets denote heteroscedasticity-robust standard errors. Significance levels: *p<0.1; **p<0.05; ***p<0.01. HHI (Value), C4 Value, Volume share of public breeders, and Volume share of farm-saved seed all range from 0 to 1.

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

A first insight regards the role of market size. Across all specifications, the estimated elasticity of innovation with respect to market size is around 0.4-0.5, indicating that a 1% increase in market size increases the innovation rate by around 0.4-0.5%.

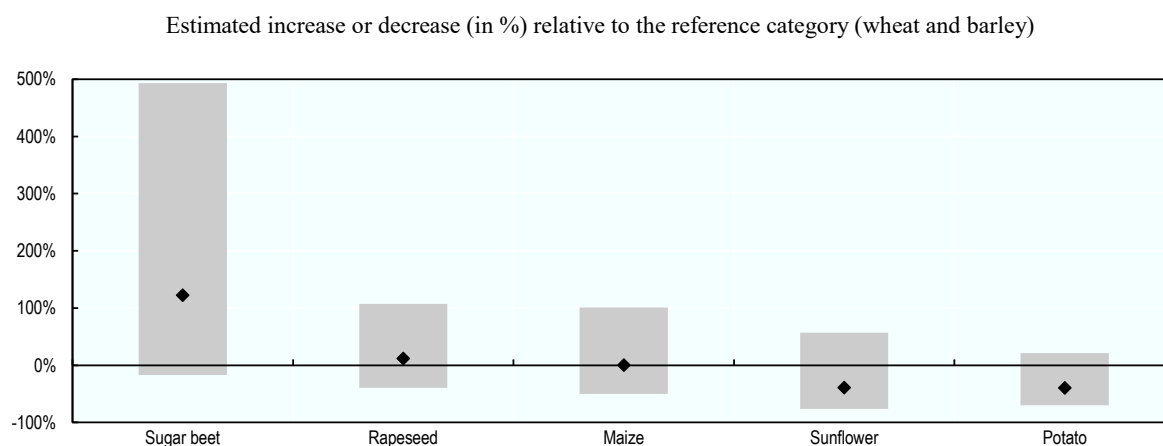
The role of market concentration is less clear. In the first two specifications, a negative effect is found, albeit not statistically significant in the case of the second specification. In the remaining specifications a term is added to capture “inverted-U” patterns between concentration and innovation (Aghion et al., 2005_[104]). The estimated coefficients are not statistically significant and contradictory. For instance, the pattern implied by the third specification is a U-shaped curve, with increasing market concentration first reducing, then

increasing innovation. By contrast, the estimates in the last column would imply an inverse U-shaped pattern. As these coefficients are all imprecisely estimated and varying across specifications, the data hence does not show any strong evidence of a relationship between market concentration and innovation in plant breeding in the dataset used here.

The final two specifications show a negative impact of the volume share of public plant breeding on innovation. The estimates indicate that a one percentage point increase in the share of public breeders reduces the annual number of new varieties by 1.6% to 2%. By contrast, the share of farm-saved seed does not appear to play a major role.

All of the specifications correct for crop and country effects. The coefficients for crop effects in Table 6.6 can be transformed into an estimated percentage change with respect to the reference category (wheat and barley). Figure 6.5 shows these estimates for the second-to-last specification of Table 6.6.⁸ The data indicates that innovation rates are not meaningfully different between wheat and barley (the reference category) on the one hand and maize or rapeseed on the other. By contrast, sugar beet in most specifications appears to have a higher innovation rate, while sunflower and potato appear to have lower innovation rates. However, all of these effects are estimated with considerable uncertainty.

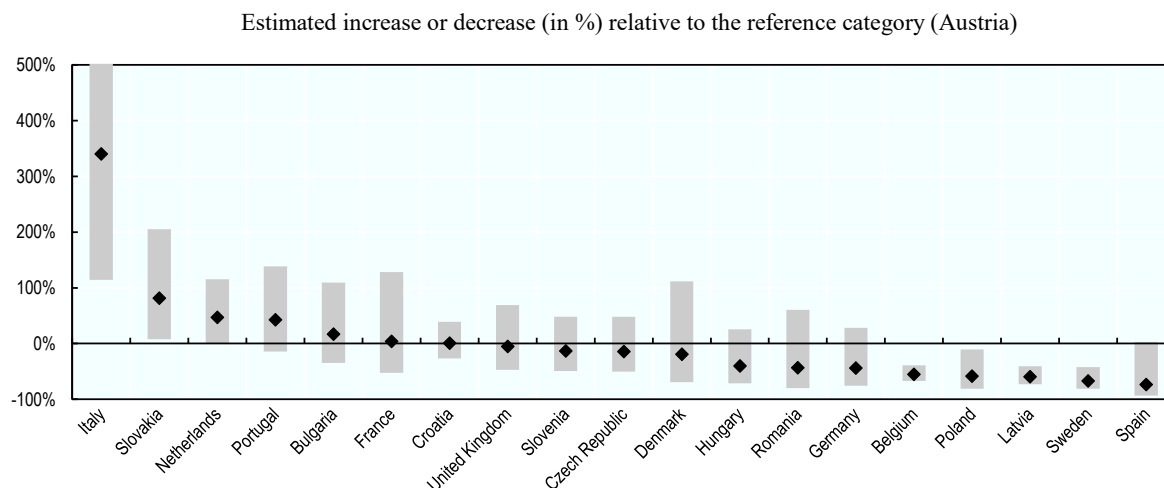
Figure 6.5. Crop differences in innovation rate



Note: Shaded area shows estimated percentage impact between the boundaries of the 95% confidence interval around the estimated crop effect (see main text for methodological notes).

Source: OECD analysis using the Kleffmann amis® AgriGlobe® database.

Similarly, Figure 6.6 shows estimated country effects, expressed as a percentage change compared to the reference category (Austria). Italy appears as a clear outlier here; the estimated effect implies that Italy's innovation rate is six times that of Austria, after controlling for all other effects in the analysis. This estimate is based on a single data point (for maize) only and should be interpreted with caution. Slovakia and the Netherlands also appear to have a higher innovation rate compared with Austria. At the other end of the spectrum, innovation rates appear lower in Belgium, Poland, Latvia, Sweden, and Spain, although in the latter case the effect is measured imprecisely.

Figure 6.6. Country differences in innovation rate

Note: Shaded area shows estimated percentage impact between the boundaries of the 95% confidence interval around the estimated country effect (see main text for methodological notes). Estimate for Italy truncated here at 500%; interval maximum is at 804%.

Source: OECD analysis using the Kleffmann amis®AgriGlobe® database.

The analysis has several limitations which need to be kept in mind. First, the overall number of observations (52) is relatively limited. Second, the measure of innovation used here is an imperfect indicator of actual innovative activity in these markets. For instance, if crops are suitable for many agro-ecological zones of the European Union but are only registered in a single country, the measure would simultaneously overstate innovation in some markets and understate it in others. Despite those potential shortcomings, the analysis presented here shows that there is at least no obvious relationship between market concentration and innovation in EU crop seed markets.

6.3. Conclusion

This chapter used disaggregated data on market concentration in seed to study effects on prices and innovation. The statistical analysis did not find clear evidence of an effect of market concentration on seed prices, after controlling for crop-specific and country-specific effects on prices. There appear to be some structural differences in price levels between countries which are not explained by market concentration levels; these could be due to quality differences and the presence of public plant breeders in some markets.

Regarding innovation, a statistical analysis for the European Union similarly did not find any clear evidence of a negative impact of market concentration on innovation, or of an “inverted-U” shaped relationship. The analysis did uncover a strong positive effect of market size, with a 1% increase in total market size leading to a 0.4-0.5% increase in the number of new varieties introduced per year, on average. Moreover, the rate of innovation appears lower when public breeders account for a larger share of the market. The analysis of innovation effects needs to be interpreted with caution, as the measure used here is only an imperfect approximation of the “true” degree of innovation in plant breeding.

The statistical analyses hence do not show a clear-cut relationship between market concentration on the one hand and prices and innovation on the other. However, the analysis here is necessarily limited and could not take into account other factors such as multimarket

contact, the possibility for outsider firms to enter a market, quality differences affecting price levels, or the R&D pipelines of different firms. On the other hand, in some cases the statistical analyses did suggest systematic differences between countries in terms of price levels or innovation rates, apart from potential effects of market concentration. This raises the possibility that other policies besides competition policy could affect the performance of seed markets. The potential for such complementary policy options is discussed in the next chapter, after a review of how competition authorities have evaluated the recent mergers.

Notes

- ¹ The countries listed are those where at least one public sector research institute was included among the ten largest firms in the market. The Kleffmann database is based on the ownership of varieties; it is possible that multiplication and distribution are outsourced to the private sector in these markets.
- ² For an indicator variable in a logarithmic regression, the impact of moving from zero to one is given by $100\% * (e^{\beta} - 1)$ where β is the true (population) value of the coefficient. However, as this expression is nonlinear, Jensen's inequality implies that substituting the estimated value $\hat{\beta}$ in this formula would give a biased estimate of the percentage change, even if $\hat{\beta}$ itself is an unbiased estimator of β . Assuming errors are lognormally distributed, Kennedy (1981_[232]) proposed using $100\% * (e^{\hat{\beta} - \frac{1}{2}\hat{V}(\hat{\beta})} - 1)$ where $\hat{V}(\hat{\beta})$ is the estimated variance of $\hat{\beta}$. Although this formula is not exact, it provides a good approximation (Van Garderen and Shah, 2002_[233]) and is therefore the approach followed here. Constructing exact confidence intervals is difficult given the small sample size (Giles, 2011_[234]). Instead, the bounds shown in the table are obtained by using Kennedy's transformation to the bounds of the 95% confidence interval for $\hat{\beta}$. While this is not an exact confidence interval for the percentage change, it gives some indication of the uncertainty around the estimated percentage change.
- ³ As mentioned in Chapter 5, there is a considerable degree of multimarket contact between seed firms, which in other industries has been found to lead to higher prices. Unfortunately, the current dataset makes it difficult to evaluate the impact on seed prices, as the dataset does not have full coverage across crops and countries. Hence, any empirical measure of whether firms have contact across different markets would tend to understate the true level of multimarket contact.
- ⁴ Data used in this analysis comes from the PLUTO plant variety database maintained by UPOV, the International Union for the Protection of New Varieties of Plants (see the annex to this chapter for details).
- ⁵ For most observations, the measure used is the year of the *grant start date* from the UPOV database; missing values for this variable were replaced by the year of the *grant publication date* where available.
- ⁶ The median number of approved entries across the European Union was three per year (one in Bulgaria, two in Spain).
- ⁷ A more detailed overview over time, by crop and by country, is provided Annex 6.A.
- ⁸ The final two specifications are to be preferred, as they both find evidence for an effect of the volume share of public plant breeders on innovation. Between these two specifications, the second-to-last specification has a higher adjusted R^2 and is therefore chosen here.

Annex 6.A.

Data on innovation in plant breeding in the European Union

Measuring innovation in plant breeding

For the empirical analysis, the rate of innovation in plant breeding is defined as the *annual number of new varieties introduced in a market*, where a market is defined as a combination of a country and a crop (e.g. the French maize seed market), and where the number of new varieties is measured by entries on the National List of EU Member States. This section explains the choice of methodology and the underlying dataset.

One approach to count the number of new varieties would be to count the number of plant breeders' rights or patents on plant varieties issued each year. However, there are several problems with this approach. First, jurisdictions differ in how intellectual property rights protection for new varieties is organised. In some countries (e.g. the United States, Australia), plant varieties can also be protected under the regular system of utility patents. While plant breeders' rights are monitored by UPOV, the International Union for the Protection of New Varieties of Plants, there is no similar harmonised database for utility patents on plant varieties, making it difficult to measure the number of new plant varieties across countries. For some varieties, breeders may also choose not to obtain a plant breeders' right.¹

Moreover, within the European Union, plant varieties in the European Union can be protected by a plant breeders' right either at the national level or at the European level, but not both at the same time. This creates a difficulty in accurately measuring the number of new varieties at the national level. Using only country-level plant breeders' rights would grossly understate the rate of innovation, given the importance of EU-level plant breeders' rights. On the other hand, EU-wide plant breeders' rights cannot easily be allocated to specific countries. Performing an analysis only at the aggregate level for the European Union is a possibility, but this assumes that the EU seed market is effectively a single market, which seems implausible given variations in agro-ecological conditions across the European Union; moreover, it greatly reduces the number of observations.

