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Research Investments and Market Structure in the Food Processing, Agricultural Input, and Biofuel Industries Worldwide

Executive Summary

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This report provides an Executive Summary of ERS Economic Research Report 130 with the same title. The longer report contains nine additional chapters with detailed analysis of seven agricultural input industries, the food manufacturing industry, and the biofuel industry, including fuller discussion of data sources and methods. For the full report, please see www.ers.usda.gov/publications/err130

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Research Investments and Market Structure in the Food Processing, Agricultural Input, and Biofuel Industries Worldwide

Executive Summary

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David Schimmelpfennig, and Sun Ling Wang

Abstract

Meeting growing global demand for food, fiber, and biofuel requires robust investment in agricultural research and development (R&D) from both public and private sectors. This report highlights the major findings of a study examining global R&D spending by private industry in seven agricultural input sectors, food manufacturing, and biofuel and describes the changing structure of these industries. For the full report, see *Research Investments and Market Structure in the Food Processing, Agricultural Input, and Biofuel Industries Worldwide*, ERR-130. In 2007 (the latest year for which comprehensive estimates are available), the private sector spent $19.7 billion on food and agricultural research (56 percent in food manufacturing and 44 percent in agricultural input sectors) and accounted for about half of total public and private spending on food and agricultural R&D in high-income countries. In R&D related to biofuel, annual private-sector investments are estimated to have reached $1.47 billion worldwide by 2009. Incentives to invest in R&D are influenced by market structure and other factors. Agricultural input industries have undergone significant structural change over the past two decades, with industry concentration on the rise. A relatively small number of large, multinational firms with global R&D and marketing networks account for most R&D in each input industry. Rising market concentration has not generally been associated with increased R&D investment as a percentage of industry sales.

Keywords: agricultural biotechnology, agricultural chemicals, agricultural inputs, animal breeding, animal health, animal nutrition, aquaculture, biofuel, concentration ratio, crop breeding, crop protection, farm machinery, fertilizers, Herfindahl index, globalization, market share, market structure, research intensity, seed improvement.

Contents

Summary

What Is the Issue?

Growth in the productivity of the global food and agricultural system will be largely determined by today's investments in research and development (R&D). In recent decades, the private sector has become a major player in developing innovations for food and agriculture. Factors spurring private companies to invest in food and agricultural research include the emergence of biotechnology and other new scientific developments, the strengthening of intellectual property rights (IPR) over agricultural innovations, new regulatory requirements, the expansion of markets for improved agricultural inputs and food products, and rising consumer demand for more diverse foods. More recently, rapid growth in the market for biofuel has pushed companies to expand their R&D investments in this area as well.

This report quantifies investment trends by for-profit companies in food manufacturing, biofuel, and agricultural input R&D and explores how these trends are affected by changes in market demand and industry structure. In particular, the report examines changes in the organization and structure of agricultural input industries (crop seed and biotechnology, crop protection chemicals, synthetic fertilizers, farm machinery, animal breeding and genetics, animal health, and animal nutrition) and whether increases in market concentration in these industries are associated with increases or decreases in the level and intensity of R&D investments.

For comparative purposes, we present some aggregate statistics on public-sector research spending for food and agriculture and ways in which these investments differ or complement R&D in the private sector. However, we do not delve much into the interactions between public and private R&D. For a detailed examination of the evolving role of the public and private sectors in agricultural R&D in the United States, see Fuglie and Schimmelfpennig (2000).

What Did the Study Find?

During 1994-2007 (the latest year for which comprehensive estimates are available), annual private-sector food and agricultural R&D grew from $11.3 billion to $19.7 billion, or 4.3 percent per year (or, in constant 2006 dollars, from $14.6 billion to $19.2 billion, or 2.1 percent per year). In high-income countries, private-sector R&D spending appeared to be roughly equivalent to public-sector spending on food and agricultural R&D, although public R&D spending continues to be larger if only agricultural-related R&D is considered.

Growth in R&D investment was uneven across industries. The most rapid increase in R&D was in crop breeding/biotechnology. Significant growth in R&D spending also occurred in farm machinery and food manufacturing. However, real (inflation-adjusted) R&D spending declined for crop protection chemicals and animal nutrition.

Other key findings include the following (figures below are in current or nominal dollars, unadjusted for inflation):

- In 2010, global private-sector investments in R&D related to *agricultural inputs* reached $11.03 billion, an increase from $5.58 billion in 1994.
- In 2007, global private-sector investments in R&D related to *food manufacturing* reached $11.48 billion, an increase from $6.02 billion in 1994.
- In 2009, global private-sector investments in R&D related to *biofuel* reached $1.47 billion, with most growth in this area occurring since 2000.
- Generally, the largest four to eight firms in each sector accounted for about three-fourths of the R&D in that sector, with larger firms spending more than smaller firms on R&D as a percentage of product sales (with the exception of small biotechnology firms). Typically, the large firms are multinational operations with global R&D and marketing networks.
- In most of the agricultural input industries, market concentration increased during 1994-2009, with the highest levels observed in the animal breeding and crop seed sectors and the largest increase observed in the crop seed sector.
- Rising levels of market concentration were not associated with larger R&D investment in agricultural input sectors.
- The globalization of food and agricultural R&D may accelerate the rate of international technology transfer, reducing productivity differences across nations and regions.

How Was the Study Conducted?

We used a number of approaches to construct estimates of private R&D spending by sector. For research-intensive agricultural input industries, we built a database of agriculturally related research spending firm-by firm over time, for all firms in the sector (including “legacy” firms, or firms that exited the industry during the period of study) that have or have had significant R&D expenditures. For large conglomerates, for which agriculture may be only one business segment, we separated agriculturally related R&D spending from R&D spending on nonagricultural business segments. We gathered this information by canvassing a broad set of material, including company annual reports and websites, reports by industry associations and consulting services, and personal interviews with company representatives. Altogether, we reviewed R&D information on more than 800 agricultural input companies worldwide. These firm-level data also enabled us to examine hypotheses regarding the relationship between industry structure and R&D spending: Do larger firms spend more (as a percentage of product sales) on R&D than smaller firms? Has the rising concentration of several agricultural input industries affected overall levels of R&D spending by that industry?

For agricultural input industries in which firms do not often report their research spending, we estimated agricultural R&D for the industry by taking a percentage of total agricultural input sales, with the percentages (or research intensities) derived from observations on R&D spending from a subset of firms and from previous surveys of the industry. For the food manufacturing industry, we relied on country-level estimates produced by the Organisation for Co-operation and Development, which covers primarily high-income countries.

With these sources, we developed a global time series of R&D expenditure for agricultural input industries from 1994 to 2010, for the food industry from 1990 to 2007, and for biofuel in 2009. We examined how trends in R&D spending were associated with changes in market demand and industry structure and reviewed the evidence on the factors causing structural changes in agricultural input industries.

Objectives and Methods of Study

Over the past several decades, the private sector has become a major player in developing new innovations for food and agriculture. The emergence of biotechnology and other new scientific developments, the strengthening of intellectual property rights (IPR) over agricultural innovations, the global expansion of markets for improved agricultural inputs and food products, and consumer demands for more diverse kinds of food products are some of the key factors driving private companies to invest in food and agricultural research. More recently, rapid growth in the market for biofuel has spurred a diverse set of firms to expand their R&D investments in this area as well. This report seeks to quantify investment trends by for-profit companies in agricultural, food, and biofuel R&D and explore how changing market demand, industrial structure, and public policy may be affecting these trends. In addition, the report examines the role of government subsidies in stimulating private R&D in the biofuel sector.

Existing information on private spending on food and agricultural research is fragmentary. James (1997) and Alston et al. (2010) are among the few studies that have attempted to provide estimates of such expenditures on a global scale. Based on findings from both studies, private R&D expenditures from the mid-1990s to 2000 are estimated at $13 billion per year, or about two-thirds of total public sector spending for agricultural R&D (about $20 billion per year globally) over the period. These estimates account for R&D by the food manufacturing sector and the agricultural input industries, but the studies did not break down these amounts by sector. Moreover, they provide limited detail (and quite different estimates) about the country-specific locations of private-sector R&D, with James estimating that about 85 percent was conducted in high-income countries and Alston et al. putting the share at 95 percent (in contrast, about 60 percent of public agricultural R&D is conducted in high-income countries, according to Alston et al.).

Other studies have provided more detailed information on private-sector expenditures on food and agricultural R&D at the country level. Klotz et al. (1995) develop comprehensive estimates of private R&D by the food sector and for major agricultural input industries in the United States between 1960 and 1992. Pray and Fuglie (2001) survey private companies in seven Asian countries about their agricultural R&D investments in the mid-1990s, and Echeverria et al. (1996) summarize available information for eight Latin American countries from around the same period.

Some estimates of R&D in specific industries, such as the agricultural chemical, crop seed, and veterinary pharmaceutical industries, are provided by industry groups through surveys of their member companies or consulting services. This information, however, may cover only a portion of an industry and may not be in the public domain.

