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**Innovation and Research by Private
Agribusiness in India**

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ABSTRACT

Agricultural research and innovation has been a major source of agricultural growth in developing countries. Unlike most research on agricultural research and innovation which concentrated on the role of government research institutes and the international agricultural research centers of the Consultative Group for International Agricultural Research, this paper focuses on private sector research and innovation. It measures private research and innovation in India where agribusiness is making major investments in research and producing innovations that are extremely important to farmers. It also reviews Indian policies that influence research and innovation. This new data and policy analysis can provide India policy makers with a basis for policies that can strengthen the direction and impact of agricultural research and innovation in the future.

Agricultural innovations in India have rapidly increased since the 1980s. Government data and surveys of seed firms show that from about 1990 to 2010 the number of new seed cultivars available to farmers in maize, wheat, and rice roughly doubled, while the number of cotton cultivars at least tripled. Biotechnology innovations went from zero in the 1990s to 5 genetically modified (GM) traits in hundreds of GM cotton cultivars by 2008. Pesticide registrations went from 104 in the period 1980–1989 to 228 during the period 2000–2010. Similar growth in innovations also occurred in the agricultural machinery, veterinary medicine, and agricultural processing industries.

These innovations have come from foreign technology transferred into India as well as from in-country public and—increasingly—private research. Based on interviews with firms and data from annual reports, we find that private investment in agricultural research grew from US\$54 million in 1994/95 to US\$250 million in 2008/09 (in 2005 dollars). Growth in private research and development (R&D) expenditure was particularly rapid in the seed and plant biotechnology industry, which grew by more than 10 times between the mid-1990s and 2009.

Private innovations have contributed to agricultural productivity and incomes. Research and innovation by private industry led to the boom in cotton exports and to rapid increases in exports of generic pesticides and agricultural machinery. Private hybrids of cotton, rice, maize, pearl millet, and sorghum increased yields over public hybrids, varieties, and landraces. Small farmers in some of the poorest regions of India—the semiarid tropics of central India and the rainfed rice regions of eastern India—get higher productivity with private hybrids.

The increases in innovation and R&D were led by expanding demand for agricultural products, which increased demand for land-, labor-, and water-saving inputs. A second major factor was the economic liberalization that allowed large Indian corporations, business houses, and foreign firms to invest in agriculture and agribusiness. Firms' decisions to conduct research in India were also encouraged by strong public-sector research, which provided firms with increased opportunities to develop new products with scientists, such as hybrid cultivars. Finally, research was stimulated by the availability of new tools of science, such as biotechnology, and by the recent strengthening of intellectual property rights.

Keywords: agricultural research and development (R&D), private sector R&D, technology transfer, innovations, innovation policy

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1. INTRODUCTION

In India and around the globe, growing demand for agricultural products is pushing up prices to record levels, but resources to meet demand are either declining or growing at slower rates. Equally worrisome, productivity growth of major food crops is leveling off (Singh and Pal 2010). These trends generate demand for innovations to increase productivity. Indian public-sector research, international agricultural research centers, and foreign public and private research provide a flow of new technology. Increasingly, private agribusinesses in India have been playing an important role—accessing and introducing available technology, and advancing what is available with further research. How much agricultural innovation comes through the private sector? How much do private companies invest in agricultural research and development (R&D) in India? What has been the impact of private innovation on production, poverty, the environment, and health? To address these questions, policymakers, economists, and the public need better data on private-sector research and innovation.

Two previous studies compiled data on agribusiness R&D in India (Pray 1986; Pray and Basant 2001). The second of these reports (Pray and Basant 2001) provided data up to the mid-1990s. Since then, Indian industrial and agricultural policies have changed dramatically, and the private sector has led the way for rapid economic growth in the Indian economy as a whole over the past decade. As a result, the role of Indian agribusiness in innovation and research should be reassessed.

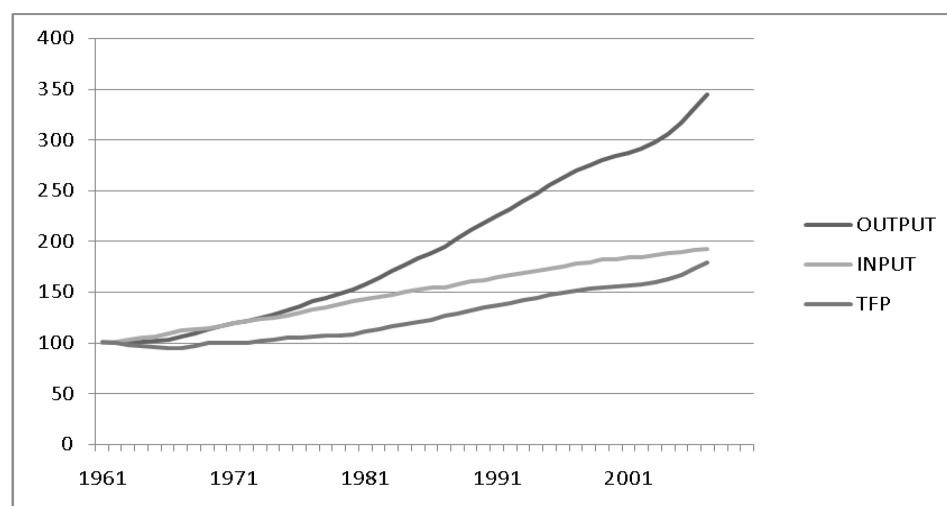
Our report has three objectives: (1) to quantify agribusiness innovation and research in India; (2) to provide information on the economic, environmental, and poverty-reduction impacts of agribusiness innovation; and (3) to identify major policies that encourage agribusiness research and innovation.

In Section 1, we review growth of the agricultural sector in India over the last 20 years. The next two sections analyze levels and trends in agribusiness innovation (Section 2) and research (Section 3). Both the rate of technology introduction and companies' R&D budgets have increased rapidly since the mid-1990s. Section 4 discusses impacts of private innovations on the agricultural economy. Section 5 examines the main factors influencing the expansion of private innovation and R&D in India. Section 6 concludes with a summary and recommendations for policies to promote and guide private agricultural innovation and the R&D sector.

Changes in Indian Agriculture

Innovations in agricultural technology and institutions and in farmers' education and experience have greatly contributed to increases in agricultural productivity in India, with agricultural production rising at an annual rate of around 2.68 percent a year from 1961 to 2007 (Figure 1.1). During the 1980s, growth rose to 3.49 percent but then sank to the long-run average of 2.69 percent for the latest period, 2000–2007. For the entire period of nearly 50 years, increased inputs (land, fertilizer, labor, machinery) accounted for 53 percent of increased output, with total factor productivity (TFP) contributing the rest. Input growth accounted for all growth in the 1960s and for 70 percent of growth in the early Green Revolution period (the 1970s). In recent years, the contribution of TFP has also increased. In the period 2000–2007, TFP growth accounted for 74 percent of output growth in agriculture while increased use of inputs accounted for only 26 percent (unpublished data reported in Fuglie 2010).

Figure 1.1—Agricultural index for India, 1961–2007 (1961 = 100)



Source: Fuglie 2010.

In the last two decades—that is, since 1991—milk production has almost doubled, and egg production has increased by 150 percent (see Table 1.1). Within the crop sector, fruit and vegetable production has increased more rapidly than that of food grains (Singh and Pal 2010). Increases in per capita income shifted consumption from basic food grains to higher-quality and higher-value foods, such as animal protein, fruits, and vegetables. Increasing income has also led to increased demand for environmental services such as clean air and water and reduced greenhouse gas emissions, leading in turn to demands for organic food and biofuels.

Table 1.1—Production shares and amounts by category and selected crop yields

Indicator	TE 1981	TE 1991	TE 2008
Share in the total value of production (%)			
Crop	75.5	70.6	67.1
Livestock	17.5	22.0	24.5
Forestry	5.2	4.7	3.6
Fishery	1.7	2.7	4.8
Agricultural production			
Food grains production (mt)	124.20	172.45	230.67
Milk production (mt)	31.60	51.23	100.87
Fish production (mt)	2.44	3.55	6.87
Egg production (billion, number)	10.06	20.10	50.66
Crop yields (tons/ha)			
Rice	1.25	1.72	2.20
Wheat	1.71	2.33	2.79
Coarse cereals	0.69	0.88	1.42
Pulses	0.46	0.58	0.64
Cotton	0.16	0.23	0.47
Groundnut	0.84	0.88	1.46

Sources: Extracted from Singh and Pal 2010; Ministry of Agriculture for the year 2008. (2011)Notes: TE indicates triennium ending; mt indicates million tons.

Farmers have also increased their use of modern inputs (see Table 1.2). From 1991 to 2006, fertilizer use almost doubled, use of tractors and quality seed tripled, and irrigation from tube wells has expanded substantially (the share of tube wells in irrigated area increased by 5 percent, while total irrigated area increased by 26 percent, from 66 to 83 million hectares [ha]).

Table 1.2—Input use in Indian agriculture, 1971–2006

Input	1971	1981	1991	2001	2006
Fertilizer use (kg/ha)	16.5	34.24	69.84	91.13	113.26
Number of tractors ('000)	148.2	275.9	738.4	1,221.8	2,361.2
Share of tube wells in irrigated area (%)	16.63	26.2	38.42	40.84	43.86
Quality seed distribution ('000 tons)	NA	450	575	918	1,550
Institutional credit (rupees/ha)	53.58	232.42	631.39	3,261.40	10,544.45

Source: Singh and Pal 2010.