An alternative measure of new varieties can be based on entries to a National List. Several UPOV member states operate such a list, which includes all varieties authorised to be traded commercially. This is in particular the case for EU Member states. All varieties to be sold in the European Union need to be registered in the National List of one Member State. The registration process requires testing whether the new variety is distinct, uniform and stable (DUS-testing) and, for agricultural varieties, whether the new variety has a sufficient value for cultivation or use (VCU-testing).

The number of new varieties on the National List has its shortcomings as a measure of innovation. First, the release of a new variety is not only a measure of innovation but also reflects different company strategies; some firms may focus on providing a wide portfolio of "niche" varieties while others prefer to focus on providing a smaller number of varieties bred for broad adaptation. Second, not all varieties will be commercially successful, even after

passing the VCU tests. However, VCU tests do provide some guarantee that the new variety is a valuable addition.²

Another concern is that, as registration in a single country is sufficient for marketing throughout the European Union, the number of new entries likely overstates innovation in some markets and understates it in others. However, because of the need for VCU testing, it seems plausible that plant breeders will apply for registration in the National List of the country for which the variety is best adapted. This makes the number of new entries in the National List a reasonable, though imperfect, proxy for the rate of innovation in a country.

In the empirical analysis, the innovation measure uses the number of *approved* applications to the National List, instead of just the number of applications. A drawback of this choice is that for countries and crops with relatively low numbers of applications, this measure may indicate zero innovations – which means it is not possible to distinguish between crops without breeder interest and crops where breeders have tried in vain to innovate. In addition, the process of DUS and VCU testing typically takes two years, which adds an extra time lag to the already long R&D cycle in plant breeding. However, using the number of applications could be misleading, as there is anecdotal evidence that plant breeders often see the National List application process as the *de facto* last stage of plant breeding research, where public tests substitute for testing by the plant breeder. Suggestive evidence for this effect is found in the relatively large number of National List applications withdrawn by plant breeders, presumably as early test results disappoint. An alternative explanation is that testing for the National List provides an opportunity for plant breeders to see the performance of their varieties against the competition; for internal trials, plant breeders may not always have the latest competitor varieties available. Regardless of the precise mechanism, the large number of withdrawn applications suggests that approved applications are a better measure of useful innovation in plant varieties.

Data for the analysis was obtained from the PLUTO plant variety database maintained by UPOV, the International Union for the Protection of New Varieties of Plants. The PLUTO database contains information on plant breeders' rights, plant patents and national listings of varieties for 4 420 different species (including ornamental species) in 59 UPOV members, including the European Union, as well as the varieties certified by the OECD Seed Schemes. As of January 2018, the database contained over 800 000 entries. The species with the most entries are maize (15% of the total), wheat (5%), barley (4%), roses (4%), sunflower (3%) and tomatoes (3%). In addition to the European Union (17% of all entries) and the certified varieties of the OECD Seed Schemes (9%), the countries with the greatest number of entries are the Netherlands (8%), France (7%), the United States (6%), the United Kingdom (4%) and Germany (4%).³ While the UPOV Convention only regulates intellectual property rights in plant varieties independent of whether they are approved for commercial use in a country, the PLUTO database nevertheless contains information provided by the UPOV members on varieties included in their National List.

The list of crop seed markets included in the analysis is similar to that studied in the previous chapter (maize, soybean, wheat and barley, rapeseed, sunflower, potato, sugar beet, cotton). For cereals, our analysis here distinguishes wheat and barley. Annex Table 6.A.1 provides the definitions of these crops in terms of the UPOV codes in the PLUTO database (which correspond to Latin names of the crops).

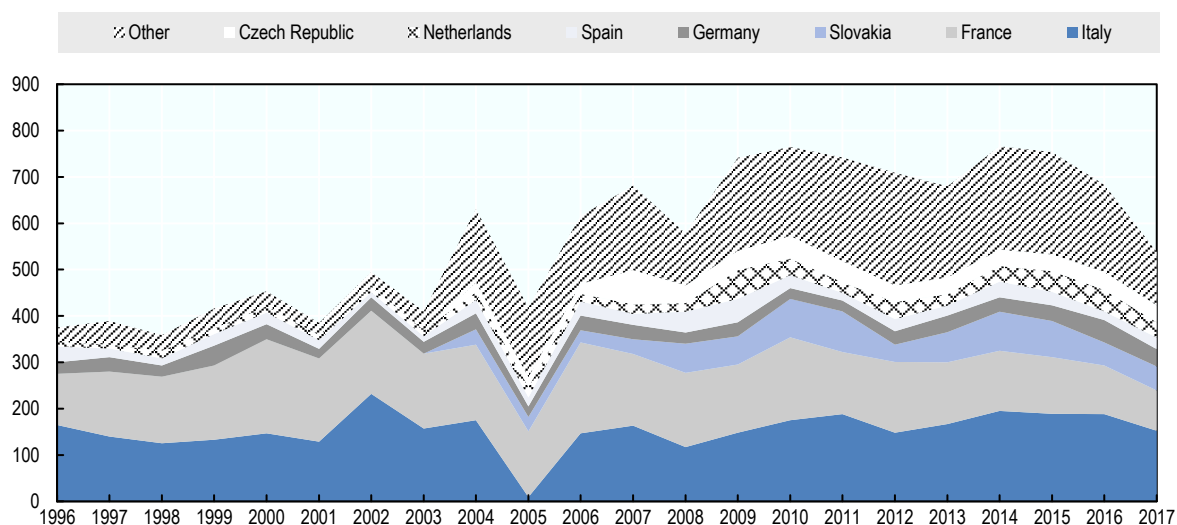
Annex Table 6.A.1. Crop definitions used

Crop	UPOV code
Maize	ZEAAA_MAY
Soybean	GLYCI_MAX
Wheat	TRITI_AES, TRITI_AES_AES, TRITI_TUR_DUR
Barley	HORDE_VUL
Rapeseed	BRASS_NAP, BRASS_NAP_NUS
Sunflower	HLNTS_ANN
Potato	SOLAN_TUB
Sugar beet	BETAA_VUL_GVS, BETAA_VUL_GV
Cotton	GOSSY_HIR

Trends in innovation per crop, 1996-2017

Using the number of new approved varieties in the National List per crop allows for an analysis of trends in innovation in the European Union over the past two decades (1996-2017). As shown in the following figures, there is no clear overall trend of increasing or decreasing innovation, apart from the increase generated by accession of new EU Members.

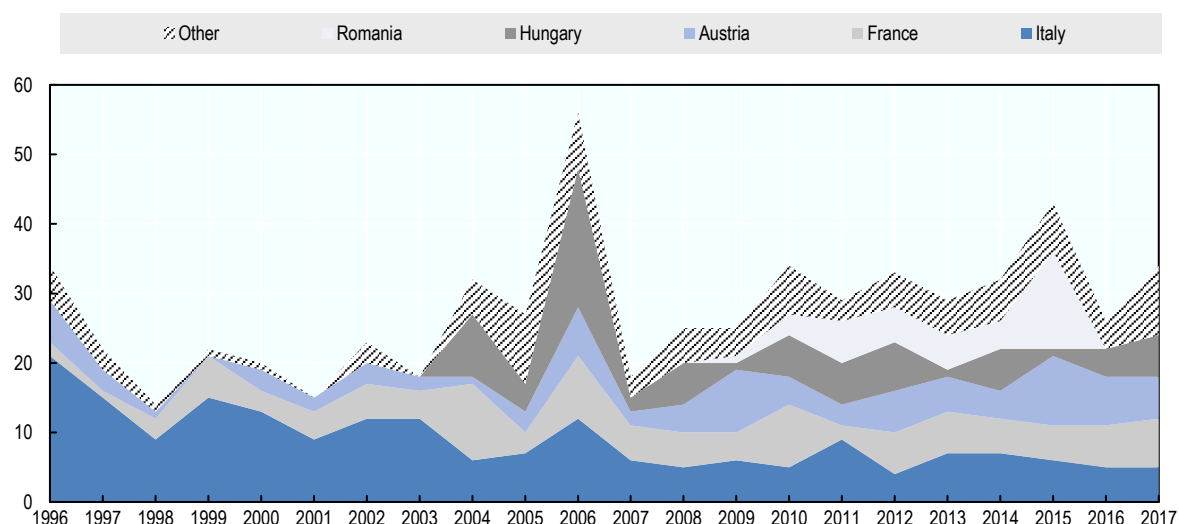
Figure 6.A.1 displays data for maize. Over the period, France and Italy have remained the largest sources of new varieties. The rate of new introductions appears stable over time in most countries.

Annex Figure 6.A.1. New varieties of maize, 1996-2017

Note: Annual number of approved applications to the National List (based on grant start date). For newer EU Member States, data is included starting from the year of accession to the European Union.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

For soybean, shown in Figure 6.A.2, there is some evidence of a decline over time in new varieties registered in Italy. At the same time, the number of new varieties appears to increase in France and Austria.

Annex Figure 6.A.2. New varieties of soybean, 1996-2017

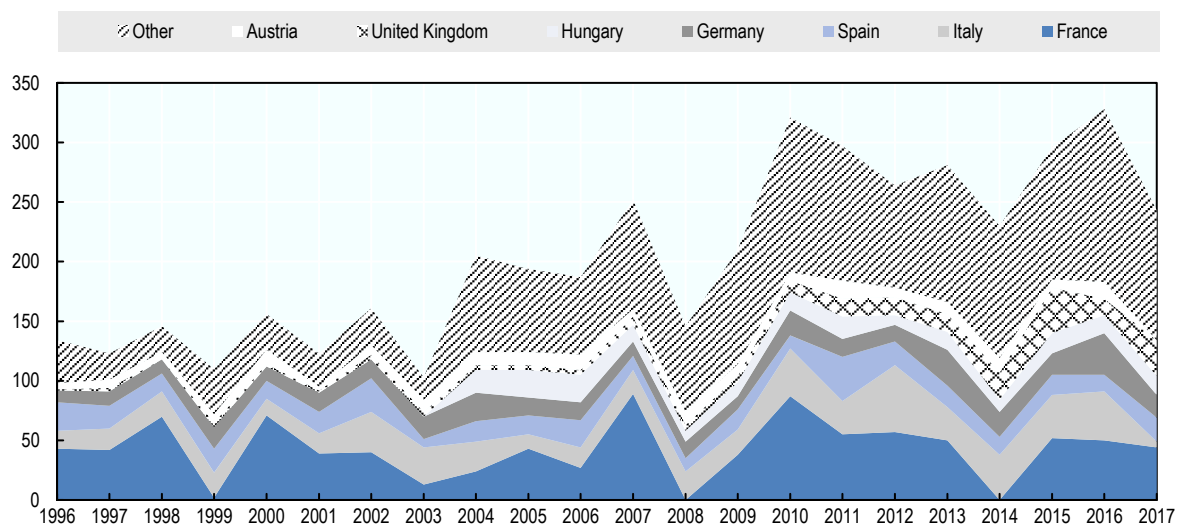
Note: Annual number of approved applications to the National List (based on grant start date). For newer EU Member States, data is included starting from the year of accession to the European Union.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

For wheat (Figure 6.A.3) and barley (Figure 6.A.4), new varieties are introduced in several countries, and the rate of innovation tends to fluctuate over time. In both cases, France is an important source of new varieties. Leaving aside the strong increase over time as new countries join the European Union, the data shows no clear pattern of an increase or decrease in innovation.