Finally, a number of studies have examined publicly available data on a range of indicators of private R&D effort, such as number of agricultural patents, plant variety protection certifications, and biotechnology field trials issued or undertaken. For example, Huffman and Evenson (2006) make extensive use of historical patent data to investigate technology flows from manufacturing sectors to agriculture in the United States. The main conceptual difference between these indicators and R&D expenditures is that the indicators reflect *outputs* from the R&D process whereas expenditures measure R&D *inputs*. It is expected that the two would be significantly correlated but with a timelag. Some of the main findings from studies assessing agricultural R&D indicators are summarized in Pray et al. (2007). In this study, we extend some of the work on R&D output indicators in the chapters on crop seed and agricultural chemicals.

This study provides new, detailed information on R&D spending by private industry for the food processing and biofuel sectors and for seven agricultural input sectors (crop seed and biotechnology, crop protection chemicals, synthetic fertilizers, farm machinery, animal health, animal breeding and genetics, and animal nutrition). For the food processing and agricultural input sectors, we report trends in private R&D spending over time. For the newly emerging biofuel sector, our estimates cover only one year, 2009. We also examine the location of private-sector R&D, but the multinational nature of many of the leading companies conducting food and agricultural R&D makes it difficult to do so. For agricultural input sectors, we can estimate total R&D for companies based in a particular country, but this estimate includes R&D by those same companies conducted in other countries and excludes R&D by foreign companies in that country. We discuss the globalization of private-sector R&D in terms of the growing international trade in agricultural inputs and how companies locate their R&D facilities to serve global markets.

The study also examines the changing structure of agricultural input industries. Several of these industries have undergone significant consolidation over the past couple of decades, with many firms exiting, merging, or being acquired by other firms. We discuss factors causing these changes and, for the agricultural input industries that do the most research, we quantify the change in concentration at the global level. Higher levels of concentration may impart greater market power to the largest firms in the industry. If this market power is exercised to raise premiums on firms' proprietary technology, it could encourage these firms to invest more in R&D. We examine whether market concentration is correlated with the share of industry revenues that is invested in R&D. We do not, however, conduct any formal tests of competitive performance in these markets.

To construct estimates of private R&D spending by sector, we use a number of approaches. For research-intensive agricultural input industries, we build a database of agriculturally related research spending firm by firm (both publicly traded and privately held) over time, for all firms in the sector that have (or have had) significant R&D expenditures. For large conglomerates, in which agriculture may be only one line of business among many, we separate agriculturally related R&D spending from other R&D spending. We gather this information primarily from firms' annual financial reports and supplement it with information from industry associations, consulting services, and personal interviews with company representatives. These firm-level data also enable us to address questions on the relationship between industry structure and R&D spending:

- Do larger firms spend more (as a percentage of product sales) on R&D than smaller firms?
- Has the rising concentration of several agricultural input industries affected overall levels of R&D spending by these industries?

For agricultural input industries in which member firms do not conduct much research, firm-level data on R&D spending is often reported for only a subset of the major companies in the industry. Our estimates of agricultural R&D for such industries reflect a share of total agricultural input sales (or research intensities) derived from observations on R&D spending from a sample of firms in the respective industries.

For the food industry, we rely primarily on country-level estimates provided by the Analytical Business Enterprise Research and Development (ANBERD) database produced by the Organisation for Economic Co-operation and Development (OECD). This database covers most high-income countries and a few developing countries.

For biofuel, we examine R&D spending across a number of sectors that are developing technologies for both biofuel feedstocks and biofuel manufacturing. Because this is a relatively young industry, we derive an estimate of private R&D for only one year, 2009.

From these sources, we are able to develop a global time series of R&D expenditures by agricultural input industries from 1994 to 2010, food processing industries from 1990 to 2007, and the biofuel industry for 2009. Significant overlap or duplication occurs between R&D reported in the food and agricultural sector and the different segments of the biofuel market chain (i.e., some seed industry R&D is directed toward biofuel feedstocks and is counted as R&D in both sectors); therefore, to avoid double counting, we report biofuel R&D estimates separately from the estimate for total private-sector food and agricultural R&D.

Having assembled data on trends and levels of private food manufacturing and agricultural input R&D spending, we examine several factors that may be influencing these trends. First, we look at market demand. Large and growing markets for agricultural inputs or new food products can be expected to attract more R&D from private firms seeking to meet these needs. Second, we examine industry structure. Mergers and acquisitions have affected many agricultural input industries examined, with the result that fewer firms account for a growing share of the market over time. This development could influence incentives for private R&D positively, negatively, or not at all. The classic Schumpeterian view is that larger firms invest a greater portion of their revenues in R&D than smaller firms. However, in a detailed study of U.S. manufacturing industries, Cohen et al. (1987) do not find empirical support for this hypothesis. Regarding concentration, Levin et al. (1985) report a general tendency for R&D intensity to first increase and then decrease as industry concentration rises, but the authors note that the differences across industries can be much larger than changes within an industry. Finally, we discuss the effects of changes in policies and technology opportunity, namely, the influence of developments in biotechnology on structure and R&D in the research-intensive agricultural input industries. Policies toward intellectual property rights (what is considered patentable) and the regulation of new technology introductions may have significant effects on how much and what kind of R&D is undertaken by the private sector, and what kinds of firms can successfully navigate these policies.

Private-Sector R&D Investment in Agriculture, Food, and Biofuel

R&D Spending Over Time

Table 1 shows trends in private-sector R&D spending in various agricultural input sectors and the food manufacturing industry in both nominal and constant (inflation-adjusted) dollars. In constant 2006 U.S. dollars, total food and agricultural R&D expenditures in the private sector increased from $14.59 billion in 1994 to $19.18 billion in 2007, or at an average annual rate of 2.1 percent. R&D expenditures in food manufacturing rose faster than those in agricultural input industries, and by 2007, food manufacturing accounted for about 58 percent of the overall annual total. Food manufacturing has relatively low research intensity (R&D as a percentage of sales), but the overall size of the market is very large. R&D in the industry appears to be directed mostly toward new product development. Food sector R&D that is directly relevant to agriculture, such as R&D on animal feed manufacturing, is also included in our estimate of R&D in agricultural input industries (but not double counted in the total for food and agriculture). Among agricultural input industries, most of the increase in R&D spending between 1994 and 2010 occurred in the crop input industries, with R&D spending in the animal-related sectors as a whole remaining essentially flat in real (inflation-adjusted) dollars. Across sectors, the most rapid growth in agricultural R&D over 1994-2010 was for crop seed and biotechnology, where annual R&D spending increased from about $1.5 billion in the mid-1990s to nearly $3.5 billion in 2010 (constant 2006 U.S. dollars). Real R&D spending declined for crop protection chemicals and animal nutrition.

Comparative statistics for government spending on agricultural research are only available for 2000 (Beintema and Stads, 2008; Alston et al., 2010, table 6-1). Beintema and Stads (2008) estimate that total global public-sector agricultural research in 2000 was $16.3 billion in U.S. dollars and $20.8 billion in purchasing-power-parity (PPP) dollars.[1] The private sector appears to account for between 39 and 45 percent of the total global investment in food and agricultural R&D worldwide, depending on whether comparisons are made using market or PPP exchange rates, and about half of the total in high-income countries (table 2). For high-income countries, Beintema and Stads estimate total public agricultural R&D in 2000 was $12.3 billion in U.S. dollars and $11.8 billion in PPP dollars, respectively. Of our estimated total of U.S. $13.1 billion (PPP $13.2 billion) in private food and agricultural R&D in 2000, U.S. $12.2 billion (PPP $11.8 billion) was attributed to companies based in high-income countries.

Although none of the global estimates of public research spending break down this investment into food and agricultural sectors, the U.S. data may be illustrative, at least for high-income countries. According to USDA's Inventory of Agricultural Research, in 2000, about 60 percent of total public agricultural R&D was allocated to research related to plant and animal systems, 15 percent went to food and human nutrition, 18 percent went to environmental issues, and the remaining 7 percent was spread across other topics not directly related to food or farm production.[2] Alston et al. (2010) also estimate that about 60 percent of U.S. public agricultural research was

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[1] Beintema and Stads (2008) actually report figures in constant 2005 dollars, which we convert to current 2000 dollars using the U.S. implicit Gross Domestic Product (GDP) price index. Global totals in U.S. dollars are calculated using market exchange rates, while totals in purchasing-power-parity (PPP) dollars are derived using the PPP exchange rates. PPP exchange rates are estimated by the World Bank by comparing the cost of a common basket of consumer goods across countries. The main effect of using PPP exchange rates is to augment estimates of research and development (R&D) spending in developing countries; aggregate spending by high-income countries remains about the same whether market or PPP exchange rates are used.