2. INNOVATIONS IN INDIAN AGRICULTURE

Agribusiness companies want to use innovation to capture or protect market shares by offering new products that buyers want (product innovations) and also by cutting costs (process innovations). In agriculture as in other economic sectors, advanced countries take advantage of technology developed in other countries, using a variety of procedures—such as licensing, buying, or simply copying—to access what others develop. When suitable technology is not readily available and identifiable, or when companies see an opportunity to improve what is available, they will invest in research to identify or develop product and process innovations.

Both for national agricultural growth and for agribusiness success, innovations and their spread are the goals. R&D is one of the costs of innovation. This section considers the rate of innovation in Indian agriculture as well as the sources of innovation. Section 3 considers private agribusiness expenditures and staff for in-country R&D.

Quantitative information on innovation is limited. To measure innovation, we used three primary sources: (1) registration of new technology, which Indian technology regulators require for many industries; (2) data on intellectual property rights, that is, patents and plant variety protection certificates; (3) supplementary data that we collected through interviews with leaders of about 100 private agribusinesses and from press articles.

Key Innovations

The most dynamic sectors for private innovation over the last decade have been the seed industry for field crops, fruits, and vegetables; the pesticide industry; and the farm machinery industry. The seed industry has produced a steady stream of new hybrids of field crops and vegetables, including revolutionary varieties like the insect-resistant cotton hybrids developed through biotechnology that now dominate the cotton seed industry.

A steady stream of new pesticides have been introduced that in general are more effective and less dangerous to people and the environment. Almost all new active ingredients were developed outside India, but at the beginning of 2011, Dow Agro Sciences and GVK Biosciences announced the development of new molecules to be used for fungicides and insecticides (Dow 2011). Innovations by local pesticide companies have largely been new, low-cost ways of producing generic pesticides and new formulations of pesticides. In addition, a number of firms have developed biopesticides.

The agricultural machinery industry has developed inexpensive, small- and medium-sized tractors for both the Indian market and small farmers in wealthy countries. This industry has also developed more efficient and less expensive micro irrigation systems.

Perhaps the least innovative sector has been the fertilizer industry, but even in that sector new products are being introduced, such as combination fertilizers and some biofertilizers. The feed industry is another industry with limited innovation, introducing a few new feed additives but primarily working on low-cost combinations of current ingredients.

Animal genetics research has had its most high-profile success in poultry. Research by the Venkateshwara Group adapted US and European breeds and developed new local layer varieties during the 1990s. Since then, it has provided a steady stream of new hybrid poultry varieties. It is the only place outside Europe and the United States where new poultry hybrids are being developed.

The agricultural processing and plantation sectors have introduced innovations for farmers and for consumers. The plantation crop sector has introduced new clones of tea and coffee, and new management practices. The sugar industry has new management practices and some new sugarcane varieties, and has started to produce electricity and biofuels. The biofuel industry has developed innovations such as new crops (tropical sugar beets, for example) and improved biofuels machinery, but with very limited adoption in India.

India also has become a global R&D center for food and beverages for many multinational corporations (MNCs), considering the size of the market in south Asia. Innovations from Indian R&D labs are mainly in the form of value-added products and supply chain management techniques.

Quantitative Data on Trends in Innovation

Time series data on innovation—pesticides, seeds, and biotech—show rapid increases in recent years. One measure of innovation in the seed industry is the number of cultivars the Department of Agriculture *notified* or recognized as new cultivars during various periods. This is an incomplete measure of innovation because notification is not required except for cultivars from public breeding. Government allows private companies to introduce cultivars without notification, which companies have preferred, and so only few private cultivars have been notified. Even with this partial measure, the rate of innovation holds steady from the 1980s to the 1990s but then grows rapidly after 1999 (Table 2.1).

Table 2.1—Trends in notified varieties of major field crops

Crop	Number of notified varieties and hybrids by decade		
	1980–1989	1990–1999	2000–2010
Rice	198	188	303
Wheat	84	66	112
Maize	43	64	113
Pearl millet	38	45	51
Sorghum	55	49	55
Cotton	72	78	95
Total	490	490	729

Source: MoA, 2011.

Notes: * Truthfully labeled varieties collected from individual firms' websites and survey (34 firms).

^a Includes only actual hybrids released by the private sector (not open-pollinated varieties).

^b Includes open-pollinated varieties (mostly), 48 of which are hybrids.

Another important area of innovation that can be quantified is the number of biotech genes (also known as *events*) and transgenic cotton hybrids. Transgenic cotton hybrids and new genes must be registered with the biosafety authority, and the rapid growth in numbers of hybrids and genes registered is shown in Table 2.2. The first transgenic hybrids of cotton containing the Bt1 gene were approved in 2002. The number of transgenic hybrids containing the Bt gene increased exponentially after 2005. The private sector has developed nearly all of these hybrids. In 2002 the first Bt gene was approved for commercialization and marketed through the joint venture Mahyco-Monsanto Biotech (MMB). In 2006, new Bt genes began appearing. In May 2006, Monsanto and Mahyco produced hybrids with stacked Bt genes, Bollgard-II (BG II). In the same year, two domestic seed companies, JK Agri Genetics and Nath Seeds, had new Bt genes approved for commercialization. The JK Bt was based on an Indian public-sector Bt gene, and the Nath Bt was licensed from a Chinese firm. In 2008 and 2009, two new Bt events were approved. The first was developed by Metahelix and the second by the University of Agricultural Sciences Dharwad (UAS Dharwad).

¹ Bt stands for *Bacillus thuringiensis*, a bacterium that is the source of the gene that makes this cotton poisonous to certain insects but not to other insects or mammals.

Table 2.2—Bt cotton hybrids and events approved annually and number of firms selling Bt cotton in India, 2002–2010

Particulars	2002	2003	2004	2005	2006	2007	2008	2009 ^a	2010 ^b
# of Bt hybrids approved	3	3	4	20	62	131	274	248	104
Events approved ^c	1	0	0	0	3	0	1	1	0
# of companies with Bt cultivars	1	1	1	3	15	24	31	33	37

Source: Compiled from IGMORIS 2010; Choudhary, B. and K.Gaur. 2010 Adityendra 2007; GEAC 2009.

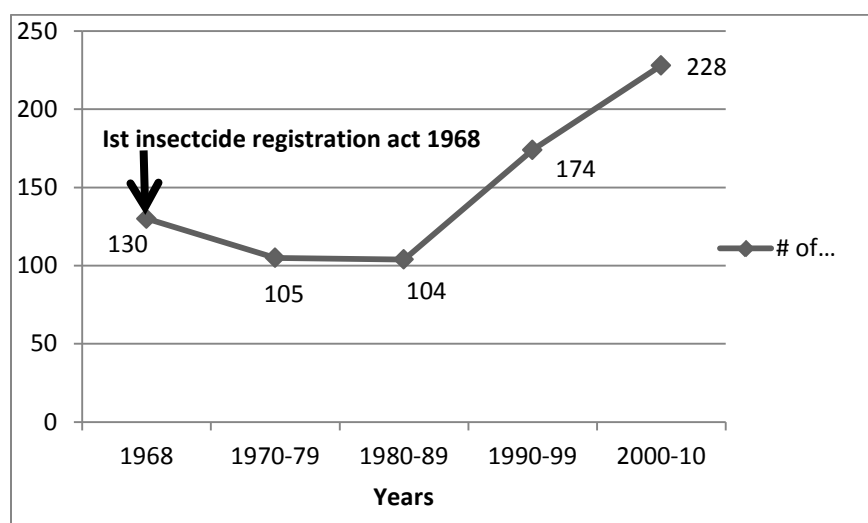
Notes: ^a Cultivars approved by the Genetic Engineering Approval Committee exclusively for 2009.

^b Approved cultivars through May 2010.

^c Approved events are Monsanto BG 1 and BG 2, JK (IIT Kharagpur collaboration), Nath event (Chinese Bt event), Metahelix, UAS Dharwad (Central Institute for Cotton Research collaboration). Events in the pipeline include Round-up Ready Flex (RRF) trait by Monsanto, Dow Agro Sciences, JK event, and Bayer Crop Science.

Pesticides registrations have increased rapidly since the 1980s. Twice as many pesticides were registered in the first decade of the 21st century as were registered in the 1980s (Figure 2.1). These registrations, all by private companies, are primarily new formulations of active ingredients, but some new active ingredients and formulations for new crops, especially horticulture crops, have been developed.

Figure 2.1—New pesticide registrations by decade, 1968–2010



Source: Compiled from Central Insecticide Board and Registration Committee, 2010.

Sources of Innovation

The innovations discussed above have come from government research programs, Indian firms' research, and foreign research. Public-sector research programs continue to make important contributions to the development of new varieties of self-pollinated crops like rice, wheat, many pulses, and oilseeds; improved dairy breeds and veterinary vaccines; and innovations in crop, pest, and resource management.