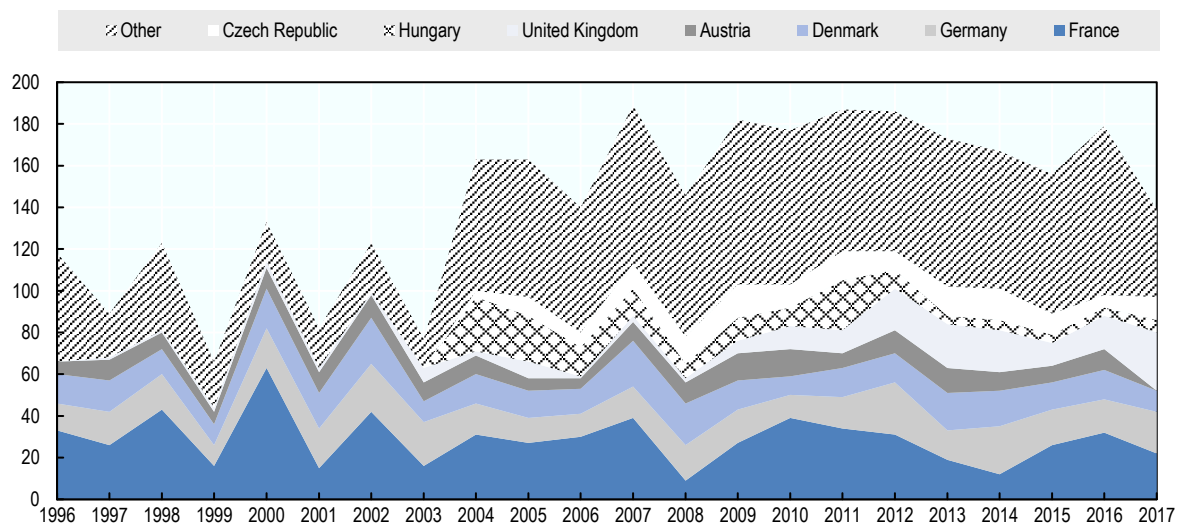
Figure 6.A.5 shows the introduction of new varieties of rapeseed. There is evidence of an increase in innovation, especially in the United Kingdom.

For sunflower seed, Figure 6.A.6 shows a shifting geographical pattern over time. While France and Spain were important sources of new varieties in the 1990s, their contribution has since decreased, while Italy has increased its rate of new variety introductions. New Member states (in particular Bulgaria and Romania) have been active as well. Data for 2017 seems to show a decline, although this may be due to delays in data submission to UPOV.

Annex Figure 6.A.3. New varieties of wheat, 1996-2017

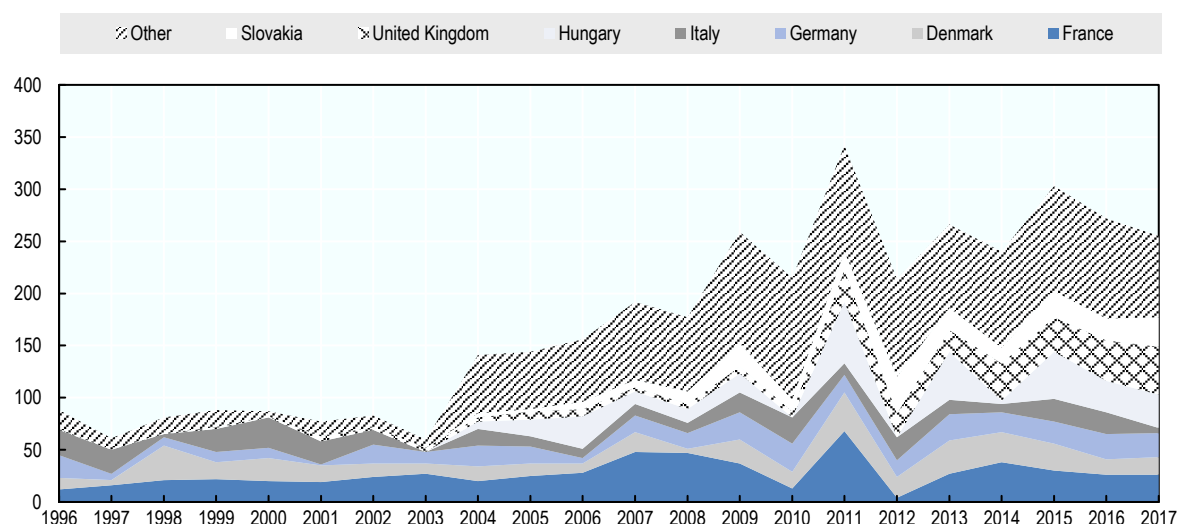
Note: Annual number of approved applications to the National List (based on grant start date). For newer EU Member States, data is included starting from the year of accession to the European Union.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

Annex Figure 6.A.4. New varieties of barley, 1996-2017

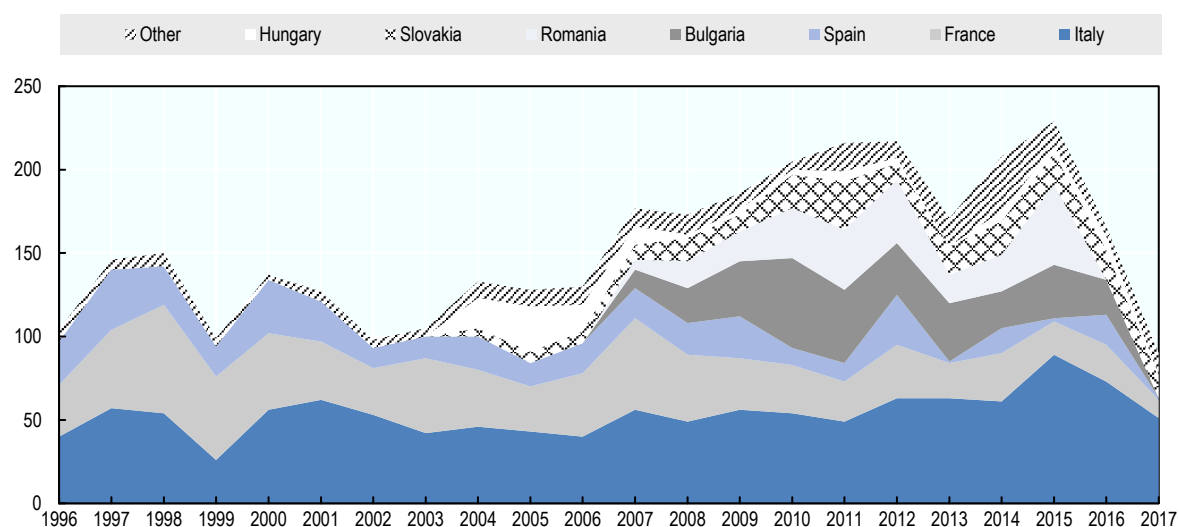
Note: Annual number of approved applications to the National List (based on grant start date). For newer EU Member States, data is included starting from the year of accession to the European Union.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

Annex Figure 6.A.5. New varieties of rapeseed, 1996-2017

Note: Annual number of approved applications to the National List (based on grant start date). For newer EU Member States, data is included starting from the year of accession to the European Union.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

Annex Figure 6.A.6. New varieties of sunflower, 1996-2017

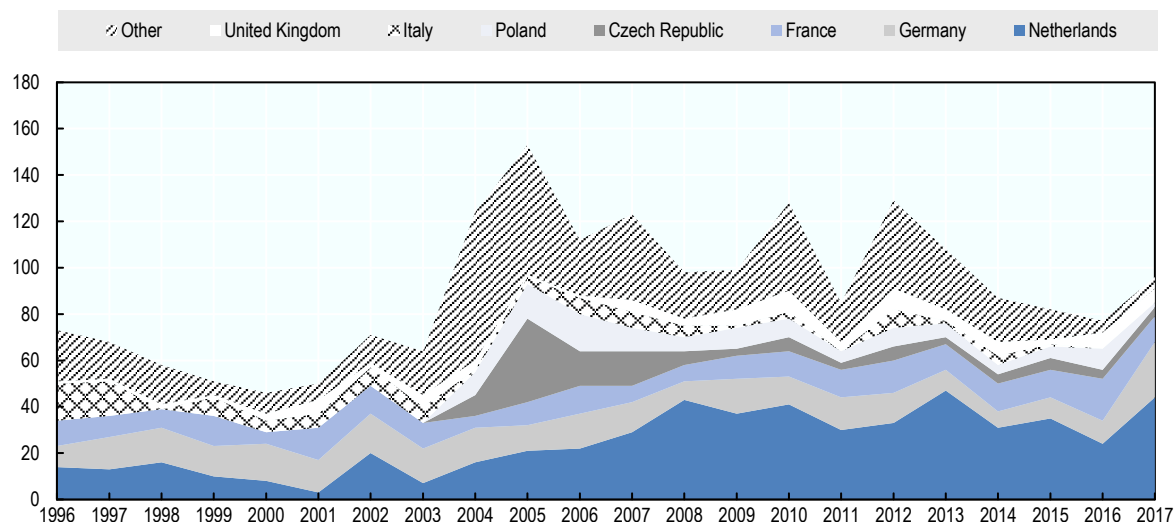
Note: Annual number of approved applications to the National List (based on grant start date). For newer EU Member States, data is included starting from the year of accession to the European Union.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018)..

New variety introductions for potato are shown in Annex Figure 6.A.7, showing a strong increase over time in new varieties introduced in the Netherlands, while the rate of innovation remains broadly stable in Germany and France. Despite an initial increase in variety registrations in new member states around 2004, the contribution of these countries (especially the Czech Republic and Poland) appears to have waned over time.

Finally, France, Germany and Spain account for most of the new varieties of sugar beet (Annex Figure 6.A.8), with evidence of an increase in new introductions over time.

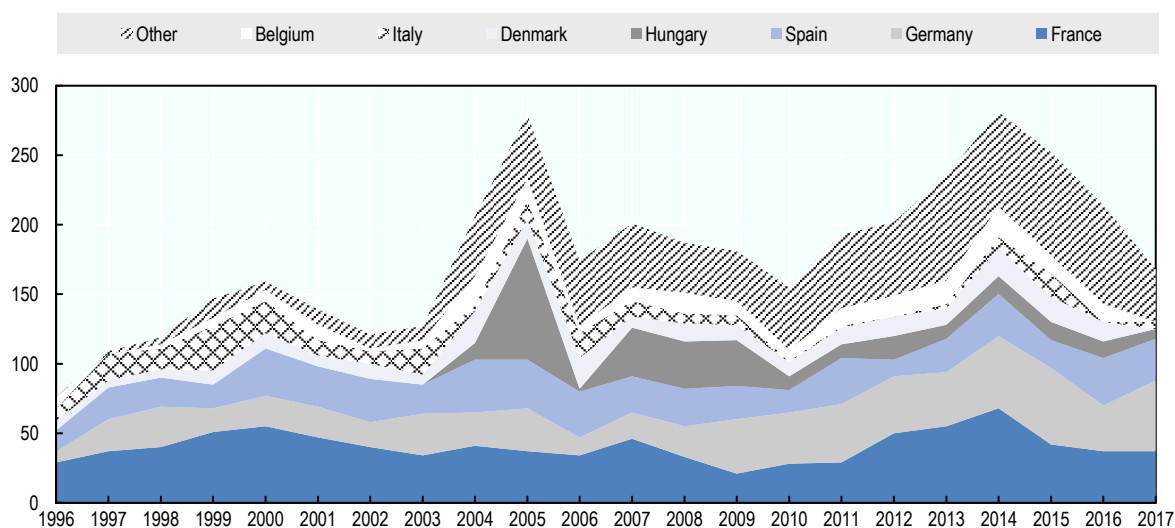
Annex Figure 6.A.7. New varieties of potato, 1996-2017



Note: Annual number of approved applications to the National List (based on grant start date). For newer EU Member States, data is included starting from the year of accession to the European Union.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

Annex Figure 6.A.8. New varieties of sugar beet, 1996-2017



Note: Annual number of approved applications to the National List (based on grant start date). For newer EU Member States, data is included starting from the year of accession to the European Union.

Source: OECD analysis using the UPOV PLUTO database (version 16 Feb 2018).

Notes

- ¹ This could be the case, for instance, if the plant variety has a rapid turnover, which reduces the usefulness of obtaining intellectual property rights protection; or in the case of a hybrid where biology provides a degree of intellectual property protection.
- ² For a discussion of breeding progress as measured in official trials in Germany, see, for example, Laidig et al. (2014_[239]) and Laidig et al. (2017_[252]).
- ³ One limitation is that contributing data to the UPOV database is voluntary; UPOV members are not required to provide data or, when they do provide data, they are not required to provide information on all items. As a result, not all countries are equally represented in the database.