[2] This breakdown of U.S. public agricultural research expenditures is according to Research Problem Areas as defined by USDA's Inventory of Agricultural Research (USDA, 2000). Alston et al. (2010) use a more detailed, project-by-project assignment to estimate (R&D) expenditures related to production agriculture. Their estimates show that the share of U.S. public agricultural (R&D) allocated to production agriculture has gradually declined over time.

Table 1

Private research and development (R&D) expenditures for food and agriculture worldwide

	Crop protection chemicals	Crop seed & biotech.	Farm machinery	Fertilizer	Food animal health[1]	Animal breeding & genetics[2]	Animal nutrition	Total crop inputs	Total animal inputs	Total agricultural inputs	Food manu-facturing	Total food & agricultural inputs[3]
						Millions of nominal U.S. dollars						
1994	2,296	1,130	920	61	664	196	314	4,407	1,173	5,579	6,016	11,282
1995	2,390	1,213	987	80	778	203	332	4,670	1,313	5,983	6,876	12,528
1996	2,523	1,322	1,110	84	767	210	373	5,039	1,350	6,389	6,468	12,483
1997	2,635	1,522	1,127	64	749	217	345	5,349	1,311	6,660	6,399	12,714
1998	2,636	1,721	1,164	56	720	225	324	5,577	1,269	6,846	6,417	12,939
1999	2,581	1,788	1,079	49	670	232	320	5,496	1,223	6,719	6,490	12,889
2000	2,352	2,055	1,197	56	655	240	329	5,659	1,224	6,883	6,516	13,071
2001	2,263	2,015	1,149	53	592	249	334	5,480	1,175	6,655	6,755	13,075
2002	2,076	1,976	1,136	56	590	258	345	5,245	1,193	6,438	7,203	13,295
2003	2,458	2,064	1,190	74	663	267	360	5,787	1,290	7,076	8,756	15,472
2004	2,628	2,180	1,275	97	712	276	377	6,181	1,365	7,545	9,620	16,789
2005	2,678	2,254	1,369	119	757	285	375	6,420	1,417	7,837	10,531	17,993
2006	2,633	2,374	1,470	99	794	295	375	6,575	1,465	8,040	10,899	18,564
2007	2,754	2,615	1,665	104	816	306	389	7,138	1,511	8,649	11,480	19,741
2008	3,012	3,093	2,003	96	960	316	400	8,205	1,677	9,882	n.a.	n.a.
2009	2,987	3,342	2,310	100	930	327	405	8,739	1,663	10,402	n.a.	n.a.
2010	3,116	3,726	2,394	100	941	339	410	9,335	1,690	11,026	n.a.	n.a.
						Millions of constant 2006 U.S. dollars						
1994	2,968	1,462	1,189	79	858	253	405	5,697	1,516	7,214	7,778	14,587
1995	3,028	1,536	1,250	101	986	257	421	5,915	1,663	7,578	8,709	15,866
1996	3,136	1,643	1,380	104	953	261	464	6,263	1,678	7,941	8,039	15,516
1997	3,218	1,859	1,377	79	915	265	421	6,533	1,601	8,134	7,815	15,528
1998	3,183	2,078	1,406	67	870	271	391	6,735	1,533	8,268	7,749	15,626
1999	3,071	2,127	1,284	58	798	277	381	6,541	1,455	7,996	7,724	15,339
2000	2,739	2,394	1,395	65	763	280	383	6,592	1,425	8,018	7,590	15,225
2001	2,577	2,295	1,309	61	674	283	381	6,242	1,338	7,580	7,694	14,894
2002	2,328	2,215	1,274	63	662	289	387	5,880	1,337	7,217	8,075	14,905
2003	2,697	2,265	1,306	81	727	292	396	6,350	1,415	7,765	9,609	16,978
2004	2,805	2,326	1,361	104	760	294	402	6,595	1,456	8,052	10,265	17,915
2005	2,765	2,328	1,414	123	781	295	387	6,629	1,463	8,093	10,875	18,581
2006	2,633	2,374	1,470	99	794	295	375	6,575	1,465	8,040	10,899	18,564
2007	2,676	2,540	1,618	101	793	297	378	6,934	1,468	8,402	11,152	19,176
2008	2,864	2,941	1,905	91	913	301	381	7,802	1,595	9,396	n.a.	n.a.
2009	2,814	3,149	2,176	94	876	308	382	8,232	1,566	9,799	n.a.	n.a.
2010	2,908	3,477	2,234	93	878	316	383	8,711	1,577	10,288	n.a.	n.a.

n.a. = not available. Current expenditures adjusted for inflation by the U.S. implicit Gross Domestic Product price deflator.

[1] Animal health R&D is for food animals only, excluding R&D for companion and equine animal health.

[2] Estimates of private animal genetics research spending are only available for 1996 and 2006. We extrapolate for other years assuming 5.24 percent annual growth.

[3] Includes Organisation for Economic Development and Co-operation food industry R&D and total agricultural input R&D (animal nutrition is a subsector of the food industry and is not double counted in the total).

Source: USDA, Economic Research Service. See Fuglie et al. (2011) for sources and estimation methods for specific industries.

Table 2

Public and private spending on food and agricultural research and development (R&D) worldwide in 2000

	Food R&D	Agriculture R&D	Food & ag R&D	Food & ag R&D[1]
	Billion U.S. dollars			*Billion PPP$*
Global total				
Public	n.a.	n.a.	16.3	20.8
Private	6.2	6.9	13.1	13.2
Total			29.3	33.9
Private share of total (%)			45.0	39.0
High-income countries				
Public	1.9(est)	7.4(est)	12.3	11.8
Private	5.8	6.3	12.2	11.8
Total	7.7(est)	13.7(est)	24.5	23.6
Private share of total (%)	76.0	46.0	50.0	50.0

n.a. = not available.

est. = estimate only. The allocation of public R&D into food-related and agriculture-related R&D in high-income countries is based on U.S. public R&D allocation shares and assumes these are roughly similar among all high-income countries. U.S. public R&D allocation is from the USDA's Inventory of Agricultural Research (USDA, 2000), which reports that in 2000, about 60 percent of total public agricultural R&D went to production agriculture, 15 percent went to food and nutrition, and the rest went to environmental and other topics. The total for public "food & ag R&D" includes all categories of research at public agricultural research institutions, while the food and agriculture sectors only include research directly related to that sector.

[1] The last column estimates international public R&D using purchasing-power-parity (PPP) exchange rates rather than the market exchange rates from which the U.S.$ estimates are derived. PPP exchange rates are based the relative price of a common basket of consumer goods. Using PPP exchange rates raises dollar estimates of R&D spending in developing countries significantly but affects spending estimates for high-income countries only marginally. PPP exchange rates are from the World Bank.

Source: USDA, Economic Research Service. Estimates of public food and agricultural research are from Beintema and Stads (2008). Estimates of private food and agricultural R&D are from this study. Private R&D on animal nutrition is included in agriculture excluded from the food sector.

allocated to research relevant to farm productivity but do not provide a breakdown for the other 40 percent. If these figures are representative of public agricultural R&D in high-income countries, it would imply that the private sector accounts for roughly 76 percent of total food-related research and 46 percent of research on production agriculture in these countries (table 2).

For the biofuel industry, we estimate total private R&D at $1.47 billion in 2009 (table 3). This total includes $340 million spent by agricultural seed and biotechnology companies to improve biofuel feedstocks.[3] Another $1.03 billion was spent by companies in the energy sector to improve the efficiency of biofuel process manufacturing as well as to develop new types of biofuel feedstocks, such as algae. Enzyme and equipment manufacturers supplying inputs to energy companies for biofuel processing accounted for the remaining $71 million. Not included in these estimates is R&D spending by the transportation industry to modify vehicle and equipment engines for biofuel use. Although our estimates cover only one year, it is clear from industry sources that most of these R&D investments have arisen since 2000.

The largest driver of private biofuel R&D is the expectation of rising demand for alternative energy sources. This demand is sparked by the rising cost of fossil fuels relative to that for biomass-derived fuels and public concerns

[3] Biofuel feedstocks are the crops and biomass materials used to produce ethanol and biodiesel. First-generation feedstocks include corn, sugarcane, soybeans, and palm oil. Second-generation feedstocks (under development) include sources of cellulosic biomass, such as switchgrass, miscanthus, corn stover, sugar bagasse, and forest-based materials. Third-generation biofuel feedstocks include algae and synthetic life forms.