Other innovations in the seed industry were primarily developed by the private sector. Varieties of other crops such as cotton, maize, pearl millet, and sorghum, which are all hybrids in India, primarily come from the private sector (Table 2.3). Since liberalization of the vegetable seed trade in 1988, vegetable varieties primarily come from the private sector, which either imports or develops its own varieties (Table 2.4).

Table 2.3—Numbers of field crop varieties by public- and private-sector institutions in India, 2005–2010

Crops	Truthfully labeled private hybrids	Notified public varieties
	2005–2010	2005–2010
Rice	79 ^a	240 ^b
Wheat	40	95
Maize	136	87
Pearl millet	97	48
Sorghum	75	46
Cotton	255	70
Total	603	346

Sources: MoA, 2010; truthfully labeled varieties collected from individual firms' websites and survey (34 firms).

Notes: ^a Includes only actual hybrids released by the private sector (not open-pollinated varieties).

^b Includes open-pollinated varieties (mostly), 48 of which are hybrids.

Table 2.4—New vegetable hybrids in India, 1998–2005

Crop	Public sector	Private sector
Tomato	3	160
Eggplant	8	218
Chili	2	73
Capsicum	1	31
Cauliflower	1	35
Cabbage	-	20
Okra	2	32
Watermelon	2	25
Cucumber	2	10
Gourd	6	80

Source: Kataria 2005.

Other innovations (in both product and design) were primarily developed abroad and then imported. These include the active ingredients of pesticides, varieties of European vegetables, designs of tractors and harvesters, biotech genes, poultry genetics, and veterinary medicines.

Patent data enable us to compare innovation among different industries and between Indian and foreign firms. Table 2.5 provides data by major industry on number of patents granted and applications for patents not yet granted. Data are not available from before 2000 in most agriculture-related industries because product patents were not allowed in chemicals (including pesticides, fertilizers, and veterinary medicines), agriculture, and biotechnology until 2005, although they could be filed before that. New plant varieties cannot be protected by product patents, but since 2009 they can be protected using the Plant

Variety Protection (PVP) and Farmers' Rights Act. The largest numbers of patents granted and of published applications² are in the pesticide industry, followed by plant biotechnology. Agricultural machinery has the third-largest amount of patenting. MNCs dominate patenting in most industries. However, patenting by Indian industries is also growing (compare granted with published patents), especially in pesticides, fertilizers, and agricultural machinery. Patents by MNCs primarily reflect research conducted outside of India and brought in through local subsidiaries and partners.

Table 2.5—Private-sector patenting in India, 2000–2010

Sector	Firm type	Granted (2000–2010)	Published (2004–2010)
Plant biotechnology	Indian	1	8
	MNC	78	245
Pesticides	Indian	58	89
	MNC	373 ^a	1,199 ^a
Fertilizers	Indian	5	46
	MNC	16	25
Agricultural machinery	Indian	31	39
	MNC	52	109
Total	Indian	95	182
	MNC	519	1,573

Source: Compiled from Intellectual Property India, 2011

Note: ^a These numbers may include some chemicals that are not used for agricultural pest control.

Table 2.6 shows that Indian companies hold most PVP certificates for new varieties, 52 of the 80 that have been issued in the two years since the PVP office was established. MNCs have 17, and government institutions have 11. Table 2.6 does not include 403 PVP certificates on previously existing varieties, of which the public sector holds more than 75 percent. In the Indian system, farmer groups may also get PVP certificates, but so far farmer groups hold only 3 existing varieties and no new varieties.

Table 2.6—Plant variety protection certificates issued for new varieties in India, July 2009–May 2011

Crop	Total	Indian firms	MNCs	Public
Cotton	24	23	1	0
Green gram	2	2	0	0
Maize	12	5	0	7
Pearl millet	7	4	3	0
Sorghum	11	3	5	3
Rice	23	15	8	0
Wheat	1	0	0	1
Total	80	52	17	11

Source: Calculated by authors from data obtained from Plant Variety Protection Authority of India 2009, 2010, 2011.

In the past, Indian firms licensed or copied agricultural innovations based on foreign technology, or foreign MNCs transferred technologies to their subsidiaries in the agricultural chemicals, tractors, and vegetable seeds industries. However, Indian firms have new methods of gaining access to international technology. Some companies are purchasing world rights to a technology. For example, the Indian pesticide company United Phosphorus Ltd (UPL) purchased DuPont's global Mancozeb fungicide business. Another new way of accessing technology is the purchasing of foreign companies to gain access

² Indian patent applications are published 18 months after application is made.

to technology and markets. For example, in February 2006 UPL bought Advanta, a Netherlands-based multinational seed company, and moved its headquarters from Europe to India. Advanta has also recently bought several sorghum seed companies in the United States. Mahindra & Mahindra has expanded in a similar fashion, buying American and Chinese tractor companies. Shree Renuka, now India's largest sugar producer, has purchased several major Brazilian sugar and ethanol companies, gaining access to their sugarcane and processing technologies.

Indian firms and subsidiaries of MNCs based in India are now becoming important innovators in other countries by exporting technology developed in India. Hybrid rice cultivars are being exported to Bangladesh and Southeast Asia. Indian small tractors are being exported to the United States, Africa, and elsewhere. Generic pesticides are exported around the world. Indian biopesticides based on neem are being exported to Europe, the United States, and Asia.

3. GROWTH IN PRIVATE R&D IN INDIA

Many of the innovations discussed above—new plant varieties, pesticides, machinery, and food products—were developed in R&D programs of private firms in India. This section reports the amount of money firms invest in R&D in India and describes the research activities of each agribusiness sector.

To quantify agribusiness R&D we collected data from individual firms and government sources when available. We relied more heavily on audited annual reports of companies listed on the Indian stock exchanges than did previous studies for two reasons: (1) More agribusiness firms are listed on Indian stock markets and are required to report their R&D, and (2) the Department of Science and Industrial Research (DSIR) now publishes only consolidated R&D data, not full reports on individual firms. DSIR data are limited—only updated, at best, every three years and often not for eight years or more. Also, DSIR collects data only from firms it recognizes as R&D centers, a practice that omits new firms and many multinationals. R&D data from annual reports and DSIR were supplemented by surveys and interviews with 30 research-based companies that were not listed on stock markets, particularly in the seed industry. The appendix provides a detailed description of data sources, including alternative data and data compilation techniques.

Trends in Aggregate R&D

Private agricultural R&D expenditure in India has increased from US\$54 million³ in 1994/95 to \$251 million in 2008/09 (Table 3.1). In the 1990s, private research made up about 17 percent of the total agricultural R&D in India. This has risen to a current 27–31 percent. Table 3.1 compares private- and public-sector research expenditure, indicating that although private research has increased more rapidly, public research expenditure still outstrips private.

Table 3.1—Public and private agricultural R&D investments in India, in millions of 2005 US dollars

Sector shares	1994/95	2008/09^c
Private R&D investment ^a	54	251.3
Public R&D investment ^b	271.8	563.2–688.3
Private + public R&D investment	325.8	814.5–939.6
Private share (%)	16.6	30.9–26.7
Public share (%)	83.4	69.1–73.3

Sources: ^a Private R&D from Pray and Basant 2001; Pray and Nagarajan 2011.

^b Public investment estimate based on Beintema et al. 2008.

Notes: ^c The public-sector investment figures for 2008/09 are projected from ASTI's (2011) last survey estimates of Indian public research in millions of 2005 US dollars. ASTI calculated 6.4 percent growth in public-sector investment between 1981 and 2003, and 2.9 percent growth between 2000 and 2003. To calculate the first numbers in column 3, we used the 2000–2003 period growth rates of 2.9 percent for public agricultural investment and projected for 2008/09 to compute the share of public-sector R&D investment in total R&D investment. To calculate the second numbers in column 3 we used the 1981–2003 period growth rate of 6.4 percent for public agricultural investment and projected for 2008/09 to compute the share of the public sector in total investment.

³ All dollar amounts are in US dollars.

Government data (Table 3.2)⁴ show rapid growth of private R&D personnel in the last two decades, with the number of PhDs increasing by 258 percent and total private scientists by 197 percent. By 2004/05, approximately 2,400 agricultural scientists were working as private-sector R&D personnel, of who about 1,300 held postgraduate and PhD degrees. There were 14,000 agricultural research personnel in the public and private sectors, 11,500 of whom held PhDs and postgraduate degrees. Thus, 11 percent of scientists with PhDs and postgraduate degrees worked in the industrial sector, and 18 percent of all research personnel worked in that sector. In contrast, Table 3.1 shows that between 27 percent and 31 percent of the money spent for research is in the private sector, suggesting private firms spend more per scientist than does the public sector.

Table 3.2—R&D personnel by qualifications in agricultural sciences, 1992/93 and 2004/05

Field	PhD		Postgraduate		Graduate		Diploma & Others		Total	
	1992/93	2004/05	1992/93	2004/05	1992/93	2004/05	1992/93	2004/05	1992/93	2004/05
Public Industrial sector (A)	12	6	10	8	3	9	1	3	26	26
Private-sector firms (B)	159	411	265	888	194	632	92	539	710	2,470
Industrial Sector (A + B)	171	417	275	896	197	641	93	542	736	2,496
Public Sector (C)	5,376	7,777	4,760	2,924	566	425	437	402	11,139	11,528
Total (Institutional+ Industrial)	5,547	8,194	9,532	3,820	763	1,066	530	944	11,875	14,024

Source: Research and Development Statistics, 1992-93 & 2004-05, Department of Science and Technology, New Delhi, India.