7. Policy responses

The debate regarding concentration in seed markets has focused on the recent mergers and how competition authorities should respond. This chapter discusses the concerns, methods and policy responses of competition authorities around the world. It then outlines several complementary policy options available to policy makers to guarantee an innovative and competitive seed industry. These include avoiding unnecessary barriers to entry, facilitating access to intellectual property and genetic resources, and stimulating public and private R&D.

7.1. Competition authorities and the seed industry

In November 2017, the OECD distributed a brief questionnaire to competition authorities of several countries with important seed markets (Box 7.1). This questionnaire asked whether the competition authority was, or had been, investigating any of the recent mergers and acquisitions in the seed and agrochemical industry. If so, they were asked to indicate the key concerns these had raised; the measures and methods used to evaluate the impact of the transactions; potential remedies (such as divestitures) considered; and whether there had been any coordination with counterparts in other countries before a final decision was reached.

In view of ongoing investigations, some competition authorities declined to answer the questionnaire. This was the case for the United States and the European Commission. One country provided input under the condition of anonymity. Responses were received from Argentina, Brazil, Canada, Chile, Japan, Mexico, New Zealand, the Russian Federation, South Africa, and Korea. In general, all competition authorities declined to answer questions regarding ongoing investigations; in these cases, additional information was obtained from public statements after the merger investigations had been completed.

Box 7.1. OECD questionnaire for competition authorities

In November 2017, the OECD sent a questionnaire to 15 competition authorities to learn about how they are responding to consolidation in the seed industry. The competition authorities contacted were those of Argentina, Australia, Brazil, Canada, Chile, the European Union, India, Indonesia, Japan, Mexico, New Zealand, Korea, the Russian Federation, South Africa, and the United States. No response was received from competition authorities in India and Indonesia. The competition authorities in the United States and the European Union also declined to comment at the time given the ongoing Bayer-Monsanto investigation, while several other competition authorities completed the questionnaire without commenting on ongoing cases. After the approval of the Bayer-Monsanto merger in the spring of 2018, public statements by competition authorities have been used to complement the information from the questionnaires.

The questionnaire included the following questions:

- Has the Competition Authority formally investigated any of the mergers currently underway in the global seed industry (Dow-DuPont; ChemChina-Syngenta; Bayer-Monsanto; any others)?
- If so, what were the key concerns of the Competition Authority? (e.g. impact on prices; impact on variety/choice; impact on innovation; potential barriers to entry).
- What were the measures used by the Competition Authority? (e.g. C4 concentration ratios; Hirschman-Herfindahl Index; existence of a sufficient number of competing firms with R&D capabilities). What were the analytical methods used by the Competition Authority to assess the impact of the transaction on the market? (e.g. a formal merger simulation; an analysis of the R&D pipeline of the parties; a consultation with stakeholders).
- If the Competition Authority found any competition concern, did it consider the possibility to accept remedies? What types of remedies (if any) were considered? (e.g. divestiture of certain businesses or R&D capabilities; mandatory licensing of intellectual property).
- Did the Competition Authority coordinate with Competition Authorities in other countries? If so, which ones and on which issues?

The questionnaire asked competition authorities to provide contact details of experts who would be willing to provide further information. The OECD gratefully acknowledges the co-operation of competition authorities in providing background and information for the purpose of this study.

Concerns

In several cases, the competition authorities noted that the mergers would have no noticeable impact on the seed markets. The ChemChina-Syngenta transaction in particular was mentioned as having little or no effect on seed markets. (As noted previously, this transaction

did raise concerns around competition in agrochemical products, and both the US and European competition authorities required the divestiture of several pesticide products.)

In Korea, none of the three transactions were considered to have a meaningful effect on the market. For the DowDuPont merger, the Korea Fair Trade Commission imposed remedies for a (non-agricultural) petrochemical product only, while the other transactions did not even meet the requirements for notification to the competition authorities. In New Zealand, authorities have been monitoring the global mergers but have not initiated any formal investigations.

The DowDuPont merger was also judged to pose no risk in the Russian Federation, Chile, Mexico and Japan. In Canada, the competition authority was concerned only about potential effects on the agrochemical sector.

In South Africa, the Competition Commission concluded that the DowDuPont merger could negatively affect maize seed prices, choice, and product choice, as well as posing a risk to innovation and entry into the industry.

Similarly, in Brazil the competition authority identified risks of a DowDuPont merger for competition in maize seeds. In some segments, the combined market share of DowDuPont would have reached 40-50% or higher. DowDuPont's combined germplasm banks are well-adapted to Brazilian soil and weather conditions, while there were concerns around the capacity of other players in the market to effectively compete with DowDuPont after the merger. In addition, the competition authority noted the high barriers and long time span required for new players to enter the market. In the end, the DowDuPont transaction was approved conditionally on the divestiture of a significant part of Dow's Brazilian business and R&D capabilities.

As noted previously, US and European competition authorities had concerns around Dow and DuPont's agrochemical business and required divestitures, most notably of DuPont's global R&D organisation.

The Bayer-Monsanto merger raised more concerns. In addition to effects in seed markets, several competition authorities were worried about the market for broad-spectrum herbicides, where Bayer's glufosinate-based product is an important alternative to Monsanto's glyphosate-based herbicide. Moreover, some competition authorities also feared a loss of competition in the emerging field of digital agriculture.

In South Africa, the Competition Commission identified potential harmful effects of a Bayer-Monsanto merger on cotton seed prices and product choice, as well as the potential for reduced innovation in biotechnology traits, especially for maize.

In Brazil, the competition authority indicated risks of a Bayer-Monsanto merger through both horizontal and non-horizontal effects. Horizontally, there was a risk of creating a large combined market share in cotton and soybean regarding biotechnology traits as well as in terms of production and commercialisation of varieties. Non-horizontally, the competition authority noted that the merger would contribute to a further vertical integration of biotechnology and seeds markets. Without remedies, the merged firm would have been able to control other firms' access to biotechnology and could adopt commercial practices to restrict competitors' development. Moreover, the merged firm would have been able to use its strong market position to achieve prominence in complementary products. In this way, the combined firm would have been able to raise barriers to entry for new firms by making it necessary to enter different market simultaneously. The competition authority thus concluded

that the merger would have impacts on prices, product choice and innovation for cotton and soybean seed if no remedies were imposed.

In the United States, negative effects on competition were foreseen in cotton, canola, soybean, and vegetable seed markets, as well as in seed treatment. In the European Union, areas of concern were cotton, rapeseed, and vegetable seeds, in herbicide tolerance and insect resistance traits, and in seed treatment. In Mexico, Bayer and Monsanto would have held a near-monopoly on GM cotton seed and a dominant position in vegetable seed. In Canada, the Bayer-Monsanto merger was judged to reduce competition in seeds and traits for canola and soybean, as well as carrot seeds and seed treatments against nematodes.

The European Commission expressed concern with regard to seed markets for vegetables, rapeseed, and cotton, as well as GM traits, non-selective herbicides, seed treatment, and digital agriculture (European Commission, 2018^[134]).

The competition authorities in the Russian Federation expressed concerns about the Bayer-Monsanto merger, noting that it would take place after two other transactions had already reshaped the global industry. The competition authority noted Bayer and Monsanto's exclusive technologies and strong positions in plant breeding as well as in digital and precision agriculture. As a result, the competition authority considered that the merger posed threats for competition by creating and strengthening barriers to entry (including regarding exclusive digital platforms for precision agriculture), by increasing incentives for anticompetitive concerted behaviour, and by creating the possibility for the combined firm to abuse its market power. The Russian competition authority ultimately approved the deal conditional on a number of remedies (discussed further below).

Measures and methods

The competition authorities generally reported using very similar analytical approaches to evaluating the mergers.

Most competition authorities start by analysing the effect of mergers on combined market shares, as well as on concentration measures such as the four-firm concentration ratio and/or the Hirschman-Herfindahl Index. Some competition authorities (e.g. Chile) emphasised that these techniques are merely a first approximation or “screening”. In terms of quantitative measures, some competition authorities (e.g. Canada) sometimes use more advanced analytical techniques such as regression analysis and merger simulation.¹ Consultations with stakeholders were mentioned by nearly all competition authorities. Such consultations typically involve competitors and customers as well as other interested parties.

Several competition authorities (e.g. South Africa, Brazil, the Russian Federation, Mexico) also explicitly mentioned an analysis of the R&D pipelines of the merging firms and/or an evaluation of the viability of alternatives to the merging firms' products, including foreign competition. The competition authority for New Zealand noted that, while it is not formally investigating the mergers, previous analyses of the seed industry have focused on the ability and incentive of other players (notably foreign firms) to enter the market.

Remedies

The term “remedies” refers to measures used by competition agencies to resolve and prevent harm to the competitive process that may result from a merger (OECD, 2011^[90]). Typically, a distinction is made between structural and behavioural remedies. A structural remedy requires the divestiture of an asset, while a behavioural remedy imposes an obligation to engage in, or refrain from, a certain conduct. The sale of a part of the business or the transfer

or licensing of intellectual property rights are considered structural remedies. Examples of behavioural remedies include non-discrimination obligations, transparency provisions, or limitations on what firms may include in contracts with customers.

In response to the questionnaire, most competition authorities did not mention any remedies regarding the ChemChina-Syngenta transaction, as there was only limited overlap in the activities of both firms. The main exception concerned several pesticide products where ChemChina's Adama subsidiary was an important generic competitor to Syngenta's products. Both US and European authorities required divestitures in this area.

The DowDuPont merger attracted scrutiny in several jurisdictions (including the European Union, the United States and Canada) regarding potential overlap on herbicides, insecticides and fungicides as well as some non-agricultural products, leading to divestitures in these areas. In other jurisdictions, there were additional concerns regarding seed and GM markets, with corresponding remedies. South Africa required DuPont to license intellectual property rights for maize seed to third parties. In Brazil, the remedies included the divestiture of large parts of Dow's Brazilian business and R&D capabilities, particularly regarding the maize seed business. (Dow subsequently sold its Brazilian maize seed business to the Chinese firm Citic Agri Fund Management for USD 1.1 billion).

In the Bayer-Monsanto case, Bayer committed to selling a number of businesses to BASF. These include its global business in glufosinate tolerance traits and glufosinate herbicide (known under the "LibertyLink" and "Liberty" brands), its global vegetable seeds business and almost its entire field crop seed business (including rapeseed, cotton, soybean, and wheat). In addition, Bayer sold some seed-treatment assets and its digital agriculture portfolio to BASF, as well as three alternatives for glyphosate currently under development.

These divestitures addressed a large part of the competition concerns across jurisdictions, but some competition authorities required additional measures. In Russia, the competition agency required Bayer and Monsanto to provide access to technologies and databases under non-exclusive licenses and non-discriminatory access of seed producers, crop protection producers, and other parties to Bayer and Monsanto's digital platforms for precision agriculture. Similar measures were required by authorities in China (Reuters, 2018^[158]). In Chile, Bayer is barred from offering exclusivity-related rebates or from using tying or bundling with respect to Roundup herbicide (McLennan, 2018^[159]). In India, the Competition Commission required the firm to provide broad-based, non-exclusive licensing of GM and non-GM traits and non-selective herbicides. The firm is also required to provide non-exclusive access to data, platforms and applications related to digital agriculture, and needs to grant the Government of India free access to Indian agro-climatic data for public purposes (CCI, 2018^[160]).

Competition authorities therefore used a broad range of tools to remedy possible risks to competition. In addition to requiring the divestiture of certain product lines, whole businesses, or even global R&D organisations, some jurisdictions have used requirements around licensing, non-discrimination and commercial practices.

Coordination

Given the global nature of the mergers, competition authorities engaged in international coordination. Such coordination was highlighted by most of the competition agencies. In its press release announcing the approval of the Bayer-Monsanto merger, for instance, the European Commission explicitly mentioned co-operation with competition authorities in

Australia, Brazil, Canada, China, India, South Africa, and the United States (European Commission, 2018^[134]).