Table 3

Global expenditures for biofuel research and development (R&D) in 2009

Sector and type of firm	R&D
	Million U.S. dollars
Private-sector market segments	
Agricultural input sectors (agricultural seed-biotechnology companies, plantations, forest product companies, and cellulosic biomass firms	340
Energy sector (biofuel producers, biofuel equipment manufacturers, and oil companies)	1,030
Enzyme and equipment input suppliers for biofuel processors	71
Total private biofuel R&D	1,470
Total public bioenergy R&D in industrialized countries	627

Source: USDA, Economic Research Service. Public-sector bioenergy R&D is from the International Energy Agency. The 2009 total includes a one-time increase of $224 million in the United States due to the American Recovery and Reconstruction Act (economic stimulus funding). See Fuglie et al. (2011) for sources and estimation methods for specific industries.

about national energy security and greenhouse gas emissions from fossil fuels. While Government subsidies and regulations have helped stimulate demand for biofuel, public-sector investments in biofuel R&D now appear to be considerably less than private-sector investments. Moreover, business spending on biofuel R&D appears to be almost entirely from private capital: Government subsidies for private-sector biofuel R&D in the United States, historically the country with the largest Government biofuel R&D program, amounted to only $24.4 million in 2009.

R&D Spending by Region and for Selected Countries

Our estimates of private agricultural input R&D expenditures in specific countries or regions are based on the R&D expenditures by companies incorporated in that country or region.[4] The estimates of food industry R&D are based on national surveys of manufacturing enterprises as reported to the OECD, so they should reflect in-country R&D by domestic and foreign firms. While information on R&D spending by the food manufacturing industry is not available for most developing countries, our estimates include data for several, including China, Turkey, South Africa, Chile, and Mexico.

Among all countries in 2006, the United States was the leader in private food and agricultural R&D, accounting for about one-third of the global total (table 4). U.S. companies were particularly dominant in the crop seed/biotechnology and animal breeding sectors, accounting for about half of global private R&D in each sector. This high level of investments partly reflects the large U.S. domestic market for agricultural inputs, a strong and complementary public agricultural R&D system, and a relatively favorable regulatory environment for the commercialization of genetically modified (GM) crops (Fuglie et al., 1996). European firms accounted for about half of total R&D by agricultural input industries and just over a third of total R&D by the food industry (with Germany, Switzerland, and the Netherlands

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[4] This is only an approximate measure of actual (R&D) expenditures within a region or country, as it includes (R&D) conducted by those same companies in other regions or countries and excludes (R&D) in those areas by companies based outside the region or country. For example, to the extent that U.S.-based companies conduct some of their R&D in foreign countries, the estimates will overstate research in the United States. But they also understate research in the United States because they exclude research conducted by foreign companies in the United States. Our assessment is that these measures are roughly correct for OECD countries, although they may understate R&D taking place in developing countries. While private-sector agricultural R&D in most developing countries is relatively small, the contribution of foreign firms to that R&D may be significant. In a survey of private business enterprises in seven developing countries in Asia, Pray and Fuglie (2002) find that about 45 percent of total private agricultural R&D in those countries was conducted by foreign firms.

Table 4

Private-sector expenditures for food and agriculture research and development (R&D) by region in 2006

Sector	North America All	North America United States	Europe-Middle East	Asia-Pacific All	Asia-Pacific Japan	Latin America	Global total
				Million U.S. dollars			
Crop protection chemicals	599	599	1,596	404	368	34	2,633
Crop seed	1,287	1,261	983	96	66	6	2,374
Fertilizers	28	19	33	35	1	3	99
Farm machinery	573	513	579	309	189	9	1,470
Animal health[1]	279	236	477	36	8	3	794
Animal nutrition	66	63	232	71	19	7	375
Animal breeding	147	132	144	5	0	0	295
Crops	2,486	2,392	3,191	844	623	52	6,575
Animals	491	432	852	111	28	10	1,465
All agriculture	2,978	2,824	4,043	955	651	62	8,040
Food industry[2]	3,400	3,267	3,692	3,735	2,808	73	10,899
Food and agriculture[3]	6,312	6,028	7,503	4,619	3,440	128	18,564

[1] Animal health R&D includes R&D for food animals only. Globally, we estimate that food animal health R&D made up about 60 percent of total animal health R&D in 2006, based on the percentage of animal health product sales for food animals.

[2] Food industry R&D is mainly for Organisation for Economic Co-operation and Development countries only.

[3] Sum of food industry R&D and all agriculture R&D. Animal nutrition is a subsector of the food industry and is counted in both food industry R&D and agricultural R&D but not double counted in the total.

Source: USDA, Economic Research Service. See Fuglie et al. (2011) for industry-specific sources and estimation methods.

being the leading countries in this region). Japan led R&D in the Asia-Pacific region. Japan had the second highest amount of R&D spending in the food industry (after the United States). In the agricultural input industries, Japan was among the leading countries in investing in R&D in the agricultural chemical and farm machinery sectors.

Table 5 presents historical data on R&D spending by U.S. food processing and agricultural input industries. These time series data are reasonably complete for the food manufacturing, agricultural chemical, farm machinery, and animal health sectors. Estimates of R&D spending by the crop seed-biotechnology sector are available for 1993 onwards and for occasional earlier years but enough to establish a trend. R&D data are limited for fertilizer, animal nutrition, and animal genetics, but relatively little R&D is conducted by private companies in these sectors. The available data are sufficient to clearly show substantial growth in private food and agricultural R&D in the United States over the past three decades. Between 1979 and 2006—2 years with R&D estimates for all sectors—R&D spending by the private sector in the food and agricultural sectors increased more than fourfold (and more than doubled, from $2.86 billion to $6.03 billion, when viewed in constant 2006 U.S. dollars), although this growth is less than that for U.S. industry generally. By comparison, total R&D funded and performed by all U.S. private industries increased nearly ninefold, from $25.6 billion to $223.4 billion (nominal dollars), over the same period (NSF, 2010).

Private spending on food and agricultural R&D in the United States has exceeded public-sector agricultural research expenditures most years since the late 1970s (fig. 1). Federal and State governments invested on average

Table 5

Private food and agricultural research and development (R&D) spending in the United States

Million nominal U.S. dollars

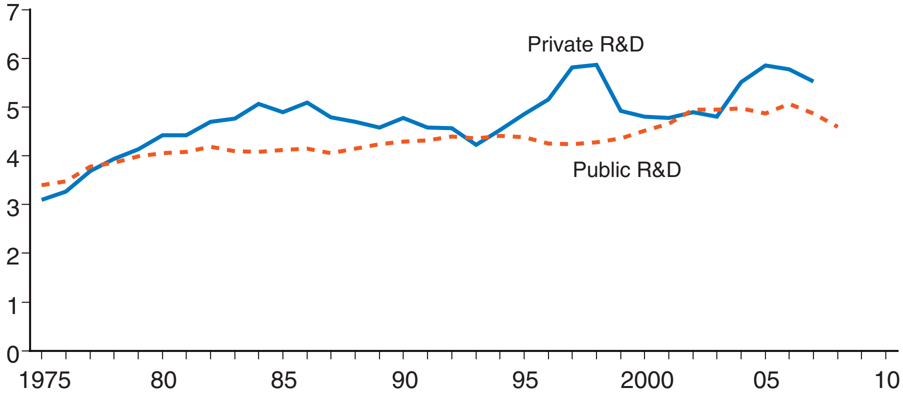
Year	Crop protection chemicals	Crop seed & biotech	Fertilizers	Farm machinery	Animal health (all animals)	Animal health (food animals only)	Animal nutrition	Animal genetics	Food industry
1960	27	4		75	6				104
1961	38			65	11				
1962	42			70	13				121
1963	45			76	15				130
1964	48			79	20				144
1965	64	6		96	23				
1966	77			100	28				164
1967	92			102	35				181
1968	99			96	36				184
1969	104			99	34				
1970	126	11		89	45				222
1971	130			90	48				238
1972	108			93	53				258
1973	114			120	62				268
1974	137			131	74				297
1975	176	24	3	138	79		28		335
1976	205			168	87				355
1977	236			221	84				415
1978			3		86		30	44	472
1979	292	43	3	295	96		33	55	528
1980					111				620
1981	487			278	125				636
1982		115			129				777
1983	587			290	147				824
1984			22		154		42		1,081
1985	432			368	159				1,136
1986					179				1,280
1987	398			483	191				1,206
1988					221				1,229
1989	561	272		281	243				1,275
1990					245				1,414
1991	614			413	276				1,277
1992					331				1,386
1993	686	409		276	315	176			1,345
1994	707	425		302	244	134			1,476
1995	751	507		361	337	182			1,566
1996	834	636		471	342	181	49	118	1,564
1997	897	791		507	353	183			1,908
1998	847	963		520	369	188			1,949
1999	756	991		371	374	187			1,563
2000	703	1,045		420	358	175			1,562
2001	531	985		395	349	168			1,971
2002	534	1,010		372	342	161			2,204
2003	558	1,012		403	417	192			2,160
2004	606	1,078		453	478	215			2,809
2005	612	1,095		504	524	230			3,255
2006	599	1,261	19	513	549	236	63	132	3,267
2007	614	1,393		628	641	269	74		2,939
2008	683	1,707		813	830	340	92		n.a.
2009	740	1,897		1,057	783	313	71		n.a.
2010	793	2,176		1,120	772	309			n.a.