Notes: A includes personnel employed in corporations such as the state seed corporations that are owned by the Indian government or state governments.

B denotes personnel in private corporations.

C includes Indian Council of Agricultural Research (ICAR), State agricultural universities and other government research institutes that do agricultural research. It excludes government owned companies such as the state seed corporations which are in Public Industrial Sector (A).

Data collected and compiled by DST, educational qualifications of personnel engaged in R&D as on 1.4.1992 based on the responses received by the DST. Data for private sector refers to 128 in-house R&D units including 148 Scientific and Industrial Research Organization (SIRO) units for 1992.

For 2004-05, data for industrial sector refers to 1510 in-house R&D units including 1108 private sector industries, 112 public sector industries and 290 Scientific and Industrial Research Organization (SIRO) units.

Table 3.3 presents total private agricultural R&D investment and also disaggregates R&D into agribusiness sectors. The seed and plant biotech sector led R&D growth in India, increasing R&D expenditure from about \$5 million in the mid-1990s to almost \$90 million in 2008/09.

4 The only source of agribusiness R&D personnel data is the Department of Science and Technology, which periodically (every three to five years) reviews all government-registered R&D facilities. Although not all firms are government registered, most large Indian firms and multinationals are. The firms report the number of scientists in preparation for the reviews.

Table 3.3—Sectoral private agricultural investment in R&D, in millions of 2005 US dollars

Industry	1984/85 ^a	1994/95 ^a	2008/09 ^b		
			Total	Indian firms	MNCs
	<i>Millions of 2005 US\$</i>				
Seed and biotechnology	1.3	4.9	88.6	49.3	39.3
Pesticides	9	17	35.7	24.4	11.3
Fertilizers ^a	6.8	6.7	7.9	4.9	0.0
Agricultural machinery	3.7	6.5	40.5	20.5	20.0
Biofertilizers and biopesticides	0	0	1.3	1.3	0.0
Poultry and feeds	-	3.5	7.8	7.8	0.0
Animal health	0.9	2.7	18.6	3.7	14.9
Sugar	0.9	2.5	10.8	10.8	0.0
Biofuels	0	0	13.1	13.1	0.0
Food, beverages, and plantations	1.3	10.3	27	16.2	10.7
Total	23.9	54.1	251.3	155.0	96.2

Sources: ^a Pray and Basant 2001; ^b Pray and Nagarajan 2011.

This survey identified several new industries conducting R&D. For example, the biofuels industry did not exist in India in the 1990s and, although now it is only in its infancy, a few firms, led by Praj Industries, are making substantial investments in biofuel R&D. The biopesticide and biofertilizer industries are also new, and both Indian and international firms outside of traditional pesticide and fertilizer industries are investing in R&D in these areas. Another new industry in India is a specialized biotech company called a contract research organization (CRO), which until recently primarily served the pharmaceutical industry. Currently, a number of Indian CROs are using their expertise in biotechnology and chemistry to conduct contracted research for both Indian and MNC agribusinesses. For example, GVK Biosciences has worked with Dow Chemicals to identify new chemical molecules with activity against insects and plants, which may become a new pesticide (Dow 2011). More research is needed to characterize the CRO industry.

Both Indian and multinational companies have contributed to R&D growth, as also shown in Table 3.3. Indian firms have the largest shares of R&D in all sectors except animal health. In the agricultural machinery industry R&D by Indian firms and MNCs was about the same.⁵ R&D by individual Indian companies in almost every agribusiness sector has grown dramatically, with the largest Indian investors in R&D—UPL/Advanta, Mahindra & Mahindra, Escorts Group, and Praj—conducting research for both the Indian and international markets. MNCs have expanded R&D in India to develop innovations tailored to the Indian market and to some international markets. In addition, during the last decade a number of MNCs have made India part of their global research system—these include Monsanto, DuPont, Shell (biofuel), Syngenta, Isagro, John Deere, Pfizer Animal Health, and Nestlé.

Seed and Biotech Industry

The seed and biotech industry leads private R&D expenditures and growth in India, with current annual investment of more than \$88 million.⁶ Table 3.4 shows that the increase in R&D expenditure was accompanied by an increase in the number of scientists and land in experiment stations.

⁵ MNCs may actually spend more because there are some large, foreign-owned labs, such as John Deere's research center in Pune, for which we do not have data.

⁶ We have combined seed and plant biotech industries because biotechnology is an important component of most major

Table 3.4—Size and structure of the Indian private seed industry with R&D, 1987–2009

	1987	1995	2005	2008/09
R&D expenses (millions of 2005 US\$)	1.3	4.9	26.9	88.6
Research staff (includes tech staff in seed & biotech labs)	76	297	NA	1,500
Area of experiment stations (ha)	408	1,503	NA	10,948
4-firm concentration ratio (% private sales by top 4 firms)	68	51	49	36
Share of firms with foreign ownership (% of private sales)	10	33	45	40
Number of firms sampled	24	51	28	34
Number of firms conducting R&D	17	38	28	34

Source: 1987 and 1995 data from Pray and Ramaswami 2001; 2005 and 2008/09 data from surveys and personal interviews by authors, and websites of individual seed firms.

Indian companies have increased R&D since early 2000, with 29 local firms accounting for 56 percent of total R&D expenditures. Although average R&D investments by local firms are less than those by MNCs, firms such as Krishidhan, Mahyco, JK Agri Genetics, Rasi, Vibha, Kaveri, Advanta, and Ankur now spend more than \$2 million on research annually in India. Some firms, such as Vibha, only established after 2000, are now spending about \$3 million annually on R&D. The Indian share of R&D would be larger if Advanta's spending on research outside India were also included, spending that exceeded by five times its level in India in 2009 (Advanta India Limited 2010).

Five US- and Europe-based MNCs account for about 44 percent of private plant breeding and biotech research conducted in this industry. DuPont and Monsanto account for a substantial part of the increase in R&D expenditure, both having made major investments in research in large facilities as part of their global R&D programs.

The structure of the seed industry has changed substantially in the last two decades. The private sector has grown rapidly. New firms have entered the industry and both Indian firms and MNCs expanded rapidly in the last decade, increasing their sales as well by mergers and acquisitions. Vibha seeds was founded in 1995 and is now one of the top 10 seed firms in sales and R&D. Perhaps the most important new Indian firm is Advanta, a Netherlands-based company that became an Indian firm when it was purchased by the Indian generic pesticide company United Phosphorus in 2007. Promising new MNCs include Devgen, a biotech firm based in Belgium that bought Monsanto's Indian rice, millet, and sorghum operations. There have been mergers and acquisitions by both Indian companies and MNCs.

The result of these changes is that the industry has become more competitive since 1987. The four-firm concentration ratio in the private segment of the industry⁷ has declined from almost 70 percent in 1987 to 36 percent today (Table 3.4). The share of foreign ownership in the private seed industry has increased from 10 percent in 1987 to about 40 percent today.

Domestic seed firms traditionally depend on their own earnings and family funds for expansion and development. However, Indian firms have sought outside investments in order to establish or upgrade biotechnology laboratories or engineering facilities. A few firms (Advanta, Kaveri, JK Agri Genetics, and Nath) have raised money through initial public offerings on Indian stock markets, and a few have obtained funding for expansion through private equity and venture capital financing. For example, Summit Partners (US) has invested \$30 million in Krishidhan seeds (Summit Partners 2010) and Blackstone Investments (US) invested in Nuziveedu seeds (Chanchani 2009).

plant breeding companies' research in India and there are virtually no stand-alone plant biotech companies that are not part of a seed company.

⁷ This calculation includes only seeds sold by private firms. It excludes seeds sold by the state seed corporations as well as farmer-saved and traded seeds.

Also, seed firms have some of the highest research intensity⁸ of any agribusiness in India, with research expenditures as high as 13 percent of sales. Research intensity for the Indian seed industry as a whole increased from about 3.0–3.8 percent in the 1990s (Pray and Basant 2001) and the first part of the following decade to 7 percent in 2009. Recent growth in research intensity is mostly due to large research investments by DuPont and Monsanto, which increased MNC research intensity from 2.5 percent in 2000 to 10.1 percent in 2009. Domestic firms kept up with growth in sales, remaining at about 5.5 percent from 2000 to 2009.

Seed industry research focuses almost entirely on hybrids such as cotton, maize, rice, and vegetables. Cotton accounts for about 40 percent of plant breeding research, followed by maize (25 percent), hybrid rice (15 percent), and vegetables (20 percent) (Pray and Nagarajan 2011). These breeding programs focus primarily on improvements in product yields and quality, and on pest and drought tolerance. Conventional plant breeding is the major tool used to develop improved hybrids, but all major plant breeding companies now complements this technique with biotechnology laboratories to make use of genomics and molecular markers in their breeding programs. During the 1990s, only 3 companies had biotech research programs (Pray and Basant 2001). This number had increased to 35 by 2008 with biotech research programs approved by the Department of Biotechnology to work on transgenic plants (IGMORIS 2010).