Topics of coordination in the seed mergers included market definition, approaches on the assessment of the consequences of mergers, and possible remedies. Coordination on remedies is particularly useful, as it allows firms to propose a logically consistent set of divestitures, which minimises transaction costs. In the Bayer-Monsanto merger, Bayer was able to propose the sale of coherent business assets (e.g. its global glufosinate business, its global vegetable seed business) to address concerns in various jurisdictions, rather than having to negotiate a patchwork of measures with different competition authorities.

Competition authorities often cooperate on mergers of multinationals, and such co-operation is beneficial for the competition authorities as well as for the merging parties. However, successful coordination requires the co-operation of the merging parties themselves. For instance, documents provided to the competition authority in one country typically fall under strict confidentiality rules, and merging parties need to agree to a waiver to allow the competition authority to share this information with other competition authorities (Competition Bureau Canada, 2014^[161]).

Successful co-operation may also require institutional changes. In Canada, a change to the Competition Act in 2009 aligned the Canadian merger review process more closely with US procedures (Competition Bureau Canada, 2014^[161]). In Argentina, prior to the adoption of a new competition law in May 2018, the merger review process worked on an *ex post* basis, where companies notified the competition authority only after the mergers were concluded (and hence approved by competition authorities in other jurisdictions). The new competition law changes the merger regime to an *ex ante* system, which will allow better co-operation with other competition authorities.

Conclusion

The results of the survey among competition authorities broadly confirm the insights presented earlier. To a large extent, the mergers combine complementary firms, with limited concerns about horizontal effects in many markets. In some markets (e.g. Korea, New Zealand) there was no formal investigation of potential impacts on seed markets, as the merging firms do not constitute a significant presence in the market. In other markets, concerns were raised about competition in certain segments or products. The importance of innovation was highlighted by the fact that many competition authorities analysed the R&D pipelines of merging firms as part of their investigation. Both horizontal and non-horizontal effects were mentioned by competition authorities as potential areas of concern. Competition authorities tend to coordinate with each other about the remedies needed to resolve these issues. These were typically structural remedies such as the sale of certain businesses or products.

In general, competition authorities appear to have a broad range of tools to prevent or limit risks to competition of a merger, from challenging a merger completely to requesting targeted structural or behavioural remedies. Such competition policy in the narrow sense is not the only way to safeguard or stimulate competition, however. Laws and regulations often inadvertently restrict competition, as highlighted in the OECD's Competition Assessment Toolkit (OECD, 2016^[162]). Conversely, other policies may stimulate competition by creating a more level playing field. Attention to the competition impact of such policies is complementary to competition policy in the narrow sense. Competition policy is often restricted to a "reactive" role, for instance intervening when market power is abused. Complementary policy options allow a more "proactive" approach and can prevent

competition problems from emerging in the first place. Some complementary policy options are presented in the next section.

7.2. Complementary policy options

Several policy options exist to safeguard or maintain competition in the seed industry. This chapter reviews some possibilities. Given the complexity of the seed industry, and the differences in organisation of the sector across different countries, not all of these options are equally feasible or desirable for all countries. However, they do provide some suggestions regarding policy levers which can influence competition in the industry. A first set of policy options aims to avoid or reduce barriers to entry caused either by regulatory requirements. A second set of policy options enables entry by facilitating access to intellectual property and genetic resources. A final set of options aims to stimulate R&D through either public investments or through other policies that stimulate private R&D.²

Avoiding unnecessary regulatory barriers to entry

While a sound regulatory framework is necessary to ensure markets function properly, regulation may also inadvertently create transaction costs and barriers to entry. An important goal for policy makers is therefore to evaluate how to achieve valid policy objectives (e.g. in terms of protecting human health and the environment) without unduly restricting competition or innovation (OECD, 2016_[162]). At the same time, the regulatory framework must also convince consumers of its effectiveness to ensure consumer acceptance, as a weak regulatory framework could lead to a lack of public trust which would in turn reduce demand and hence innovation.

In the context of innovation in seed markets, two relevant dimensions involve the regulatory environment for New Plant Breeding Techniques and the costs of regulatory science.

Regulatory environment for NPBT

Plant breeding techniques have seen rapid developments in the last few years. Several so-called New Plant Breeding Techniques (NPBT) have emerged, which potentially enable more precise, faster, and therefore more cost-effective plant breeding. NPBT refers to a broad set of different techniques, including cisgenesis, intragenesis, genome editing through Site-Directed Nuclease (SDN), and reverse breeding, among others. A brief introduction is provided in Box 7.2, based on Schaart et al. (2015_[11]).

For several of the techniques, the resulting product may be similar to varieties generated using traditional breeding techniques, but some processes may rely on genetic modification along the way. For instance, cisgenesis introduces a new gene into the genome of a plant, similar to transgenic genetic engineering; but in contrast with transgenic techniques, the new gene is taken from the same plant species. The resulting genome could therefore potentially also arise through traditional plant breeding. Similarly, SDN techniques can lead to the “knock-out” of a gene or its targeted modification or replacement, both of which could be achieved through traditional plant breeding (e.g. through mutagenesis).

From a policy perspective, a key question on NPBT is therefore under which regulatory regime these techniques (or more properly speaking, the products which result from them) should fall (Laaninen, 2016_[163]). It is important for policy makers to strike the right balance between providing sufficient safeguards to protect public health and the environment while avoiding excessive regulatory burdens that would slow or stall these important innovations, and while ensuring consumer trust in the regulatory framework. These questions are studied

in ongoing OECD work in the Environment directorate under the auspices of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology.

In March 2018, the United States Department of Agriculture announced that it would not regulate “plants that could otherwise have been developed through traditional breeding techniques,” provided that they are not “plant pests or developed using plant pests” (USDA, 2018^[164]). This statement implies that new plant breeding techniques such as genome editing will not fall under the same level of regulatory scrutiny used for genetically modified organisms.

In the European Union, it was unclear whether NPBT fell under the existing legislation on genetically modified organisms (EU Directive 2001/18/EU on Deliberate Release of Genetically Modified Organisms). The existing legislation lists a number of techniques excluded from the regulation, including mutagenesis. However, the text does not precisely define mutagenesis, while the definition of a genetically modified organism itself is also somewhat ambiguous (Eriksson et al., 2018^[165]). On 25 July 2018 the European Court of Justice clarified the interpretation of the Directive. The Court ruled that varieties obtained using the new plant breeding techniques are GMOs and hence fall under the same regulatory framework (Court of Justice of the European Union, 2018^[166]). In reaching this conclusion, the Court deviated from the Opinion of the Advocate General (Court of Justice of the European Union, 2018^[167]).

Box 7.2. New plant breeding techniques

The term “New Plant Breeding Techniques” covers a broad range of tools and techniques. Based on the characteristics of the final product after breeding, there are three broad possibilities:

- Plants with new genes
- Plants without new genes but with modifications of genes
- Plants without new genes and without modifications of genes

Several techniques result in plant varieties which could in principle also be obtained through traditional breeding techniques, although NPBTs are potentially faster and cheaper than traditional techniques. However, during the breeding process, NPBTs often use steps that could be interpreted as genetic modification, as (recombinant) DNA is introduced into the plant.

Cisgenesis is a technique similar to transgenic genetic modification, but using only genes of the species itself or from a closely related species. The technique can be used to transfer e.g. disease-resistance genes from wild relatives into commercially produced species. This can be done using traditional methods, but cisgenesis is potentially faster, as it can achieve the desired outcome without having to go through several generations of cross-breeding to introduce the gene into the commercially produced species. Hence, in principle, a cisgenic plant could also be achieved through traditional breeding.

Intragenesis is comparable to cisgenesis in its reliance on genetic material from the same or a closely related species. However, in contrast to cisgenesis, intragenesis introduces new combinations of elements of different genes. Changing these combinations can for instance combine a desirable gene with a stronger “promoter gene” that enhances the expression of the desirable gene. While this process still relies on genetic material of the same or a closely related species, an intragenic plant could *not* be achieved through normal breeding, as the recombination of elements is highly unlikely to occur in a traditional breeding process.

Genome editing through *Site-Directed Nuclease (SDN)* techniques (also called site-specific or sequence-specific nuclease techniques) comprises a number of different specific technologies with a common operating principle: exploiting the fact that the biological mechanism to repair broken DNA is itself relatively inaccurate. All SDN techniques therefore first deliberately create a *lesion* at a specific location in plant DNA. In some cases, the plant fails to accurately repair the lesion, causing the targeted gene to be “knocked out.” This application of SDN is referred to as SDN-1.

The plant's own DNA repair machinery can also use a copy of the gene as a template for repair. A second application of SDN, referred to as SDN-2, exploits this fact by providing a modified copy of the gene as a template, inducing the plant to create the desired modifications during the repair process.

Finally, SDN-3 uses the same principle as SDN-2 but induces the plant to insert a large fragment (e.g. a complete extra gene) instead of merely a modified copy of the original gene. This latter approach can be used as a way to introduce new genes (whether transgenic, cisgenic or intragenic).

SDN focuses on a specific target DNA sequence and can hence be used as a precise tool to knock out (SDN-1), mutate (SDN-2), or replace (SDN-3) specific genes. Plants resulting from SDN-1 and SDN-2 could in principle be obtained through traditional methods using mutagenesis.¹ Compared with traditional techniques, SDN has the advantage of producing only a change at the desired location, whereas mutagenesis can create random mutations throughout the genome and therefore may require several generations of breeding to remove the undesired mutations.

SDN covers four main technologies: *Zinc Finger Nucleases (ZFN)*, *Meganucleases*, *TALENs*, and *CRISPR-Cas*. One version of the latter, CRISPR-Cas9, appears to be particularly promising as it is relatively cheap, easy to implement, and versatile (Bortesi and Fischer, 2015^[168]) (Belhaj et al., 2015^[169]). While not an SDN-technology, *Oligonucleotide-directed mutagenesis (ODM)* works along similar principles as SDN-1 and SDN-2.

In contrast with the above techniques, *RNA-dependent DNA methylation (RdDM)* does not change the DNA sequence of the plant. Rather, it exploits an innate defense mechanism of plants which blocks the transcription of foreign DNA (e.g. from viruses). This mechanism is triggered by the presence of short double-stranded RNA molecules, as these could be degradation products of viral origin. The mechanism then locates the matching DNA sequence and attaches a methyl group to it. This deactivates the expression of the DNA while leaving the DNA sequence itself unchanged. The principle behind RdDM is to "trick" this defence mechanism into methylating a part of its own DNA. As this does not change the DNA of the plant, it is an *epigenetic* modification. However, the methylation is not stable; it tends to fade out over generations.

Reverse breeding solves the difficulty of reproducing a heterozygous offspring plant (i.e. a plant where chromosome pairs are not homogeneous). Such a plant cannot be reproduced from seed, as the next generation will be heterogeneous; the unique combination of characteristics is lost. Currently, such plants are reproduced vegetatively. Reverse breeding instead attempts to "reverse engineer" homozygous parental lines from which the heterozygous plant would be the offspring, similar to the way F1 hybrids are the offspring of true-breeding parental lines. The homozygous parental lines can be reproduced from seed, and the offspring plants will each time have the same desired genetic make-up. Reverse breeding uses a GM step to suppress recombination of chromosomes, although the gene used for this genetic modification is crossed out during the process. The end product does not contain genetically modified DNA.

Induced early flowering is a genetic modification used to speed up the process of plant breeding with fruit trees. For example, an apple tree takes five or six years before first flowering. This greatly slows down cross-breeding. By using genetic modification, an apple tree can be created which flowers within a year. This allows plant breeders to perform one breeding cycle per year. In the final step, the early flowering genes are crossed out, resulting in the desired variety, without genetically modified sequences in the final DNA.

Grafting on a GM rootstock involves letting the top part of a non-GM plant grow on a rootstock which has been genetically modified to improve characteristics such as resistance to soil-borne diseases.

As these examples show, the range of New Plant Breeding Techniques encompasses a broad range of techniques that can result in plants: with small genetic modifications, plants with new genes (transgenic, cisgenic, or intragenic); with unchanged DNA but where some genes are disabled through epigenetic modification; or without modifications to DNA but where genetic modification was used as a step in the breeding process. Policy discussions of the NPBT need to take into account the diverse nature of the techniques.