Sources: USDA, Economic Research Service. For 1993-2007 continuous time series, see Fuglie et al. (2011) for industry-specific sources and estimation methods. For pre-1993 data: crop seed research: 1960-1979 (Perrin et al., 1983); 1982 (Kalton and Richardson, 1983); 1989 (Kalton et al., 1989). Animal genetics research: 1978-79 (Malmstead, as reported in Ruttan, 1982); 1996 (Narrod and Fuglie, 2001). Agricultural chemicals, farm machinery, and food industry (NSF, various issues). Animal health (Pharmaceutical Research and Manufacturers of America, annual reports). Fertilizer and/or animal nutrition: 1975 (Wilcke and Williamson, 1977); 1978-79 (Malmstead, as reported in Ruttan, 1982); 1984 (Crosby, 1987), 1996 (Fuglie et al., 2000).

Figure 1

Trends in public and private food and agricultural research spending in the United States

Billions constant 2006 U.S.$



Source: U.S. public agricultural research and development (R&D) spending is from USDA, Economic Research Service. U.S. private R&D spending is derived from the data in table 5, with interpolations for missing data. Nominal research expenditures are adjusted for inflation by the agricultural R&D price index developed by ERS. This price index takes into account changes in the cost of research inputs (scientist salaries, scientific equipment, etc.).

$4.40 billion annually (constant 2006 dollars) in agricultural research between 1980 and 2007, while the private sector spent an average of $4.95 billion per year (constant 2006 dollars) over the same period. But each sector focuses its research resources differently. The private sector accounts for about 80 percent of total food-related research and about 47 percent of total research related to production agriculture. Within these areas, public research is more oriented toward basic or fundamental science and scientific training, as well as topics like food safety, genetic resource conservation, and farming practices to conserve natural resources, research that has high social value but for which private incentives are relatively weak.

Market Size and Private Food and Agricultural R&D

One key determinant of private investment in R&D is the size of the market for products or processes developed from the R&D. Sales of new products or cost savings from manufacturing (process improvements) are necessary for firms to earn a return from their R&D. Moreover, firms must be able to price new products above their cost of manufacture, at least for some period of time, to help recoup the sunk costs of R&D, regulatory approval, and market development. *Appropriability* is the ability of firms to exercise some market power in the marketing and pricing of new products derived from their R&D investments. Securing patents and other forms of intellectual property rights enables firms to exercise appropriability over the economic benefits provided by the application of new technology.

Global Demand for Agricultural Inputs

Information on the size of global markets for agricultural inputs is not readily available. Thus, we assembled data from a variety of sources or made estimates of the wholesale value of market sales for agricultural inputs by product type. We estimate that in 2006, total company sales of these inputs were $355 billion (table 6). Fertilizers and animal feed (not including medicated feeds, which we include in the animal health sector) are the largest markets in terms of sales and consist of mostly bulk inputs that do not involve much R&D. These products accounted for about 60 percent of total agricultural input sales. Another 21 percent was for farm machinery and equipment. Crop protection chemicals and crop seed together accounted for about 15 percent of inputs purchased by farmers, while animal health and breeding materials accounted for the remaining 4 percent. Measures of the size of the various input markets vary somewhat depending on the source. Estimates of private-sector sales of crop seed and animal breeding materials vary the most. Historically, farmers have met a portion of their demand for crop seed and animal breeding stock through self-supply or by obtaining these inputs through informal markets or from neighboring farms. Over time, specialized breeding firms have increasingly helped meet this demand. By 2006, private seed companies appeared to be supplying about two-thirds of the crop seed used globally. The private-sector share of animal breeding stock is not known with much precision but appears to be very high for poultry, high and rising for swine and dairy cattle, and relatively low for beef cattle, small ruminants, and aquaculture (with the exception of some species, such as salmon).

A comparison of private-sector sales of farm machinery, crop protection chemicals, crop seed, and food animal health products worldwide since 1994 shows that only the markets for farm machinery and crop seed have grown significantly in inflation-adjusted dollars (fig. 2). Global sales of crop protection chemicals recovered somewhat from their low in 2002 but only to mid-1990s levels (to some extent, the increasing use of GM crops with pesticidal properties may be substituting for chemicals in crop protection). Most of the growth in sales of animal health products was attributed to markets for nonfood animal species, such as companion and equine animals. The figure does not show market trends for the animal feed and fertilizer markets. Although these are the largest agricultural input markets (in terms of sales),

Table 6

Global market for agricultural inputs supplied by the private sector in 2006

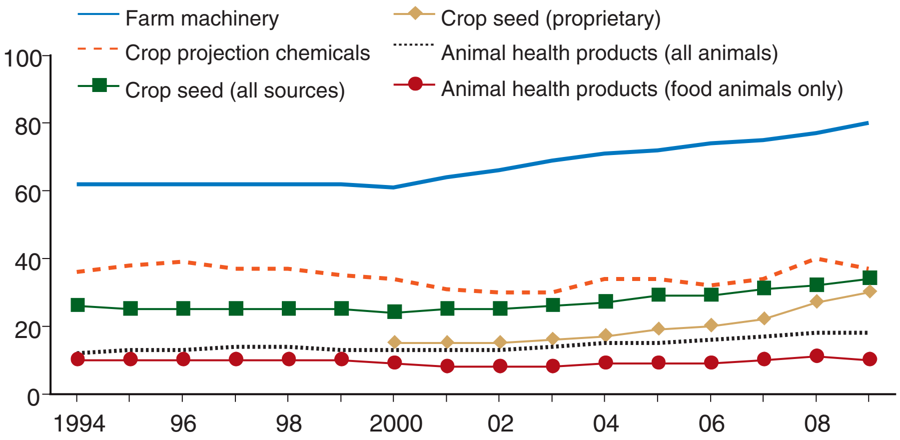
Industry	Segment	Private-sector sales
		Million US$
Crop protection chemicals	Total for agricultural uses	31,962
	Herbicides	15,246
	Insecticides	7,895
	Fungicides	7,671
	Other	1,151
Crop fertilizers	Total (168 million tons)	74,692
	N fertilizer (99 million tons)	48,076
	P_2O_5 fertilizer (39 million tons)	17,875
	K_2O fertilizer (30 million tons)	8,741
Crop seed	Total proprietary seed sales	19,600
	Conventional seed (proprietary)	11,800
	Genetically modified seed (proprietary)	7,800
	Public seed sales and farmer-saved seed (not included in total)	9,400
Farm machinery	Total	73,579
	Farm tractors	21,321
	Harvesting machinery	16,455
	Planting and fertilizing machinery	35,802
Animal health	Total for food animals	9,455
	Total (food, companion and equine animals)	16,065
	Pharmaceuticals	10,410
	Biologicals (vaccines)	3,660
	Medicated feed additives	1,995
Animal nutrition	Total	141,833
	Compound feed (656 million tons)	137,429
	Nutritional feed additives	4,404
	Medicated feed additives	(see animal health)
Animal breeding	Total	4,062
	Poultry	1,742
	Pigs	1,303
	Cattle	931
	Aquaculture	87
All private-sector sales of farm inputs		355,182

Sources: USDA, Economic Research Service. Agricultural chemicals from AGROW Reports (2007); crop seed sales from Context Network (2007); fertilizer sales derived from quantities of nutrients reported in Food and Agricultural Organization multiplied trade prices (dollars per metric ton of nutrient) from Haver Analytics; animal health products from Vetnosis as reported in International Federation for Animal Health (2007); animal feed sales derived the quantities reported in Best (2008) multiplied by International Monetary Fund corn and soy meal prices adjusted for processing costs; animal breeding are authors' estimates; farm machinery from Freedonia (2006).

Figure 2

Global market sales of selected agricultural inputs

Billions constant 2006 U.S.$



Source: USDA, Economic Research Service. See sources listed in notes to table 6.

they are mostly characterized by bulk, homogeneous products and little private R&D. Data are unavailable for trends in commercial sales of animal genetics products.