As mentioned above, the private sector is the main innovator in the vegetable industry, importing improved hybrids and varieties when possible and then conducting research to adapt and develop new hybrids and varieties when it can. Private firms such as Indo-American Hybrid Seeds, Mahyco, Nath Seeds, Bejo Sheetal, Biogene, Namdhari, and Unicorn have established R&D facilities on their own or in collaboration with MNCs. Companies that collaborate with MNCs usually obtain production and marketing rights of selected adaptable hybrids and also maintain their own parental lines, and multiply seeds using their own facilities. In addition, MNCs such as Seminis, Syngenta, and Nunhems also have entered directly into the Indian market with their own R&D agenda for vegetable crops. MNCs and their subsidiaries obtain breeding material from parent companies, isolate adaptable lines, make crosses, and thus develop superior hybrids suitable for the Indian market (Arora 2008).

More than 35 companies have research programs to develop transgenic plants, most using genes licensed from other companies. A few private seed research programs conduct basic biotech research to identify important molecular markers and genes that could be used in transgenic plants. Insect resistance is clearly the major focus of this research, followed by disease resistance, herbicide tolerance, drought tolerance, and finally, quality traits. Nine firms focus on rice, six on cotton, five on okra and eggplant, and four on maize (IGMORIS 2010). Mahyco leads in developing new events, with 10 registered with the Genetic Engineering Approval Committee, but other firms such as Nuziveedu and Metahelix are also developing their own hybrids and biotech events (Box 3.1). Foreign companies dominate biotech patenting—78 patents have been granted to foreign firms and 1 granted to an Indian company (see Table 2.6).

⁸ Research intensity, defined as R&D expenditure divided by sales.

Box 3.1—Seed and biotech innovations by domestic firms

Nuziveedu Seed Private Ltd (NSPL) has led the market in the sale of cotton seeds for more than a decade because it developed two superior cultivars, Bunny and Mallika, from its own R&D in 1995. When commercial cultivation of Bt cotton started in India in 2002, NSPL licensed Bt and released Bt Bunny and Bt Mallika in 2005. By 2007, Bt cotton was marketed by more than 25 companies in India. Because almost all 25 companies used the same Bt gene, the principal differentiating factor of NSPL hybrids to farmers was the superior attributes of background hybrids. So far, NSPL has about 142 varieties of hybrid commercial cotton seeds, approved by the Indian government's Genetic Engineering Approval Committee. The market share of NSPL hybrids has been greater than 35 percent over the last decade as a direct result of superior germplasm (NSL limited website (2010) and Indian Credit Rating Agency(ICRA) Perspective, February, 2010).

Metahelix is an R&D-led agricultural biotechnology company focusing on developing traits and cultivars for crop protection and improved productivity. Metahelix used its expertise in crop genetics and plant biotechnology to develop high-performance hybrid seeds in rice, maize, cotton, and millets for Indian markets with transgenic traits for insect, viral, and fungal protection. Although Monsanto and its partner Mahyco began marketing Bt cotton in 2002, Metahelix was the first Indian company to develop its own proprietary Bt trait, Cry1C, approved for cotton in 2009 (Metahelix,2010).

Sources: Nuziveedu Seeds Limited 2010, ICRA Perspective 2010, and Metahelix 2010.

Pesticides

Although pesticide research worldwide has declined since the 1990s (Fuglie 2010), pesticide research in India has grown—particularly in the last decade. Pesticide R&D of MNCs listed on the Indian stock exchange (Bayer Crop Science, Monsanto India, Syngenta, and BASF) tripled their R&D expenditures between 2003 and 2008.⁹ Increases in sales, which doubled during this period, account for research increases, although research intensity also increased slightly. In the 1990s, most pesticide companies were spending about 0.8 percent or 0.9 percent of sales annually on R&D (Pray and Basant 2001). This increased to 1.5 percent in 2009.

R&D data for large Indian pesticide firms listed on stock markets show a different pattern than the data for MNCs, with slower and less uniform growth among firms. Rallis, the clear leader in 2000, declined in research investment from 179 million rupees (Rs) in 2000 to Rs 23 million in 2008. Gharda, on the other hand, continued to spend about the same amount each year on research and its research intensity is high. In contrast, UPL R&D has increased from about Rs 100 million in 2000 to Rs 6.7 billion in 2008,¹⁰ and it has become the leading Indian pesticide research firm. Research intensity of domestic firms, which account for about two-thirds of the research, has increased somewhat—from just less than 1 percent of sales to slightly more than 1 percent.

Indian companies tend to focus research on process innovation, such as finding inexpensive ways of making active ingredients (AIs) developed elsewhere, and on developing new formulations and combinations of AIs. In addition, firms are developing crop management practices to enable farmers to use pesticides more safely, more efficiently, and with less environmental impact. Excel and Rallis focus research on the manufacturing process to develop efficient processes to produce off-patent AIs that have available regulatory dossiers containing efficacy, toxicity, and environmental impact data and therefore can easily move through the Indian regulatory approval process. United Phosphorus reports research activities extending from more efficient manufacturing processes to developing safer, easier, and more effective spraying methods. Some firms are also involved in extension demonstrations, regulatory affairs, and product stewardship. Gharda Chemicals pioneered pesticide manufacturing technology.

⁹ The increase would have been even greater if data from Dow and DuPont had been available because both of them are making substantial investments in pesticide research, but they do not make data on their R&D expenditures in India public.

¹⁰ A large share of this growth appears to be due to the acquisition of foreign pesticide firms and Advanta.

Multinationals are also improving pesticide production and formulation as well as the safety, efficacy, and environmental impact of pesticides in India, but they are investing in basic research as well to develop new molecules for pesticides in India. Syngenta established a research and technology center in Goa in 2006 that has grown to more than 100 scientists working on new chemical products for crop protection (Syngenta, 2010). Bayer is also developing active ingredients in India, where it is working specifically on developing new synthetic pyrethroids through its joint venture with Mitsui called Bilag. Isagro's India division has a large research program on developing pesticide production processes. Its new AIs are identified in Italy, and then the India branch develops the least expensive production process. In 2007, DuPont built a basic sciences center for chemical and biological research in Hyderabad, and BASF announced in 2010 that it will establish a research center in India to develop new agricultural chemicals.

Patent data and interviews with firms suggest that while much research in India is still on insecticides, fungicides and herbicides are growing research areas. Both Indian and foreign firms in India conduct significant research on biopesticides. These include the Indian firms TERI, Coromandel, and Excel Industries, which together have been granted 25 patents on biopesticides between 1991 and 2009. Camson Bio Technologies entered the biopesticides market in 2001 and spends 20 percent of its revenues annually on research, having developed 22 biopesticides and 7 biofertilizers, and capturing 20 percent of the Indian bioproducts market (Camson Bio Technologies 2010). Research investment in this area totals about Rs 68.7 million (\$1.4 million), nearly 3 percent of sales, and investment is increasing as new firms enter the market.

Fertilizer

Private R&D expenditure within the fertilizer industry has grown slowly, rising from \$6.7 million in the 1990s to only about \$7.9 million in 2008/09. A few firms conduct most of the research. In 2009, Nagarjuna and Tata Chemicals conducted 75 percent of private research, and Tata Chemicals accounted for most of the growth. Among government-owned firms and cooperatives, Gujarat State Fertilizers and Chemicals leads R&D.

The fertilizer industry also has the lowest research intensity of all input industries, and its research intensity is declining. In 2000, research intensity of private firms was about 0.22 percent, and it declined to 0.12 percent in 2009. Research intensity of government-owned firms declined from 0.08 percent to 0.03 percent over the same period.

Fertilizer research efforts have recently focused on developing fertilizers that combine standard nitrogen, phosphorous, and potassium (NPK) with minor and micronutrients to meet the needs of specific regions. For example, Tata Chemicals established a new crop nutrition and management research program in Aligarh in 2006 that included 10 scientists, 20 agronomists, and a research budget of about Rs 20 million in addition to scientist salaries (Tata Chemicals, pers. comm. 2009). This center designed and developed customized fertilizer grades for rice, wheat, maize, potato, and sugarcane, and other R&D related to foliar applications of nutrition. Another rapidly growing area of research is water-soluble fertilizers. Coromandel Fertilizers in South India is conducting research on specialty nutrients for niche markets, including water-soluble organic and micronutrient-based fertilizers.

Globally, there has been little innovation and R&D in the fertilizer industry. Subsidies, price controls, and regulations on new products have meant that, until recent deregulation, there was little incentive for research. Government subsidies reserved for Indian firms made it virtually impossible for foreign companies to enter the Indian fertilizer industry except with some specialty products.

Innovation and research on biofertilizers and organic fertilizers has grown substantially in recent years. Sales and innovation in this area have increased so much that it was brought under government control in 2005. All biofertilizers now have to be tested for efficacy and approved by the government in order to control quality and prevent fraud. TERI has been a leader in research on biofertilizers and has commercialized a number of products in joint ventures with commercial fertilizer companies. Its main product is arbuscular mycorrhiza. International firms such as Novozymes are also entering the market.

Sales of phosphate solubilizing bacteria (PSB) in particular are soaring because the product works on any crop. Companies that sell phosphorus fertilizers tend to push PSB because it improves the performance of their chemical fertilizers. Currently, at least 10 fertilizer companies are working on PSB and related formulations (Fertilizer Association of India 2009) toward commercialization.