1. Mutagenesis is an approach where the plant breeder creates variation by deliberately triggering random mutations in the DNA of the species, for instance by exposing seeds to chemicals or radiation. The technique was developed in the first half of the 20th century and widely used by the early 1990s. By 1990, around one thousand commercially-available crop varieties had been created through induced mutation, mostly via gamma rays and X-rays (Kingsbury, 2009^[30]). A drawback of mutation breeding is that it often generates undesired mutations, which subsequently need to be bred out again.

Source: Schaart et al. (2015^[11]).

Cost of regulatory science

The high costs of regulatory science for genetically modified varieties have been noted earlier. While these costs by themselves do not explain the current merger wave, it is plausible that high costs associated with regulatory science reduce the rate of innovation by increasing the cost of introducing new traits and genetically modified varieties. Miller and Bradford (2010^[53]) have argued that high regulatory costs explain the relative scarcity of GM traits for specialty crops, as opposed to large-scale commodity crops.

One solution to reduce such regulatory burdens to innovation without reducing safety standards would be to let public institutions take care of some or all regulatory science. Such an approach would have the benefit of drastically reducing the fixed cost associated with the introduction of new genetically modified varieties, by 26% according to some estimates (Phillips McDougall, 2011^[52]). Such an approach would stimulate innovation and would also enable the development of new GM varieties by smaller firms without the financial resources and regulatory expertise of large firms.

There are precedents for letting public institutions take care of the regulatory science. In jurisdictions where tests for Value for Cultivation and Use (VCU) are a requirement for marketing a new variety, the necessary tests are usually performed by public research institutions.

A clear drawback of this proposal would be the budgetary cost. Public agencies might be able to partly recover their costs using a levy on the sales of approved GM varieties, similar to commodity checkoff programs used to fund generic marketing. However, such a levy would reduce the expected revenues of new GM varieties, which could partly offset the benefit of lower regulatory costs in stimulating innovation. A more targeted approach could be to allow small and medium-sized plant breeders to rely on public institutes for assistance with the necessary tests and data generation. A related option is to provide subsidies, grants or loans for small and medium-sized plant breeders to cover some of the costs of regulatory science.

Other ways of reducing regulatory costs without weakening regulatory standards include simplifying regulatory processes and providing advice on the regulatory approval process tailored to small and medium-sized plant breeders, e.g. through liaison officers.

Facilitating access to intellectual property and genetic resources

Access to intellectual property and genetic resources has been mentioned as a major concern regarding market concentration in the seed industry. Yet, several policy options exist to facilitate access.

Licensing of proprietary genetic material

Under the UPOV convention, which forms the basis of legislation on plant breeders' rights in many countries, an exemption is provided for other plant breeders to use varieties with a PBR in breeding programmes. This exemption provides other breeders with non-exclusive access to proprietary germplasm as long as this germplasm is protected only by plant breeders' rights. However, specific genetic traits (and in some jurisdictions, including the United States, plant varieties as such) can be protected with a patent. In contrast with plant breeders' rights, patents do not always provide a breeder's exemption (Box 3.1). In that case, a plant breeder who wishes to include patented genetic material may need to negotiate a licensing agreement with the owner.

The risk exists that firms refuse to license their patented genetic material to a competitor. Moreover, for smaller firms, the transaction costs of negotiating a licensing fee may be considerable. Both to stimulate innovation and to safeguard competition, licensing should be made easily available. In particular, licensing should ideally happen in a non-discriminatory way, at low transaction costs, while providing sufficient financial rewards for the original innovator to stimulate investments in R&D.

A promising development is the emergence of “patent clearinghouses” in plant breeding. In November 2014, eleven leading companies from the vegetable plant breeding industry (jointly representing more than 50% of the global vegetable seed market) created the *International Licensing Platform – Vegetables*, with support from the Dutch government (Bruins (2015^[170]), Kock & ten Have (2016^[171])). The goal is to provide an easy way for plant breeders worldwide to access each other’s patented genetic traits for a reasonable licensing fee.

Members of the ILP make all their patents related to vegetable traits available to other members under the conditions of the ILP. When a breeder wants to use a trait patented by another ILP member, the parties engage in bilateral negotiations. If no agreement is reached within three months, both parties submit their own license fee proposal to independent experts. The experts can only choose the most reasonable proposal among the two (and hence cannot formulate a compromise). This method of decision-making, known as “baseball arbitration,” has the benefit of forcing both parties to formulate a reasonable proposal from the outset. The license fee chosen by the experts is subsequently communicated to all other ILP members to increase transparency.

This innovative approach allows access to traits at modest transaction costs, yet maintains incentives for innovation through the licensing fee. The ILP therefore provides “free access but not for free.” Moreover, the ILP uses a most favoured nation-style approach where a firm is required to grant a license to a member under the best terms it has granted to other members.³

A “patent clearinghouse” could be set up among private-sector actors without requiring any formal change in public policies. But, as was the case with the ILP, governments can play a facilitating role, for instance by taking the initiative or by encouraging private-sector actors throughout the process of setting up a platform.

Such initiatives deserve further study and would clearly help avoiding transaction costs for firms willing to share access to proprietary genetic material, but would be of little use when a dominant firm refuses to license its intellectual property to competitors. Under some circumstances, this might be considered an abuse of a dominant position in the European Union, and competition law may require compulsory licensing (Slaughter and May, 2016^[172]). In the United States, compulsory licensing is not uncommon as part of merger remedies, but relatively rare outside of merger contexts (Delrahim (2004^[173]), Pate (2005^[174])). One notable example in recent years was the Microsoft case, where the US Department of Justice required Microsoft to license a range of intellectual property rights needed to create products interoperable with Microsoft Windows (Page and Childers, 2009^[175]). In the seed industry, mandatory licensing has been used in the context of mergers. For example, when Monsanto acquired DeKalb in 1998, competition authorities required Monsanto to allow competitors access to patented technology on agrobacterium transformation of maize, as well as Monsanto’s stock of maize germplasm obtained during the earlier acquisition of Holden’s Foundation Seed company.

These examples all involve competition authorities acting in reaction to threats to competition. It is unclear whether policy makers in other domains are able to rely on similar tools to stimulate licensing. Outside of competition policy, the only prominent example of compulsory licensing involves provisions under the TRIPS agreement, which allow countries to procure “generic” versions of patented products under certain conditions. These rules are most commonly used for pharmaceuticals (Reichman, 2009^[176]).

Some have proposed a more widespread use of compulsory licensing to ensure that plant genetic material remains easily available. Bjørnstad (2016^[177]) has suggested an approach whereby plant breeders are allowed to use patented plant material, but are required to declare the patents used when they register a new variety. A fair royalty fee could be established by a system such as the *ILP Vegetables* example. This approach could also be used for patented processes and methods, as well as for material obtained through the International Treaty or the Nagoya Protocol (Box 7.3). Bjørnstad (2016^[177]) emphasises the many outstanding questions around this proposal, including compatibility with existing laws and the TRIPS agreement.

Several jurisdictions already seem to have the necessary legal framework in place. In the European Union, the “biotech directive” (Directive 98/44/EC) provides for the possibility of compulsory cross-licensing (Article 12). The possibility exists for plant breeders who “cannot acquire or exploit a plant variety right without infringing a prior patent” and symmetrically also for holders of a patent concerning a biotechnological invention who cannot exploit it without infringing a prior plant variety right. The EU regulation requires that the applicant had unsuccessfully applied for a contractual license and that the new plant variety or invention constitutes considerable technical progress. The EU Directive requires Member States to ensure that in such cases a non-exclusive compulsory license can be granted in exchange for an appropriate royalty.⁴ A similar provision exists in Swiss law (Article 22a of the Swiss Plant Variety Protection Law and Article 36a of the Patent Law). If an applicant has unsuccessfully applied for a contractual license, a compulsory license can be granted by a court. So far, this possibility has never been used.

Rules regarding intellectual property need to strike a careful balance between providing incentives for investments in research and providing access to intellectual property. Proposals to facilitate licensing of intellectual property while remunerating the original inventor could benefit both competition and innovation in plant breeding, and therefore deserve further study.

Access to international germplasm

Access to genetic resources is essential for plant breeding, and it is therefore an important policy goal to maintain genetic diversity as well as providing easy access to this diversity. This creates a global policy challenge. Most countries grow food crops which originated in other countries or even other continents (Khoury et al., 2016^[178]). Wild ancestral relatives or landraces which could be useful in plant breeding are therefore likely to be located outside of national borders (ISF (2012^[179]), BSPB (2014^[65])). This raises questions about how to ensure access to genetic resources, how to stimulate the preservation and sustainable use of genetic diversity, and how to organise benefit-sharing arising from the use of genetic resources, some of which may be the result of centuries of cultivation efforts by farmers.

These questions are governed by two international treaties (Box 7.3). The Convention on Biodiversity (1992) is the “default” treaty governing genetic resources in general for countries that have ratified it. The Convention recognises national governments’ sovereign rights over these resources, as well as the authority to determine access to them. The Nagoya

Protocol (2010) further specifies the implementation of the “access and benefit-sharing” provisions of the Convention on Biodiversity.

For many agricultural crops, however, the relevant framework is provided by the International Treaty on Plant Genetic Resources in Food and Agriculture, which was adopted in 2001 and entered into force in 2004. For a list of 64 crops (known as “Annex I” crops) parties to the treaty agree to make genetic resources from local, national and international gene banks in the public domain available through a standardised procedure. Plant breeders consider that the International Treaty offers a more efficient access to genetic material for plant breeding, thanks to its standardised Material Transfer Agreements. For this reason, the International Seed Federation (2012^[179]) has suggested delegating the Access and Benefit Sharing responsibilities for *all* genetic resources for plant breeding to the authority managing genetic resources under the International Treaty. One possibility could be expanding the list of crops in Annex I to cover all crops where breeding occurs, as well as other genetic resources used in breeding these crops (ISF, 2012^[179]).

An important emerging policy issue concerns access to digital sequence information (DSI) (Halewood et al., 2018^[180]). The current governance of genetic resources is based on access to physical material, and genetic information is likely to pose serious governance challenges within the current framework (Welch et al. (2017^[181]). For instance, in its current formulation the treaties do not cover genetic information, so the terms and conditions for access to genetic resources and benefit sharing mechanisms do not apply. At the same time, an overly strict application of the existing legal access and benefit-sharing framework to digital sequence information risks creating excessive costs for researchers and plant breeders and significant obstacles to further research (Marden, 2018^[182]). The International Seed Federation (2018^[183]), for instance, is strongly opposed to regulating the access and utilisation of DSI.

In addition to ensuring an efficient and equitable system for accessing genetic resources, an important task is the preservation of these genetic resources. At a global level, the gene banks of the CGIAR Research Centers in particular play a significant role in conserving and providing access to the world’s genetic resources. At present, these gene banks contain 750 000 accessions, about 12% of all plant genetic resources conserved in gene banks.⁵ Between 2012 and 2016, the different gene banks of CGIAR distributed almost 600 000 samples of their accessions. In recent years, most Centres have reported an increase in distribution. For instance, between 1985 and 2009 nine CGIAR gene banks registered an annual rate of distribution of about 40 000 samples; the annual rate was 92 000 samples per year for 2012-2014. CGIAR expects this upward trend to continue given the rise of new technologies (CGIAR, 2017^[184]). Of the materials reported as exchanged through the multilateral system of the International Treaty, more than half are genetic materials managed by CGIAR gene banks, in particular CIMMYT (accounting for 30% of all materials) and ICARDA (23%) (FAO, 2017^[185]).⁶ In other words, a large part of the benefits of the International Treaty derive from the participation of the CGIAR gene banks, which constitute an international public good.⁷

The continued funding of these gene banks should therefore be an important priority for policy makers, especially since the benefit-cost ratio of doing so appears overwhelmingly positive while the magnitude of investments is modest. The annual costs of operating the CGIAR gene banks are estimated at around USD 6 million. As Koo et al. (2003^[186]) note, these costs have to be compared with benefits estimated in the tens of billions of dollars due to higher crop yields made possible by the existence of these gene banks.