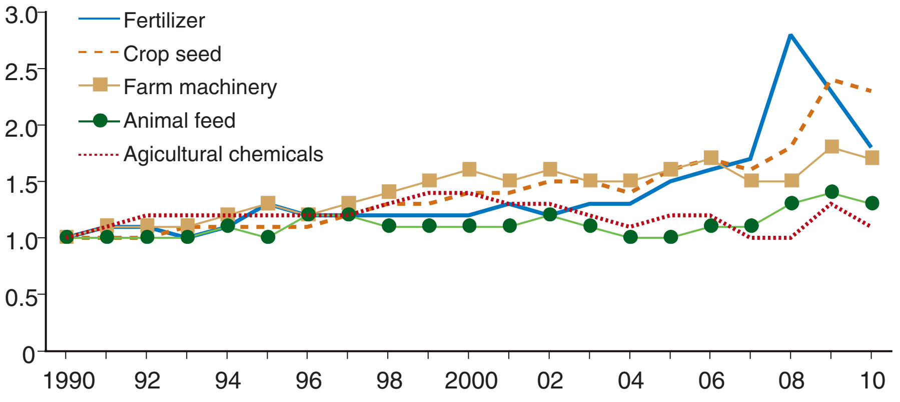
Price Trends for Some Agricultural Inputs

Markets for agricultural inputs can expand through either larger volumes of sales or through higher unit prices. Upward trends in unit prices may reflect rising quality of inputs, such as new technologies embodied in the inputs due to past investments in R&D. Higher input prices may also stem from increases in manufacturing costs due to rising labor, capital, or material costs. Based on a comparison of five categories of agricultural input prices received by farmers in the United States,[5] the largest change during 1994-2010 was in crop seed prices, which more than doubled relative to the price received for agricultural commodities sold by farmers (fig. 3). This increase

Figure 3

U.S. agricultural input prices relative to prices received by farmers

Index, 1990=1.00



Source: USDA, Economic Research Service. Indexes of prices paid and received by farmers from USDA (various issues).

[5] Global average prices of agricultural inputs are not available, although they can be derived from trade statistics. Using trade data, we constructed global price series for farm machinery, fertilizer, and animal feed and compared these with global indexes of agricultural commodity prices. We found similar trends to the price trends for the United States shown in figure 3.

was due, at least in part, to the increase in value-added characteristics developed by private seed and biotechnology companies through R&D programs. Le Buanec (2008) estimates that between 32 and 74 percent of the price of seed for corn, soybeans, cotton, and sugar beets in the United States and the European Union (EU) reflects technology fees or the cost of seed treatments. The sharp rise in the price of fertilizer in 2008-09 was driven by a significant increase in the cost of energy and materials used to manufacture fertilizer (especially natural gas, sulfur, and phosphate rock), as well as an increase in transportation costs and the falling value of the U.S. dollar (Huang, 2009). For agricultural chemicals, prices rose relative to commodity prices during 1994-99 but have since fallen. The recent decline partly reflects the rise in crop commodity prices after 2005 as well as an increasing market share for off-patent (generic) crop protection chemicals.

Market Structure and R&D in Agricultural Input Industries

The growth rates in the global market size for agricultural inputs is generally consistent with the trends in private spending on agricultural input R&D (see table 1), with the important exception of crop seed-biotechnology, where R&D grew more rapidly than sales value. We generally expect research investments to be correlated with industry sales (i.e., that *research intensity*, or the R&D-to-sales ratio, remains stable over time) unless other factors are changing incentives for private R&D. Other factors include (1) expectations that future demand growth will accelerate, (2) advances in scientific knowledge that have created new technological opportunities for commercialization, and (3) stronger IPR or changes in market structure that have made it easier for private R&D investors to appropriate economic benefits of new technology. Greater industry concentration, like stronger IPR, can increase appropriability if it strengthens the market power of large firms. Market power enables firms to charge more for new or existing products and recoup their sunk investments in R&D and market development. These factors may not be acting separately but may be working concurrently to change incentives for private R&D. For example, scientific advances in molecular biology have created new technological opportunities in agricultural biotechnology and changes in IPR have increased appropriability over biological innovations (Fuglie et al., 1996). In such an environment, firms may consolidate to acquire complementary technology and marketing assets, capture economies of scale in R&D, and strengthen their market power. Indeed, across a number of agricultural input industries, mergers, acquisitions, and consolidation among firms are affecting industry concentration and structure.

Changes in Industry Concentration and R&D Intensity Over Time

In each of the five agricultural input industries with significant R&D, the degree of concentration in the global market rose significantly over 1994-2009, although a lack of data prevented us from quantifying this change for the animal breeding sector (table 7). We measure concentration using the Herfindahl index and by four-firm and eight-firm concentration ratios.[6] By the end of the present decade, the largest four firms accounted for at least 50 percent of global market sales in each of these five agricultural input sectors. By 2006/07, market concentration was particularly high in the animal breeding sector, where the four-firm concentration ratio reached 56 percent. Growth in market concentration over time was most rapid in the global seed industry, where the market share of the four largest firms more than doubled from 21 to 54 percent between 1994 and 2009.

Table 1.7 also shows the trend in R&D intensity (i.e., R&D spending as a percentage of sales) for each agricultural input industry. With the exception of the crop seed-biotechnology sector, R&D intensity for each sector remained fairly constant over 1994-2009, although it varied significantly across sectors. R&D intensities averaged 8.6 percent for the animal health industry, 6.7 percent for the agricultural chemical industry, and 2.3 percent for the farm machinery industry. For the crop seed industry, R&D intensity increased from 11.0 percent in 1994 to 15.0 percent in 2000 and then fell back

[6] The Herfindahl index (or Herfindahl-Hirschman index, or HHI) is a commonly used measure of market concentration. Higher levels of HHI indicate that sales are concentrated among a smaller group of firms and the potential for an increase in market power by the largest firms. The Herfindahl index is calculated as $HHI = \sum_i^N S_i^2$, where S_i is the market share of firm *i* in a market with N firms. The (four- and eight-firm) concentration ratio measures the market share of the (four and eight) largest firms. Unlike the concentration ratios, the Herfindahl index reflects the distribution of the market shares among the top firms and the composition of the market outside the top firms. It also gives proportionally greater weight to the market shares of the larger firms (Scherer and Ross, 1990). Note that the concentration measures in table 7 refer to an entire global agricultural input sector. Market concentration in a particular country or for a particular product (corn seed, or a class of herbicide, for example) could be considerably higher.

Table 7

Market concentration and research and development (R&D) intensity in global agricultural input industries

Year	Herfindahl index	4-firm concentration ratio	8-firm concentration ratio	Industry R&D intensity
		Share of market (%)		*R&D/sales (%)*
Crop protection chemicals				
1994	398	28.5	50.1	7.0
2000	645	41.0	62.6	6.8
2009	937	53.0	74.8	6.4
Crop seed and traits				
1994	171	21.1	29.0	11.0
2000	349	32.5	43.1	15.0
2009	991	53.9	63.4	10.5
Animal health				
1994	510	32.4	57.4	8.6
2000	657	41.8	67.4	8.5
2009	827	50.6	72.0	8.6
Farm machinery				
1994	264	28.1	40.9	1.9
2000	353	32.8	44.7	2.3
2009	791	50.1	61.4	2.7
Animal genetics				
1994	n.a.	n.a.	n.a.	n.a.
2000	n.a.	n.a.	n.a.	n.a.
2006/07	1,025	55.9	72.8	7.3

n.a. = not available.

Source: USDA, Economic Research Service estimates based on firm-level sales and R&D expenditure data collected for this study. See Fuglie et al. (2011) for sources and methodology.

to 10.5 percent by 2009. For the animal breeding sector, we have an estimate of R&D intensity for 2006/07 only: an average of 7.3 percent across species.

Greater concentration was not associated with a permanent rise in R&D intensity in these input industries. In the crop seed industry, there was a temporary increase in research intensity in the late 1990s and early 2000s as the industry sought to commercialize a number of genentically modified crop varieties. But by the late 2000s, research intensity in the crop seed industry was back to its mid-1990s level. In fact, the underlying causes of growing concentration in these sectors appear to be quite specific to each sector and may not have affected private incentives to invest in R&D (table 8). In the crop seed and animal breeding sectors, the emergence of biotechnology was a major driver of consolidation. Firms sought to acquire relevant technological capacities and serve larger markets to spread the large fixed costs associated with meeting regulatory approval costs for new biotechnology innovations. In the poultry and livestock sectors, vertical integration enabled some large firms to acquire capacity in animal breeding as part of their integrated system. In the farm machinery industry, many of the major mergers and acquisitions can be traced to large financial losses sustained by some leading firms during periods in which the farm sector was in prolonged recession, which substantially reduced demand for farm machinery as farmers delayed major capital purchase. Firms experiencing large financial losses are

Table 8

Factors driving changes in market structure in global agricultural input industries

Sector	Factors driving consolidation and concentration	Change in real R&D spending between 1994 and 2010[1]
		Percent
Crop seed & biotechnology	Acquisition of complementary technology and marketing assets, economics of scale in crop biotechnology R&D	138
Farm machinery	Financial losses of major manufacturers during farm sector business cycles (which strongly influence demand for large capital purchases)	88
Animal breeding & genetics	Vertical integration of poultry and livestock industries; economics of scale in animal biotechnology R&D	25
Animal health (food animals only)	Forces driving consolidation in the pharmaceutical industry: loss of profit streams and idled capacity when major drugs go off-patent	2
Crop protection chemicals	Stricter environmental and safety regulations; maturing markets; rise of generic products	-2

[1] We have data on research and development (R&D) spending by the animal breeding and genetics industry for 1996 and 2006/07 only. The estimate of 25 percent growth between 1994 and 2010 is derived by applying the 1996-2006 average annual growth rate to these years. Changes in real R&D spending calculated from the data in table 1.