Agricultural Machinery

The R&D expenditures in the agricultural machinery industry have increased from \$6.5 million in 1994-95 to \$40.5 million in 2008-09—a six fold increase—and focus primarily on tractor and irrigation technology. Research intensity in general has not increased, with the industry steadily spending about 1 percent of sales on R&D annually. Mahindra & Mahindra leads both the tractor market and R&D investments, with about an \$11 million research budget in 2009 that is 3.6 percent of sales (Mahindra & Mahindra 2010), followed by TAFE, Escorts, and International Tractors.

The MNCs John Deere and CN Holland have made major investments in R&D in India in recent years. In 2000, John Deere began building its manufacturing, technology, and engineering center in Pune, which now employs 1,200 professionals working in product design, engineering, and information technology for worldwide John Deere markets. CN Holland Fiat maintains a major R&D center in Noida near New Delhi. Same Deutz-Fahr also conducts some research in India. We were unable to obtain R&D data from these firms and, as a result, both the level and the growth of tractor R&D in Table 3.3 are underestimated.

The private sector dominates the tractor business in India with greater than 95 percent market share. HMT, the only public-sector corporation specializing in tractors, has an R&D investment of less than 0.2 percent of sales (HMT Annual report 2009; DSIR 2009/10).

Tractor innovation has focused on improving engine technology and new product development. Mahindra designs, develops, manufactures, and markets tractors along with farm implements. Mahindra introduced an Indian-made high-horsepower tractor to export markets in 2004, including the “World Tractor,” a 75-horsepower model (model number 7520), to the US market. The firm also introduced two new low-horsepower products to the domestic market to strengthen the company’s position. TAFE has focused its R&D on developing new models in the 41- to 50-horsepower range, as has Escorts, which is also developing products for the export market. John Deere is introducing new 31- to 40-horsepower models, starting with two 35-horsepower tractors specific to the Indian market by 2011, and exporting tractors from India to the United States (Box 3.2).

Box 3.2—“Polycentric innovations” from MNC R&D in India

John Deere developed a new, low-cost series of tractors for Western markets, the 5003 series designed by a team of US and Indian engineers in Deere’s research facility in Pune, India. The series was inspired by the success of the Indian tractor maker Mahindra & Mahindra in selling tractors in the United States to a market Deere had largely ignored, hobbyists and bargain hunters who do not require advanced features and want two key qualities that Indian farmers also value, affordability and maneuverability.

Deere, taking a cue from Mahindra, in 2002 transplanted a slightly modified version (with softer seats and higher horsepower) of the Indian line of tractors, which it markets as the 5003 series in the United States at a starting price of \$14,400. Today, about half the tractors Deere manufactures in India are exported overseas. Deere is reaping financial benefits from transplanting Indian innovations, born out of *frugal engineering* that minimizes cost with greater efficiency, to the United States and other Western markets.

Source: Colvin 2008.

While big companies focus more on medium- and higher-horsepower markets, small, domestic companies such as Captain Tractors are designing and producing mini tractors. Angad-SAS Motors of India has developed low-cost tractors with in-house technology, while Rajkot, in Gujarat, has become the country's only mini tractor manufacturing hub.

Jain Irrigation, which produces drip and sprinkler irrigation equipment, leads irrigation research with a research budget of about \$4.3 million per year, or 0.7 percent of sales (Jain Irrigation Systems 2010). Jain's main competitor in micro irrigation is the Israeli company Netafim, alongside many small local firms; recently John Deere and Godrej have entered the micro irrigation market. Jain conducts both engineering and agricultural research, with engineers working to develop new drip and sprinkler irrigation equipment, reduce production costs, and improve factory efficiency. Jain's agricultural research focuses on developing efficient water and fertilizer management systems; developing varieties of a few key crops like jatropha, onions, and mangoes; and working with engineers to develop micro irrigation systems for cotton and to make drip irrigation systems compatible with mechanized harvesting systems. Netafim, with research facilities in Israel, conducts no research in India.

Livestock

Data on two components of the livestock industry—poultry breeding and feed, and veterinary medicine—show that R&D investment in the breeding and feed industry has doubled since the 1990s and the investment in veterinary medicine has almost tripled during the same time. However, research intensity in the poultry breeding and feed industry has declined from 1 percent in 2000 to about 0.8 percent in 2009. Data in this sector are from three major local firms—Venkateshwara Hatcheries (VH), Godrej Agrovet, and Suguna. VH claims its hybrid breeds control 85 percent of the layer market and 65 percent of the broiler market. The VH layer line, BV 300, developed from a breeding program that started in 1980 (VH website). VH continues to develop its layers, and all three companies are working on improving broilers through adaptive poultry breeding using lines from European and US-based partners (Cobb-Vantress and Ross). In addition, all conduct research on farm management to reduce disease and increase productivity, and on vaccines and specialized egg and poultry products.

The veterinary medicine industry has seen rapid growth in R&D due to increased research by specialized foreign veterinary medicine firms such as Virbac (France) and Provimi (the Netherlands) and due to expansion into the Indian market of the veterinary pharmaceutical wings of major multinationals such as Pfizer and Merial. Additionally, local veterinary medicine firms such as Venkateshwara's vaccine subsidiary, Ventri, have also increased R&D, and Indian pharmaceutical companies such as Cadila have entered the market. These firms report investing between 4 and 7 percent of Indian sales in R&D. Pfizer has built a \$40 million research facility in Thane near Mumbai and so we expect to see R&D increasing even more rapidly in the near future.

Food, Beverage, Tobacco, and Plantations, and the Biofuel Industries

Over the last two decades, R&D in the food industry has grown from about \$14 million to \$27 million. Biofuel has grown from zero in 2000 to \$13 million in 2008. Sugar industry R&D has grown slowly with the exception of Shree Renuka, whose R&D accounts for most of the growth in sugar R&D between the mid-1990s and the present. Current levels and growth in agricultural processing R&D may be underestimated because some of the largest food companies, such as Ruchi Soya Industries, do not publish R&D expenditures in annual reports.

Agricultural processing industries conduct research to develop agricultural technologies and new food products, and to increase processing efficiency. Processing firms may also conduct agricultural research to improve crop quality or reduce production costs if they control land and produce crops, as tea and coffee companies do, or hold a monopsony position, as ITC does in tobacco and eucalyptus.

In India, ITC controls about 90 percent of cigarette sales, buys most cigarette tobacco, and maintains a major research program to develop tobacco varieties and management practices that reduce

production costs for contract farmers and increase leaf quality. In addition, ITC is also the largest producer of paper and pulp in India and has a large research program to improve the productivity of eucalyptus production. Finally, ITC is an important part of the food industry and does product and process research for that component of the corporation.

Major companies that own tea and coffee plantations are Tata Tea, Hindustan Unilever (HUL), and Goodricke Tea. All are conducting research to produce better clones and crop management practices, and investing in developing new consumer products such as nutritionally enhanced tea (HUL; see Box 3.3), flavored teas (Tata), and instant teas that dissolve in cold water (Goodricke).

Box 3.3—Fortification of beverages: A Unilever India innovation

According to World Bank surveys, more than 950 million people in south Asia are moderately to severely malnourished. Offering a product that provides essential nutrients daily without additional cost is a challenge. To accomplish this, Hindustan Unilever's (HUL's) R&D labs based in India picked tea, consumed by almost all Indians two to three times a day. Tea is an excellent vehicle for nutritional fortification with its low processing cost and acceptable vitamin stability. HUL developed a new value-added tea product by adding a vitamin mix to the tea to fight vitamin B deficiencies. Launched in January 2010 under the brand name of Sehatmand, the product has a market share of 0.6 percent, with tea sales around 1,300 tons in the major south Asian countries.

Source: John 2009.

Nestlé has increased its R&D investment in India from about \$2 million to \$4 million over the last five years and has announced it will develop a \$50 million R&D center with 40 scientists in Haryana to work on developing new food products, cereals, beverages, and dairy products for the Indian market. GlaxoSmithKline has also greatly increased research activity, and India is the only country where the company has a food business.

Multinational food chains such as McDonald's have also established R&D facilities in India. McDonald's R&D center in Maharashtra is the corporation's only vegetarian-based innovation center and has developed two products, the McWrap and Pizza McPuff, aimed at its global outlets. The American pizza chain Domino's retains chefs at its R&D center in Noida, and the company's innovations include Peppy Paneer Pizza and Cheese Burst Pizza, which have 65 percent of the domestic pizza market (F&B News, October 2010).

Biofuel R&D is led by Praj Industries, originally an engineering company making equipment and factories for ethanol production for both industrial and beverage ethanol. In response to both domestic and foreign ethanol demand, Praj recently established a major biofuel research institute called Matrix Innovation Center near Pune with financial backing from foreign venture capitalists such as Vinod Khosla. This center works on every aspect of biofuel from breeding of plants for feedstocks to developing improved enzymes and yeasts for conversion of feedstocks to ethanol and developing improved machinery for biofuel production. Praj reported expenditures on R&D of about \$9 million in 2008/09 (Praj Industries 2010).