To organise funding in perpetuity, the United Nations Food and Agriculture Organization (FAO) and CGIAR have jointly established the Global Crop Diversity Trust in 2004. The

goal of this Trust is to fund not only collections such as those of the CGIAR, but also those preserved by countries and regions, as well as maintaining a global last-resort seed vault, the Svalbard Global Seed Vault, located in Spitsbergen (Norway) and managed in collaboration with the Norwegian government and the Nordic Genetic Resource Center.⁸ The Crop Trust's goal is to secure an endowment of USD 850 million overall, of which some USD 300 million has been secured already (Burwood-Taylor, 2016^[187]). Conservation and sustainable use of global genetic resources is a crucial public good, and contributing to these initiatives should have a high priority for policy makers.

Box 7.3. International agreements on plant genetic resources

Two international treaties govern questions of access and benefit sharing (ABS) of genetic resources. The first is the Convention on Biodiversity (CBD), which entered into force in 1993. This convention recognises sovereign rights over genetic resources and the authority of national governments to determine access to those resources. The CBD also tasks governments with the responsibility of preserving genetic diversity. The Nagoya Protocol, which entered into force in 2014, is a supplementary agreement to the CBD and provides (among other things) a framework for the implementation of the "fair and equitable sharing of benefits arising out of the utilization of genetic resources," one of the three objectives of the CBD.

Countries adopting the Nagoya Protocol commit to setting up a transparent, non-arbitrary process for access to genetic resources, as well as domestic benefit-sharing measures. The Nagoya Protocol also sets up an "Access and Benefit-sharing Clearing-House" to share information on topics such as domestic regulatory ABS requirements. The United States has not ratified the CBD, limiting the global impact of these provisions.

The second treaty is the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), which entered into force in 2004. This treaty is a more specialised agreement focusing specifically on plant genetic resources used in food and agriculture, with the Nagoya Protocol serving as a "default" for countries that have not ratified the International Treaty (but which have ratified the Nagoya Protocol).

The ITPGRFA sets up a system to govern access and benefit sharing of genetic resources for a specific list of 64 crops known as "Annex I" crops. This list of crops includes the major food crops (e.g. rice, maize, wheat, potatoes) but excludes some other major agricultural commodities, notably soybeans.

In terms of access, countries ratifying the ITPGRFA agree to make available their genetic diversity as well as information about the crops stored in gene banks (Hufler, 2009). Under the ITPGRFA, material in local, national and international gene banks, including the collections of the CGIAR, are put in a Multilateral System for Access and Benefit-Sharing. This global pool of genetic material is made available to users (e.g. plant breeders) under terms and conditions of a Standard Material Transfer Agreement.

In terms of benefit sharing, users accessing genetic materials through the ITPGRFA agree to share benefits from their use, following the conditions stipulated in the Standard Material Transfer Agreement. In particular, if users of genetic materials create products which have restrictions on further research and breeding, they agree to pay an "equitable share" of commercial benefits into a Benefit-Sharing Fund to support conservation and sustainable use projects, especially in developing countries (FAO, 2017). In addition, users agree to share non-monetary benefits through exchange of information, technology transfer and capacity building, among others.

The ITPGRFA manages the Annex I plant genetic resources as a pooled good, using the Multilateral System and the Standard Material Transfer Agreement as a low-cost way to enable access and benefit sharing. The advantage of this system is that it avoids bilateral negotiations between users and individual owners, thus greatly reducing transaction costs (Hufler, 2009).

Since its introduction, the ITPGRFA has enabled 4.2 million exchanges of genetic material through almost 60 000 Standard Material Transfer Agreements. The largest share of genetic resources (2.1 million accessions, half of the total) has been sent by countries in Latin America and the Caribbean, while most of the genetic resources transferred so far have gone to Asia (1.3 million accessions) (FAO, 2017). In addition to crops covered by Annex I of the ITPGRFA, the Multilateral System can also be used for other crops using a similar Material Transfer Agreement. Overall, around 4% of accessions to genetic resources have been for non-Annex I crops.

Despite the large number of successful accessions, problems remain. Bjørnstad et al. (2013^[188]) sent seed requests to 121 countries that are Contracting Parties. They received no response from 54 countries, mainly in Africa and Latin America and the Caribbean, and concluded that the "facilitated access" promised by the ITPGRFA is not straightforward.

Open source germplasm

Some actors have proposed open source initiatives for access to germplasm, analogous to open source software (Kloppenborg, 2014^[189]). In the most commonly used approaches to open source software, users can access the source code of the software, modify it, and build derived applications as long as those modifications or derived applications are distributed under similar open source permissions. The result is the creation of intellectual property in a “protected commons.” While there is no individual owner of the intellectual property, open source products cannot be appropriated as intellectual property by others. In such a setup, private seed companies could still multiply and sell open source seed, but would not be able to use intellectual property rights law to prevent competitors from selling the same seed or further improving the open source variety. Advocates of open source seed see this as a method to avoid the appropriation of germplasm by major corporations, and cite its potential value for safeguarding genetic resources in developing countries in particular. Some organisations have already emerged to promote such “open source seed” (Open Source Seed Initiative, 2016^[190]).

An interesting characteristic of open source initiatives from a policy point of view is that they do not require any changes in the legal or institutional framework. Open source software operates using a “general public license” which relies on standard contract law; open source initiatives for germplasm can similarly be implemented when initial owners provide free access to germplasm under such a license. The only policy question in this setup relates to whether public plant breeding initiatives and other public organisations such as the CGIAR should adopt an open source approach to the distribution of their germplasm.

However, an important drawback of open source initiatives for germplasm is its incompatibility with other intellectual property rights regimes. For instance, the Open Source Seed Initiative (OSSI) allows certain restrictions and allows benefit-sharing arrangements (similar to royalty payments), but only when these restrictions are limited to the contracting parties. Restrictions (e.g. on seed saving or further breeding) cannot be passed on to customers under this system, and this makes “OSSI-Pledged” seed incompatible with current intellectual property rights for plant varieties. For advocates such as Kloppenborg (2014^[189]) this is precisely one of the attractive properties of open source germplasm, as it allows the creation of “a mechanism for germplasm exchange that allows sharing among those who will reciprocally share, but excludes those who will not” (p. 1238). The open source seed system would therefore essentially be a *parallel* system to the commercial seed system, with little or no exchange of germplasm between the two domains. This limits the availability of germplasm in both systems. If public organisations such as CGIAR adopted this approach for distributing their germplasm, they would thus deprive private-sector plant breeders from an important source of genetic material. At the same time, given the long time lags and capital-intensive nature of plant breeding, it is doubtful whether an open-source approach could provide sufficient incentives for private investments in plant breeding.

Creating a generic market for GM traits

The expiry of patents can lead to the emergence of a generic market, as in pharmaceuticals or agricultural chemicals. A similar process could occur for patented genetic material, in particular for patented GM traits. Allowing the emergence of a generic market for GM traits would be beneficial as it would allow off-patent GM traits to become available to farmers at lower costs, while stimulating innovative firms to continue to invest in R&D (rather than benefiting from high prices for GM traits long after patents have expired).

However, some regulatory obstacles may prevent the emergence of such a generic market. Seed companies seeking to sell generic GM seed need to obtain regulatory approvals before the seed can be sold. The firms therefore need to submit a “data package” to the regulatory authorities, which requires either access to the original data submitted by the patent holder, or the ability to experiment on the patented material. However, patent laws may make it difficult to conduct research on the patented seed or trait for these purposes. The pharmaceutical industry has resolved this problem by creating an exemption under patent laws to allow collection of data for regulatory approvals before the patent has expired. Introducing a similar exemption for utility patents on biotech traits would be important to stimulate a generic market for GM traits (Schenkelaars, de Vriend and Kalaitzandonakes, 2011^[29]).⁹

In the United States, private-sector actors have taken the initiative to introduce the “Ag Accord,” a pair of agreements setting up a legal framework for dealing with the expiry of patented GM traits: the Generic Event Marketability and Access Agreement (GEMAA) and the Data Use and Compensation Agreement (DUCA).¹⁰

The GEMAA was signed by large seed and biotech firms (DowDuPont, Bayer, BASF, Monsanto) and several farmer organisations (e.g. the National Corn Growers Association). It sets up an orderly process for dealing with patent expiration of biotechnology traits by creating clarity over who has responsibility for maintaining regulatory authorisations, and who has access to the proprietary data and other information necessary to obtain these authorisations (in the terminology of the GEMAA called the “proprietary regulatory package”).

Under the GEMAA, when a patent expires its owner can choose to maintain regulatory responsibility, seek to share responsibility, or discontinue. Under the first option, the original patent holder continues to be responsible for managing regulatory authorisations, at no cost to users of the (now-generic) biotechnology trait, but without providing access to the regulatory package. Under the second option, the firm can seek other firms willing to share the responsibility. These other firms then obtain access to the regulatory package. The third option, discontinuing regulatory responsibilities, builds in a seven-year transition period and starts a negotiation process with other firms for taking over the regulatory responsibilities and access to the regulatory package.

The DUCA is similar to the GEMAA, but provides an alternative mechanism for access to proprietary data and compensation for this access to the original patent owner. At present, this mechanism has not been implemented.

As with the *International Licensing Platform – Vegetables* discussed earlier, the “Ag Accord” is an agreement among private-sector actors and does not rely on any changes in public policies. But again, governments can play a facilitating role by encouraging such initiatives and bringing together the relevant stakeholders.

Stimulating public and private R&D

The policy options identified so far aim to stimulate competition and innovation by avoiding or reducing regulatory barriers and facilitating access to intellectual property and genetic material. Several other options exist to more directly stimulate innovation, including through public R&D.

Investing in public R&D

A large body of literature has documented high rates of return from public investments in agricultural R&D (e.g. Hurley et al. (2016^[191]), Alston et al. (2010^[192]), Alston et al. (2000^[193]), Alston et al. (2000^[194]) and Andersen (2015^[195])). Given high levels of private R&D in plant breeding, what role should the public sector play? A useful conceptual framework to study the complementary roles of public and private R&D is the “Stokes-Ruttan paradigm” described by Heisey and Fuglie (2018^[196]).

In this paradigm, types of research are classified according to whether the research is fundamental or applied, and whether there are explicit considerations for commercial use or not. This creates four possibilities. “Bohr’s Quadrant” includes fundamental research undertaken without any direct commercial objective; “Pasteur’s Quadrant” includes fundamental research with an ulterior commercial objective; “Edison’s Quadrant” contains applied research with a commercial objective; while the fourth category, “Rickover’s Quadrant,” includes applied research without a commercial objective.¹¹

The private sector will tend to focus its efforts on Edison’s Quadrant, provided that its investments in R&D can be recovered through either sufficient protection of intellectual property rights or biological mechanisms (such as hybrid varieties). The historical role of the public sector in applied plant breeding was often due to a lack of private interest. Where the private sector has sufficient incentives and resources to engage in R&D, the public sector has tended to retreat from direct plant breeding (Heisey and Fuglie, 2018^[196]).

It is possible in theory to maintain public plant breeding in Edison’s Quadrant strategically as a check on private-sector plant breeders. Kloppenburg (1988^[14]) provided an early criticism of increasing concentration in the US seed industry and the diminishing role of public plant breeding. He advocated continued public efforts to develop and release finished plant varieties (as opposed to the trend towards fundamental, non-applied research), among other reasons to provide a “restraint on the activities of private industry” (p.285). The availability of affordable and high-quality public varieties would then serve as a check on the exercise of market power by large firms. However, where sufficient competition and innovation in a crop variety exists, public plant breeding would be a duplication of efforts, or might lead to a crowding-out effect where increased public plant breeding leads to a reduction in private-sector investments.

Public R&D may be more useful for exploring the potential of orphan crops or underutilised crops, for which there is less competition and/or less interest from private-sector breeders overall. Public R&D could also develop new varieties with positive environmental externalities. Similarly, public R&D could focus on biofortification, the practice of breeding new varieties with a better micronutrient content to combat malnourishment in the developing world.¹² These are examples of applied research without a commercial objective (“Rickover’s Quadrant”) where public R&D has a role to play.