Source: USDA, Economic Research Service. See Fuglie et al. (2011) for discussion of specific industries.

often vulnerable to acquisition. The crop protection sector has been heavily affected by changes in regulations governing the health, safety, and environmental impacts of new and existing pesticide formulations. The consolidation in the animal health sector appears to be largely a byproduct of mergers and acquisitions in the pharmaceutical industry (as most of the leading animal health companies are subsidiaries of large pharmaceutical companies).

R&D Spending By Firm Size

Large firms usually account for most of the R&D spending in an industry. They may have, on average, higher R&D-to-sales ratios than smaller firms. If R&D-oriented large firms acquire small firms that do not make considerable investments in R&D, such consolidation could lead to greater R&D by the industry as a whole. On the other hand, mergers between R&D-oriented firms could reduce overall R&D spending as duplication and redundancies in their merged R&D programs are eliminated. Merger activity may also be led by firms that specialize in off-patent generic products. A growing market share by these firms may lead to lower R&D in the industry as a whole. But the results reported earlier suggest that with the exception of the crop seed-biotechnology industry, market consolidation has generally not been correlated with changes in overall R&D by the sector.

An examination of average R&D intensities, global R&D shares, and global market shares for different classes of firms in four agricultural input sectors reveals trends between R&D and firm size (table 9). The general pattern is for four to eight of the largest firms to have the highest R&D-to-sales ratio and account for most R&D by the sector. For crop protection chemicals, five large, research-oriented ("discovery") firms accounted for 74 percent of total R&D and 57 percent of total market sales for this sector. Another group of 17 midsized firms also invested in the discovery of new proprietary products and accounted for most of the rest of the R&D related to agricultural chemicals.

Table 9

Company size and research and development (R&D) spending in agricultural input industries in 2006

Sector	Companies	Average R&D intensity	Global R&D share	Global market share
	——— Number———		——— Percent ———	
Crop protection chemicals				
Large discovery companies (>$2 billion sales)	5	9.0	74.1	57.4
Second-tier discovery companies (<$2 billion sales)	17	7.3	19.6	18.7
Other manufacturers	23	2.3	7.7	23.9 est.
Crop seed and biotechnology				
Large seed companies (> $600 million sales) + BASF	8	15.8	75.6	48.8
Midsize seed companies ($50-600 million sales)	29	7.3	13.7	19.2
Other seed companies	n.a.	2.0	3.1	16.0 est.
Agricultural biotechnology companies	58	42.1	7.6	1.8
Animal health				
Large animal health discovery companies (>$800 million in sales)	8	10.0	66.7	79.6
Midsize animal health companies ($250 million-$800 million sales)	5	7.6	11.8	10.6
Other manufacturers	n.a.	3.8	21.5	9.8 est.
Farm machinery				
Leading multiline farm machinery companies (>$5 billion sales)	4	3.0	57.4	38.7
Second-tier farm machinery manufacturers	30	2.4	27.6	22.9
Other manufacturers	n.a.	2.4	0.6	0.5 est.

est. = authors' estimate. n.a. = not available.

Source: USDA, Economic Research Service. See Fuglie et al. (2011) for industry-specific sources and estimation methods.

The average R&D intensity for the smaller sized firms was slightly below that of the largest. Generic producers (firms not investing in new product discovery) conducted a small amount of R&D related to product manufacture and registration. In the crop seed-biotechnology sector, the largest eight seed sellers plus BASF (a firm investing significantly in agricultural biotechnology R&D but with few direct seed sales) accounted for 76 percent of private-sector seed research and had an average R&D intensity more than double that of midsized seed firms. However, small agricultural biotechnology firms had by far the largest research intensity in this sector, at about 42 percent. These operations tend to be startup organizations seeking to commercialize new research discoveries. If they are successful, they are likely to partner with large seed-biotechnology firms or be acquired by one of them. They play an important role in bringing high-potential but high-risk technologies into the marketplace. In the animal health and farm machinery sectors, the leading firms also had the highest average R&D intensities. (A number of biotechnology firms are conducting research on animal health, but few specialize in the agricultural sector and none are included in table 9.)

Globalization of Private Agricultural R&D

All of the leading firms and many of the second-tier firms in food manufacturing and agricultural input industries are multinational, offering product sales spread across several continents. In fact, global trade in agricultural inputs has grown rapidly over the past two decades (table 10). Between 1990 and 2007, international trade in animal breeding material grew by 260 percent and trade in farm machinery grew by 190 percent (in constant 2006 U.S. dollars). Trade in crop protection chemicals and crop seed also grew over the period (trade statistics for animal health products are not available).

Since the performance of agricultural technologies tends to be site specific (due to variations in weather, soil type, and other environmental conditions), many of the leading agricultural input firms have located R&D facilities around the world. This global R&D presence not only allows firms to develop and adapt new technologies to regional conditions and meet local regulatory requirements, but it also may enable them to achieve cost economies in some R&D activities (e.g., by conducting certain kinds of research in countries where highly trained personnel or specialized R&D services can be hired more cheaply).

While we do not have direct information on R&D investment in foreign countries by these firms, we have assembled information on the global R&D presence for several of the leading agricultural input firms (see table 11). Based on information from company websites, we indicate the sectors in which these firms made R&D investments in 2007 and the countries or regions of their principal agricultural R&D facilities. In addition to these principal research locations, the companies may have field-testing stations and manufacturing facilities in several other countries. For comparative purposes, the last three rows of table 11 show R&D spending by some of the largest public-sector agricultural research institutions. It is noteworthy that at least five firms made larger investments in crop improvement than the world's largest public-sector agricultural research agency, USDA's Agricultural Research Service (ARS), and several times the investment in crop genetic conservation and breeding than the network of centers that

Table 10

Global trade in agricultural inputs

Input type	Value of global exports		
	1990	2000	2007
	Billion constant 2006 U.S.$		
Farm machinery	24.1	33.3	69.6
Crop protection chemicals	10.6	13.0	18.2
Crop seed	4.1	4.3	6.0
Animal breeding material	0.3	0.5	1.2

Sources: USDA, Economic Research Service. Farm machinery and pesticide export values from Food and Agriculture Organization; Crop seed export value from the Le Buanec (2007) and International Seed Federation; trade in animal breeding material includes value of exports of day-old poultry chicks, swine and bovine live breeding animals, and bovine semen (UN ComTrade). Export values adjusted for inflation by the U.S. Gross Domestic Product implicit price deflator (*Economic Report of the President, 2009*).

Table 11

Agricultural research and development (R&D) spending by major multinational corporations and public institutions in 2007

Company	Country of incorporation	Sector of R&D activity	Agricultural R&D spending (estimate only)	Principal agricultural R&D locations
			Million U.S.$	
Bayer[1]	Germany	Ag. chemical, crop seed, animal health	978	Germany, France, Belgium, Netherlands, U.S., Japan
Syngenta[2]	Switzerland	Ag. chemical, crop seed	830	Switzerland, UK, U.S., China, Australia
Monsanto[3]	U.S.	Ag. chemical, crop seed	770	U.S., France, Brazil, Argentina, India, Australia
BASF[4]	Germany	Ag. chemical, crop seed, animal nutrition	655	Germany, U.S., India
Dupont[5]	U.S.	Ag. chemical, crop seed, food ingredients	633	U.S., France, Japan, India
Dow[6]	U.S.	Ag. chemical, crop seed	294-380	U.S., Japan, Argentina, Puerto Rico
Limagrain[7]	France	Crop seed	171	EU, U.S., Brazil, Chile, China, Japan, Israel, Morocco
KWS[8]	Germany	Crop seed	104	EU, U.S., Argentina, China, Turkey, Russia
John Deere[9]	U.S.	Farm machinery	461	U.S., India, Israel
CNH[9]	Netherlands	Farm machinery	272	U.S., EU, Brazil, Turkey, India, China
CLAAS[10]	Germany	Farm machinery	150	Germany
Pfizer[11]	U.S.	Animal health	317	U.S., UK, Japan
Merial[11]	U.S. & UK	Animal health	250	U.S., France, 9 global locations
Schering-Plough[11]	U.S.	Animal health	113	U.S., 14 global locations
Fort Dodge (Wyeth)[11]	U.S.	Animal health	115	U.S., EU
DSM[12]	Netherlands	Animal nutrition	114	Netherlands
Genus[13]	UK	Animal genetics	33	U.S., UK
Public – USDA/ARS[14]	U.S.	Crop science	456	U.S.
Public – USDA/ARS[14]	U.S.	Animal science	171	U.S.
Public – CGIAR[14]	Global	Agricultural biodiversity and genetic improvement	178	9 centers with crop breeding programs, all in developing countries