In addition to Praj, major investments in biofuel feedstock research are being made by Tata Chemicals and Reliance Life Sciences (jatropha), Syngenta (tropical sugar beet), and Advanta and Nimbkar Agricultural Research Institute (sweet sorghum). Novozymes conducts research on enzymes for biofuels in India. Shell Oil has located part of its global biofuel research program in Bangalore, and BP has funded the Energy Research Institute in New Delhi to work on jatropha. Unfortunately, we do not have estimates of R&D on biofuel by Tata Chemicals, Reliance, or Shell. So \$13 million is a lower-bound estimate of biofuel R&D.

Another agricultural processing industry R&D that grew rapidly during this period is the sugar industry. In real dollars, R&D increased from \$2.5 million in 1994-95 to \$10.8 million by 2008. Four companies—EID Parry, Godavari, Shree Renuka, and Dhampur Sugar Mills—accounted for 74 percent of sugarcane R&D in 2009 (data from our survey). Only one private company, EID Parry, conducts

sugarcane breeding, which is primarily conducted by the government's Sugarcane Breeding Institute in Coimbatore and institutes related to the Indian Council of Agricultural Research (ICAR). Most research by sugar mills focuses on developing more efficient sugarcane crop production and management technologies to reduce factory water and energy use and increase energy sales to the electrical grid. In addition to their own research, sugar mills in Maharashtra, which are officially cooperatives, tax themselves and support the Vasantdada Sugar Institute near Pune for variety selection, crop management, supply chain logistics, and factory management research.

4. IMPACT OF PRIVATE-SECTOR INNOVATION

In this section, we examine impacts of private-sector technology on agricultural productivity, poverty, agricultural input exports, and the environment using recent literature, available government data, and company information. The seed and biotech industry has the most readily available data on impacts of its technologies, which show that seed/biotech innovations have increased yields, particularly of cotton, maize, pearl millet, sorghum, and rice. The spread of biotech cotton has also reduced pesticide use, resulting in substantial savings on inputs for farmers. Data in Table 4.1 suggest the importance of proprietary hybrids in increasing productivity. Private companies' proprietary hybrids cover at least 75 percent of areas cultivated in improved varieties or hybrids. Millet, cotton, and maize, the focus of research by most companies, also had the most rapid growth in yield/ per ha over the last 20 years and the largest number of hybrids and proprietary hybrids. Crops with lower yield increases also had fewer hybrids and proprietary hybrids, and fewer private companies conducting R&D on them. Although these associations do not prove that private R&D caused yield growth, they are consistent with the hypothesis that private R&D plays a major role in yield growth.

Table 4.1—Impact of private-sector R&D on major crops in India, 2008/09

Impact indicator	Millet	Sorghum	Rice	Cotton	Maize	Sunflower
Total area under cultivation (2008/09), million hectares	8.8	7.5	45.5	9.4	8.2	1.8
% change in mean yield (1980/01 to 2008/09)	54.9	31.4	38.7	58.8	52.0	13.1
% change in area under crop (1980/01 to 2008/09)	-33.3	-47.2	12.0	17.0	26.4	93.4
% area under high-yielding varieties or hybrids (2008/09)	68.6	53.1	3.1 ^a	80.8	58.8	41.7
# of private firms with R&D focus (2008/09) ^b	30–35	20–25	24 ^a	> 50	25–30	15–20
Proprietary hybrids as share in the supply of high-yielding varieties (%)	82	75	95 ^a	95	> 90	> 95

Sources: Pray and Nagarajan 2009, 2011; MoA 2010; NSAI 2010; Verma 2008; Prabhakar 2008.

Notes: ^a Indicates area occupied by hybrid rice only—does not include improved varieties (open-pollinated varieties); ^b authors' estimates based on interviews, surveys, and annual reports.

Several studies support the argument that propriety hybrids of pearl millet, sorghum, and maize increased productivity of these crops in the semiarid tropics, areas not well served by Green Revolution varieties. Pray and colleagues (1991) measured the impact of private pearl millet and sorghum hybrids in the 1980s and found that farmers captured substantial economic gains from high yields of proprietary pearl millet and sorghum hybrids. A decade later, an econometric analysis of maize, sorghum, and pearl millet yields in the semiarid tropics of central and southern India conducted by Ramaswami, Pray and Kelly (2001) found that private hybrids raised yields after controlling for other factors such as public hybrids and high-yielding varieties (HYVs).

Analysis of rice yield data for 2008/09 shows that, on average, in the states that grow hybrid rice, yields of private rice hybrids are 22 percent higher than yields of HYVs and traditional varieties. Our econometric analysis, which controlled for region, irrigation, pesticide, and quantity of seed use, shows that private hybrids yield 14 percent more than varieties (Pray and Nagarajan 2011). Somewhat surprisingly, hybrid rice, now covering about 5 percent of the rice area, is spreading to less favorable rice environments, also not well served by the Green Revolution varieties. It is replacing older improved varieties and landraces. Green Revolution varieties were generally not cultivated in eastern India because they were considered unsuited to these regions. More than 80 percent of rice hybrids in India are cultivated in eastern Uttar Pradesh, Bihar, Jharkhand, and Chhattisgarh, and 15 percent in the northwestern and western parts of India. Less than 5 percent of total rice acreage is under hybrid rice

cultivation in southern Indian states (Viraktamath 2009). So far, 33 rice hybrids have been officially released for cultivation; of these, 25 are from the public sector and 8 from the private sector. However, 7 private hybrids dominate the market, and the private sector supplied almost 95 percent of total seeds (19,400 tons) in 2007/08 (Viraktamath 2009).

Proprietary cotton hybrids and biotech hybrids now cover more than 90 percent of the Indian cotton crop. Cotton yields began increasing with the spread of hybrids in the early 1970s, but yields jumped in the last decade as new proprietary hybrids took over the market and Bt cotton hybrids were adopted. Bt genes and hybrids increased crop yields directly by adding hybrid vigor and cutting pest loss. They also increased yield indirectly—by inducing farmers to invest in more fertilizer and other inputs, also increasing yield. An econometric model of cotton yields found that proprietary hybrids added 210 kg/ha to the yields of public hybrids and that Bt hybrids added another 139 kg/ha onto the yields of proprietary hybrids without Bt.¹¹ These are impressive gains considering that average yields for the whole sample were 379 kg/ha. (Pray et al. 2011).

A recent paper by Pray et al (2011) summarized the impact of private-sector biotech on cotton. In addition to increasing cotton productivity, adoption of Bt cotton is associated with a rapid increase in cotton exports. Cotton exports increased from 0.05 million bales in 2002/03 to 8.5 million bales in 2007/08, with earnings increasing from \$10.4 million in 2002/03 to \$2.2 billion by 2007/08. Cotton textile exports also increased in value from \$3.4 billion in 2002/03 to \$4.7 billion in 2007/08 (CCI 2009). Although these export increases are attributed to changes in domestic and international agricultural trade regulations, they would not have been possible without increases in production and yields due to private-sector hybrids and biotechnology.

Many other private innovations had important impacts on agricultural productivity and saving scarce resources. One example is drip irrigation, introduced by the Israeli firm Netafim and soon improved on and popularized by such Indian firms as Jain Irrigation, which introduced a number of important innovations in drip and sprinkler irrigation. Drip irrigation is now used in India on 100 percent of the grape area, 100 percent of pomegranates, 80 percent of bananas, and 40 percent of citrus. Micro sprinkler systems, reducing the cost of drip irrigation from Rs 40,000 per acre to Rs 20,000 per acre, doubled yields, saved water in the onion crop, and will soon cover most of the 100,000 acres cultivated in onions in Maharashtra. Jain's under-surface drip system allows mechanical harvesting of sugarcane, saving farmers about Rs 500 per acre. This system was used on 30,000 acres of sugarcane in Tamil Nadu in 2009 and is spreading into Andhra Pradesh with state government assistance (Jain Irrigation, pers. comm. December 14, 2009).

The only econometric study to measure the impact of private research on total factor productivity (TFP) is now somewhat dated (Evenson, Pray, and Rosegrant 1999). The study estimated changes in TFP in crop production for each district in 13 states of India using data from 1956 to 1987. TFP was regressed against public and private research, extension, and other variables. The private-sector research variable included both local research and imported mechanical and chemical technology. To capture technology spill-ins from the international agricultural research centers, the share of cropland planted with HYVs of rice and wheat was included as an explanatory variable. The study found that over the whole 30-year period public research and extension contributed most to productivity growth, and private research accounted for about 11 percent of productivity growth. Since the measure of private research included both local and imported technology, the authors were unable to assess the role of international technology transfer by the private sector.

Private research in India has also helped increase Indian exports of agricultural inputs and technology. For example, India has exported hybrid rice seed, developed from research conducted in India by Bayer, Pioneer, Bioseed, Mahyco, Advanta, and Devgen, to its neighbors and to Southeast Asia. The tractor industry is also currently exporting technology based in part on Indian research that has designed and produced 40-horsepower and larger models for the North American and European markets.

¹¹ The model was based on survey data from more than 12,000 farmers per year in all major cotton-growing states in 1998, 2000, 2002, 2004, and 2009.