Public R&D might be similarly useful in Bohr’s Quadrant (fundamental research without a commercial objective) and in Pasteur’s Quadrant (fundamental research with a commercial objective), where the private sector will tend to underinvest. Public R&D efforts here could focus on *pre-competitive* research, e.g. on new breeding methods and tools, or on developing whole genome maps. By making the fruits of this research available in the public domain, public R&D can stimulate competition between different firms for the applications resulting from these more fundamental techniques and insights. Continued investments in such R&D might be useful to ensure that innovative techniques and tools (such as those underpinning the New Plant Breeding Techniques) remain accessible. Such an approach would also remove

a “winner takes all” dynamic where the firm which first develops a new technique can in theory block its use by others.¹³

Public-private partnerships

There is a fundamental tension between stimulating private R&D and stimulating the widespread adoption of a useful innovation. With private funding of R&D through intellectual property rights, the innovator can temporarily charge a monopoly price for the innovation. This provides incentives for private R&D investments, but it limits broad and easy access to the innovation. On the other hand, if R&D is financed by the public sector, the innovation could be made available more cheaply, but the question is to what extent public funds should be allocated to it, and whether there is a way to make the ultimate beneficiaries of innovation pay for the R&D efforts. Public-private partnerships can under some conditions reconcile these conflicting goals. An interesting example in the case of plant breeding is *industry-directed, levy-funded research* such as the Saskatchewan Pulse Growers described by Gray (2012^[197]).¹⁴

Saskatchewan Pulse Growers (SPG) represents over 18 000 pulse crop producers in the province of Saskatchewan (Canada) and is directed by seven farmers, elected by their peers. The scheme uses a mandatory 1% check-off (levy) on the value of the gross sale of all pulse crops, which is collected similar to a sales tax. An independent body appointed by the Ministry of Agriculture and Food supervises the activities. The revenues from the check-off are used to fund various projects such as research on pulse breeding, the provision of royalty-free seed, agronomic research, a Pulse Production Manual and efforts to increase domestic and international demand. Plant breeding funding from the SPG is directed to the University of Saskatchewan’s Crop Development Centre. The SPG also engages with private plant breeders. For instance, private firms may be given the right to distribute new varieties abroad in return for royalties; SPG also grants access to BASF for certain lentil varieties so the firm can incorporate its herbicide-tolerant traits. The SPG has been highly successful; Saskatchewan pea yields have increased by 40% in two decades and the internal rate of return on SPG investments has been estimated at 20% per year.

Compared with IP-protected private research, levy-funded research such as that by the SPG has three main advantages. First, if research is financed with a levy on farmers’ total output (regardless of the varieties used), royalties for the use of a new variety can be set at zero. In this way, farmers can adopt new, improved varieties more quickly and at a lower cost than under a ‘pure’ private system. Second, if all growers are paying for research, it makes sense for them to invest in R&D which would not be protectable under IP rules (e.g. research on agronomic best practices), and which would therefore not be provided by the private sector. Third, if this research is commissioned or undertaken by a single industry association, it avoids a possible duplication of research effort across different private plant breeders.

Levy-funded research also has several advantages compared with publicly funded research. First, as funds are managed by farmer associations, the system gives voice to end users. This ensures that research will benefit those who are paying for it. Second, as a semi-private initiative it may be easier to enter agreements with the private sector (e.g. by outsourcing certain types of research or by licensing intellectual property). Third, compared to public R&D, this organisational set-up does not require the use of public funds. Benefits are more likely to accrue when the levy system is mandatory. If the system is voluntary, some farmers may choose not to pay the levy and instead free-ride on the contributions of others.

Levy-funded research is not the only possible model for such public-private partnerships. In Australia, the Grains Research and Development Corporation was created in 1990 to provide

levy-funded R&D (Gray, 2012^[197]). Over time, the GRDC has explored new institutional mechanisms to organise R&D, in particular the development of for-profit partnerships with multinationals such as Monsanto, Syngenta, and Vilmorin (Limagrain). Such a setup can potentially tap private investment as well as managerial and technological capabilities while providing a check on over-pricing. An important institutional innovation was the introduction of *end-point royalties*, collected when the farmer sells the final product instead of when the farmer buys seed. Similar to the levy used by the SPG, end-point royalties ensure that breeders receive revenues even when farmers rely on farm-saved seed of the protected variety, while simultaneously lowering the initial cost for farmers and sharing the production risk between farmers and breeders.¹⁵

Despite these promises, farmer-funded research has often had disappointing results. The United Kingdom and the Netherlands have not had much success in stimulating R&D through such systems; in the United States, most producer levies are used for advertising and promotion instead of research to improve productivity. Successful examples often appear to rely on a combination of farmer contributions with matching public funds, to provide incentives to farmer associations to invest sufficiently in R&D (Heisey and Fuglie, 2018^[196]).

7.3. Conclusion

The increasing levels of concentration in seed markets have led to concerns about the potential impact on prices, product choice, and innovation in the industry. As this chapter has illustrated, the recent mergers have been scrutinised by competition authorities to avoid harmful effects. Decisions by competition authorities, however, are not the only factor affecting seed markets; several other policies can influence competition and innovation in this sector. These policy options can be summarised as avoiding regulatory barriers to entry, facilitating access to intellectual property and genetic resources, and stimulating both public and private R&D.

Notes

- ¹ For an overview of analytical methods used in merger analysis, see OECD (2011^[241]).
- ² As noted earlier, a broad range of policies affect the seed sector. Countries differ in the extent to which they have an integrated seed policy. Developing countries in particular often have explicit seed policies formulated in relation to strategies for agricultural development and food security. These policies may cover varietal development, seed production (multiplication), quality certification, agricultural extension, and/or stimulating the growth of a domestic seed industry. Some developed countries (e.g. Switzerland) similarly have a strategy for the development of their seed industry. In other countries, aspects of seed policy may be distributed over different agencies or ministries.
- ³ In addition to patented traits, a second pillar of the ILP also covers patents on plant varieties through a mutual “non-assert” clause, effectively creating the equivalent of a breeder’s exemption for patented varieties. An ILP member can use a patented variety of another ILP member free of charge as the basis for further breeding, as long as the patent owner is notified and as long as the new variety is sufficiently different from the protected variety.
- ⁴ A Commission Notice (2016/C 411/03) regarding this Directive notes the difficulty in demonstrating technical progress, and further notes that the European Commission may study this issue further. Bjørnstad (2016^[178]) suggests that registration on the National List (after VCU

testing) could be used as sufficient proof of such progress, so that the compulsory license can be granted almost automatically when a variety passes the VCU test.

- 5 An *accession* refers to a “distinct, uniquely identifiable sample of seeds representing a cultivar, breeding line or a population, which is maintained in storage for conservation and use” (FAO, 2018^[242]).
- 6 However, it should be noted that nationally operated gene banks are not obliged to report on exchanges.
- 7 A detailed overview of conservation and use of genetic resources, including information on the state of different collections worldwide, is provided by the Second Report on the State of the World’s Plant Genetic Resources for Food and Agriculture, published by FAO (FAO, 2010^[237]).
- 8 The global back-up already proved its usefulness. ICARDA, one of the CGIAR centres with a regional seed bank, was initially located in Aleppo in Syria. Due to the conflict in Syria, ICARDA moved to Lebanon and withdrew some of its back-up samples from the Svalbard vault to reconstitute the collections (Regan, 2015^[247]).
- 9 As noted previously, countries differ in the scope and strength of their patent law; in some jurisdictions research on patented products may be allowed under a “research exemption.”
- 10 See www.agaccord.org.
- 11 The quadrant is named after Admiral Rickover, who led efforts to develop a practical nuclear power plant to power naval vessels.
- 12 See, for example, HarvestPlus, a joint initiative of the International Centre for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI), <http://www.harvestplus.org/>.
- 13 Another mechanism through which public R&D can stimulate private R&D is by training future private-sector breeders. Public-sector R&D often takes place at universities, where researchers may also have teaching duties as part of their appointment. In the United States, some public-private partnerships exist between large plant breeding firms and universities, with training of future plant breeders as one of the objectives (Stephen Malone, personal communication).
- 14 For a broader discussion of farmer-funded R&D, see Alston et al. (2012^[253]).
- 15 In 2015, Canada amended its Plant Breeders’ Rights Act to bring it into conformity with the 1991 UPOV Act. This reform includes the possibility to introduce regulations to improve remuneration mechanisms for breeders by placing conditions or restrictions on the use of farm-saved seed. The Canadian grain industry has suggested using an end-point royalty system or royalty collection on farm-saved seed via production contracts. At the time of writing, the Government of Canada has not yet decided how to proceed.

8. Final remarks

This chapter places the findings of the report in the context of broader concerns on market concentration in the food chain, and draws conclusions regarding the importance of moving beyond highly aggregate data in discussing issues of market concentration.

Market power along the food chain is a recurring concern for stakeholders, academics and policy makers (OECD, (2014^[198]), Howard (2016^[199]), Wesseler et al. (2015^[26]) MacDonald (2017^[102]), Saitone and Sexton (2017^[200]), Sheldon (2017^[201])). An abuse of market power could allow dominant firms to extract rents from other players in the food chain, and could lead to an inefficient allocation of resources. At the same time, researchers have pointed out that a high degree of market concentration is not necessarily harmful. For instance, economies of scale and other mechanisms may provide offsetting efficiency gains (Sexton, (2013^[202]); Mérel and Sexton, (2017^[203])). In an innovative industry in particular, a concentrated market could still be characterised by intense competition between a few large players (MacDonald, 2017^[102]); these firms may be the only ones large enough to finance the high costs of R&D. A similar logic holds for the evaluation of mergers, where efficiency gains may exist that offset the potential harmful effects of increased market power.

Theoretical arguments can help clarify potential mechanisms and potential risks, but the question of whether concentration and consolidation along the food chain is harmful is ultimately an empirical one. Yet, an informed debate on these questions has been hindered by a lack of detailed data on levels of market concentration, evidence on its effects, and information on relevant policy options.

In this spirit, the present study has tried to bring together relevant information for the global seed industry. Given the challenges confronting the global food system, it is important to safeguard competition and innovation in the seed industry, which has an important role to play in improving agricultural productivity, sustainability, and resilience. Over the past decades, the industry has undergone a tremendous consolidation, culminating in three major transactions since 2015: the merger of Dow and DuPont, the acquisition of Syngenta by ChemChina, and the merger of Bayer and Monsanto. The changes taking place in the global seed industry have attracted an unusual level of public attention, with the European Commission's Directorate-General for Competition receiving over a million petitions, emails and tweets expressing concerns about the Bayer-Monsanto merger (European Commission, 2018^[204]).

An important conclusion from this study is that aggregate figures on market shares and concentration are not very useful in informing the public debate. The detailed data presented here shows large variations in seed market concentration across different crops and countries. Moreover, the set of firms competing in a market varies. Despite their broad scope in terms of geographies and crops, the former "Big Six" firms were not active in all seed markets, although they have a more pronounced role in the market for GM traits.

It is precisely such a detailed assessment of market shares which underlies the decisions of the Competition Authorities regarding the mergers. In several jurisdictions, the mergers were only allowed after considerable divestitures. In the Bayer-Monsanto merger, Bayer was required to divest practically its entire seed business, as well as its glufosinate-based herbicide, the main alternative to Monsanto's glyphosate-based herbicide. These and other Bayer assets were sold to BASF, which may emerge in the coming years as an important new player in global seed markets.

A second conclusion is that competition policy is not the only factor influencing the future path of the global seed industry. EU Competition Commissioner Vestager pointed out that many of the concerns voiced by citizens regarding the Bayer-Monsanto merger were about genetically modified organisms and the use of glyphosate herbicide. These topics go beyond the scope of competition policy and are the proper domain of regulatory authorities on human health and the environment (European Commission, 2018^[204]).

A similar point can be made about innovation and competition in the seed industry. The seed industry is affected by a range of public policies beyond competition policy, which creates scope for policy makers to consider complementary policy options to safeguard and stimulate competition and innovation. This study has identified a number of possibilities under three broad themes: avoiding unnecessary regulatory barriers to entry, facilitating access to intellectual property and genetic resources, and stimulating both public and private R&D in the industry. As each country faces a different agro-ecological and economic context, and different policy preferences, there is no single set of policies to be adopted in this regard. Rather, a range of options exist for policy makers to enable the seed industry to meet the challenges of increasing the productivity, sustainability and resilience of agriculture.

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