[1]Bayer reports spending 506 million euros on crop protection R&D and 131 million euros on environment science/bioscience in 2007 (bioscience is mostly seed and crop biotechnology research while environmental science includes nonagricultural applications of crop protection chemicals and related products). Since 2006, Bayer no longer reports animal health R&D separately from its Consumer Health business segment, but it did report animal health product sales of 956 million euros in 2007. We estimate Bayer spent 8 percent of animal health sales on R&D, or 76 million euros. These figures are from Bayer (2008). [2]Syngenta reports spending $496 million on crop protection R&D, $283 million on crop seed R&D, and $51 million on new business development (mostly crop biotechnology) R&D in 2007 (Syngenta, 2008). [3] Monsanto reports spending $770 million on agricultural R&D in 2007, mostly for its seeds and genomics division, with the remainder to support its crop protection products (Monsanto, 2009). [4]BASF (2007) reports that the company spent 328 million euros on crop protection R&D in 2007 and 400 million euros on plant sciences R&D over 2006-08 (the latter is included as part of its corporate"Verbund" research for future business development). We assume it spent about one-third of this 3-year total, or 135 million euros, for plant sciences R&D in 2007. In addition, BASF develops animal nutrition specialty products (vitamins, enzymes, and minerals). It does not report animal nutrition sales or R&D separately but includes this in its fine chemicals business segment, although for 2009 it reported that animal nutrition sales made up 16 percent of product sales from this segment (BASF, 2010). We assume animal nutrition products accounted for 16 percent of sales of fine chemicals in 2007 (485 million euros) and that BASF invested 3 percent of this, or 15 million euros, in animal nutrition R&D in 2007. [5]Dupont (2008) reports that its agriculture and nutrition division spent $633 million on R&D in 2007. Net sales from this business segment included crop seeds (49 percent), crop protection chemicals (34 percent), and food ingredients (17 percent). [6]Dow does not report R&D spending by business segment but is known to invest significantly in both crop protection and crop seed and biotechnology R&D. In 2007, Dow's total R&D spending was $1,305 million (Dow Chemical Co., 2009). We derive a lower bound estimate of Dow's agricultural R&D spending by multiplying total R&D by the share of agricultural science patents in Dow's total U.S. patent holdings, which were 508 out of 2,266 patents as of December 31, 2008, according to Dow Chemical Co. (2009). Our upper bound estimate is derived assuming Dow invested 10 percent of its crop protection sales and 33 percent of its seed sales in R&D. While this research intensity for seed is high, it reflects Dow's stated intention to expand its market presence in the global seed industry. [7]Limagrain spent 102 million euros in crop seed research in 2006/07 (Limagrain, 2007). [8]KWS spent 75 million euros in crop seed research in 2006/07 (KWS, 2008). [9]John Deere and CNH report total spending for research, development and engineering for agricultural, construction, and other equipment sales. We estimate their R&D spending for agricultural equipment by taking the proportion of agricultural sales in total equipment sales. For Deere, this implies 56 percent of its total R&D spending of $817 million was for agriculture in 2007 (Deere & Company, 2007) and for CNH, 66 percent of total R&D spending of $409 million was for agriculture in 2007 (CNH, 2008). [10]CLAAS reports spending 110 million euros on research, development, and engineering for agricultural equipment in 2007 (CLAAS, 2009). [11]These pharmaceutical companies do not report animal health R&D separately, although they do report animal health product sales. To estimate animal health R&D for these countries, we use estimates of R&D as percentage of animal health sales as reported in Animal Pharm Reports (2007). These are: 12 percent for Pfizer, 10 percent for Merial and Fort Dodge, and 9 percent for Schering-Plough. See chapter 6 for recent merger activity in animal health. [12]DSM develops and markets both animal and human nutrition and health products. Its total R&D spending in 2007 was 136 million euros. We assume that 57 percent of this was for animal nutrition R&D, the same proportion of animal product sales out of total nutrition sales. (DSM, 2007). [13]Genus reports 17.7 million euros in R&D spending for livestock (cattle and pigs) research in 2007 (Genus, 2007). [14]For comparative purposes, we show agricultural R&D spending for two prominent public-sector institutions: USDA's Agricultural Research Service (USDA/ARS) and the research centers that are supported by the Consultative Group for International Agricultural Research (CGIAR). USDA/ARS expenditures for crop and animal sciences are from USDA (2007); CGIAR spending on biodiversity conservation and genetic improvement (which is mostly for food crops) is from CGIAR (2007).

We convert foreign currencies into U.S. dollars using the exchange rates reported in the *Economic Report of the President* (2009).

Sources: USDA, Economic Research Service and others, as noted above.

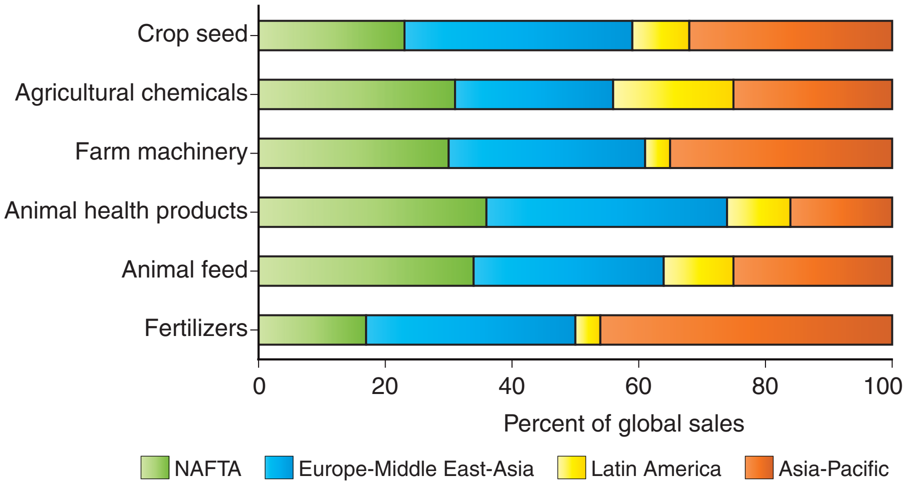
make up the Consultative Group for International Agricultural Research (CGIAR).[7] The three companies that made the largest investments in agricultural research in 2007 were the European firms Bayer and Syngenta and the U.S. firm Monsanto, each with over $700 million in R&D spending for crop and/or animal agriculture. By 2007, the agricultural R&D investment by these three firms together was $2.47 billion (and it rose further to over $3 billion by 2009[8]).

Another indicator of the degree of globalization of agricultural input markets is the global distribution of agricultural input sales (see fig. 4). In 2006, member countries of the North American Free Trade Agreement (NAFTA—United States, Canada, and Mexico) accounted for about 23 percent of the global seed market and 30-36 percent of global sales of agricultural chemicals, farm machinery, animal feed, and animal health pharmaceuticals (including those for nonfood animals). The Europe-Middle East-Africa market (which is mostly Europe) had the largest aggregate seed sales in 2006, whereas Asia-Pacific countries used the most fertilizers and bought the most farm machinery. Together, Asia-Pacific and Latin America are indicative of a rough estimate of the developing-country share of global agricultural input markets.[9] They account for 37-51 percent of global sales of crop seed and chemicals, farm machinery, fertilizers, and animal feed.

These indicators—trade in agricultural inputs, location of R&D facilities, and the wide distribution of agricultural input sales—demonstrate the multinational nature of private-sector investments in agricultural R&D and the role of these companies in developing and transferring agricultural technology around the world. One implication of the globalization of private-sector food and agricultural research is that the rate of international technology transfer may accelerate, eventually serving to reduce productivity differences across nations and regions. Moreover, the location of principal R&D centers may be less important than the location of markets and flow of trade in the agricultural inputs that embody the technology developed through this R&D.

Figure 4

Global distribution of agricultural inputs sales in 2006



Note: Global distribution of sales of animal genetics is not available.

USDA, Economic Research Service. See Fuglie et al. (2011) for sources on specific industries.

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[7] These figures are presented to characterize the scale of private R&D, but it should not be inferred that the public and private sectors engage in similar kinds of research. Rather, each sector is likely to play complementary roles. A detailed 1994 survey of public and private crop breeding in the United States, for example, found that about 80 percent of private-sector crop breeding research was on varietal development, while breeders at USDA's Agricultural Research Service focused exclusively on more "upstream" (basic) research like developing new breeding methods and introducing new genetic diversity into breeding pools (Frey, 1996). See Fuglie et al. (1996) for more information on the roles of the public and private sectors in agricultural research and development.

[8] Bayer reports $907 million in agricultural R&D by its CropScience division in 2009, while its Consumer Health division likely spent an additional $110 million on animal health R&D (Bayer, 2010). Monsanto reports total R&D spending of $1.1 billion in 2009 (Monsanto, 2010), while Syngenta reports $960 million in agricultural R&D in the same year (Syngenta, 2010).

[9] This is not a precise estimate for developing countries, however, because the Asia-Pacific region includes Japan, South Korea, Australia, and New Zealand (high-income countries) while the Europe-Middle East-Africa region includes some developing countries.

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