In 2007/08, \$452 million worth of agricultural machinery was exported from India (IBEF 2009). The pesticide industry is the third-largest exporter, producing low-cost generic pesticides in part based on research conducted in India to reduce the costs of active ingredients and formulations. In 2009, Indian pesticide exports were valued at about \$1.8 billion (Pesticide Manufacturers and Formulators Association of India [PMFAI] June 2010).

Private-sector hybrid seeds and biotech have benefited both rich and poor farmers. Hybrids of pearl millet, sorghum, and rice were primarily used in some of the poorest regions, such as the semiarid tropics of central India (see Pray and Nagarajan 2009) and the nonirrigated rice regions of eastern India (Pray and Nagarajan 2011). The adoption of Bt cotton has increased rural employment and reduced poverty in Maharashtra (Subramanian and Qaim 2009). Commercial farmers, small farmers, and agricultural laborers have all benefited from the rapid spread of horticulture, especially vegetables, driven in part by private-sector cultivars, irrigation methods, and pest control techniques. In addition, some firms such as Namdhari and Shriram Bioseed have diversified from the seed business into vegetable retailing and exports (seeds and fresh products), expanding income-earning opportunities in the entire value chain.

The impact of private innovation on the environment has been mixed. The spread of high-value vegetables and fruit, driven by increased demand and aided by high-yielding, private-sector cultivars, has increased fungicide demand. However, the spread of Bt cotton has reduced insecticide use in the field crop sector. The Central Insecticide Board and Registration (2008) reported a consistent decline in consumption from 48,350 million tons (MT) in 2002, the year Bt cotton was first introduced, to 37,959 MT in 2006 (worth \$80 million), when Bt cotton occupied 40 percent of the cotton area.¹² Pesticide consumption is likely to continue to decline, since Bt cotton occupies more than 90 percent of the total area cultivated (Choudhary and Gaur 2010). Pesticide usage could be further reduced if Bt eggplant is approved for commercial cultivation.

Other innovations in the pesticide and chemical industry include chemical biofertilizers and biopesticides, formulations considered less dangerous to human health and the environment than those used in the past. The Indian biopesticide and biofertilizer market is fast emerging due to the steady increase in export of fruits and vegetables governed by maximum residue limit specifications and the emergence of major supermarket chains that market their products as natural, organic, and healthy. Environmental innovations in the sugar industry have primarily been the use of waste products such as bagasse to produce clean energy. Indian sugar mills earn carbon credits for producing electricity from wastes. The adoption of mechanized sugarcane harvesters also has helped to reduce air pollution. When sugarcane is harvested by hand, sugarcane fields have to be set on fire to burn the dry leaves and waste so that they can be cut by hand. If the sugarcane is harvested by machine it does not have to be burned, dramatically reducing air pollution at harvest time.

¹² Indian Chemical Industry (2007) estimated a savings of \$82 million, or 56 percent, in 2006 compared with 1998 through the introduction of Bt cotton.

5. REASONS FOR GROWTH IN PRIVATE R&D

As shown in Section 3, Indian agribusiness R&D grew by \$250 million between 1996/97 and 2008/09, with the seed industry accounting for 35 percent of the growth, followed by machinery at 16 percent, the pesticide industry at 14 percent, agricultural processing and plantation industries at 11 percent, and animal health industries at 7 percent. All other industries (sugar, fertilizer, and poultry) contributed 5 percent or less. Multinational corporations (MNCs) account for 40 percent of R&D. MNCs have made particularly important contribution to the growth in Indian R&D in animal health, pesticides, agricultural machinery, and seed/biotech.

Many factors influence the R&D investment decisions of firms and governments. To sort out the relative importance of these factors, R&D investments by profit-maximizing private companies should be empirically modeled. The model would include expected market size for new products and processes; firms' ability to appropriate benefit generated by innovations; the state of science on which new technological opportunities are based; and research and innovation costs such as land, labs, scientists, and financing. This paper does not develop an economic model of research and innovation but uses these categories to discuss influences on research investment. In addition, two types of government policies that have considerable impact on research are examined: liberalization and agricultural subsidies.

Markets for Agricultural Innovations

The growing demand for agricultural products and for modern agricultural inputs is the major factor inducing R&D growth and innovation in India. Increases in per capita income have increased demand for food, especially high-quality food such as vegetables, fruit, milk, and meat. Increased income and urbanization have also increased demand for processed and fast foods. Globally, higher incomes, higher agricultural input prices (particularly oil prices), and demand for biofuels pushed world prices for agricultural products higher. Indian farmers responded to this increase in demand by increasing production and use of modern inputs (see Tables 1.1 and 1.2).

If the major driver of growth in R&D and innovation is market size, R&D would be expected to grow as sales grow. Research intensity, defined as R&D expenditure divided by sales, would remain constant. This section examines industries with constant research intensity, suggesting that market growth was indeed the main factor in R&D investment and growth, and also examines industries with increasing research intensity (Table 5.1), suggesting that other factors also influenced R&D investment decisions.

Table 5.1—Size of the market and research intensities of private agribusiness

Sector	Market size 2009 ^a (in millions of 2005 US\$)	Research intensity (%)	
		1990s ^b	2009 ^a
Seed and biotechnology	1,300	3.5–3.8	6.9
Pesticides	3,200	0.8–0.9	1.1
Fertilizers	13,732	0.22	0.1
Agricultural machinery	2,100	1	1.2
Poultry and feeds	1,010	1	0.8
Animal health	325	NA	5.7
Food, beverages, processing, and plantations	5,650	NA	0.5

Sources: ^a Pray and Nagarajan 2011; ^b Pray and Basant 2001.

R&D primarily seems to have followed market growth in two industries: pesticides and agricultural machinery. Since the 1990s, both spent about 1 percent of sales on research, with only a small increase in research intensity. A rapid increase in exports and in local demand has benefited both industries. In 2009, about half of the \$3.2 billion in sales of pesticides produced or formulated in India was from exports (Pesticide Manufacturers and Formulators Association of India [PMFAI] June 2010). Internal pesticide sales have not kept up with exports. Sales of insecticides slowed after 2001 due to the spread of Bt cotton (Choudhary and Gaur 2010).

Indian agricultural machinery R&D has grown more rapidly than pesticide R&D as machinery sales have soared internally and abroad. Tractor sales in India have tripled since 1991 (Mahindra & Mahindra 2010), driven in part by increasing rural labor costs. Exports of medium and large tractors, primarily to developed countries, totaled 37,900 tractors during 2009/10, contributing around 13 percent of total revenue earned by the industry as a whole (IBEF 2009). Irrigation equipment sales also grew dramatically in India in the last decade. Jain Irrigation's sales increased from a low of Rs 2.2 billion in 2005 to Rs 18.9 billion in 2009 (Jain Irrigation Systems 2010). Indian demand for drip irrigation almost entirely accounts for this increase.

R&D in the seed, veterinary medicine, and agricultural processing industries has grown much faster than sales. Research intensity in the seed industry declined from about 3.5–3.8 percent in the mid-1990s (Pray and Basant 2001) to around 3 percent during the 2000–2005 period, and then increased to 6.9 percent in 2009. Although 1990s data is limited for the veterinary medicine industry, it seems that this industry has increased R&D intensity. Currently, veterinary medicine firms report investing between 4 and 7 percent of Indian sales in R&D, while no animal feed or veterinary medicine firms in the 1990s had more than 1 percent of sales in R&D (Pray and Basant 2001).

The fertilizer, poultry breeding and feed, and sugar industries have generally had declining research intensity. The fertilizer industry has had the lowest research intensity of any industry studied, and it has declined steadily—from 0.22 percent for private firms in the mid-1990s to 0.12 percent in 2009. The poultry breeding and feed industries also have not kept up with the explosive growth of sales, with research intensity declining from slightly above 1 percent in 2000 to about 0.8 percent in 2009. The sugar industry's R&D intensity was 0.15 percent and declined until 2009/10, when Shree Renuka Sugars expanded.

All three of the above industries have significantly increased sales in India, but the government has tightly controlled both prices and technologies in the fertilizer and sugar industries. This provides little incentive for innovation or research. In addition, government-organized cooperatives or state-owned enterprises control a major share of the fertilizer and sugar industries.¹³ A few private Indian sugar companies, led by Shree Renuka, have moved into foreign markets by buying sugar and ethanol mills in Brazil and Africa to supply sugar for the Indian market.

More research on the poultry industry is needed to account for its low research intensity. One hypothesis is that there is too much concentration in the poultry industry. Venkateshwara Hatcheries reportedly has 80–85 percent of the broiler breed market and 60 percent of the layer breed market, with only two or three other firms in the market. This could reduce research incentive.

Growing per capita income has also led Indian consumers and farmers to increase their demand for environmental services from the agricultural sector, such as cleaner air, water, and agricultural products. This has led to growing demand for organic products, reduced chemical use in agriculture, and sustainable biofuels. Industry has responded with research on safer chemicals, biopesticides, and biofertilizers.

¹³ Sugar and fertilizer have been considered essential commodities and as such have been protected by government price controls and quotas through the Essential Commodities Act of 1955 to prevent competition and price hikes.

Appropriability

In addition to the rapid growth in markets for new agricultural technology, the strengthening of the laws governing appropriability of benefits of new technology has encouraged more R&D and innovation. The industry that has increased its research intensity most, seeds/biotech, has the second-highest number of agricultural patents (Table 2.5) and also protects its innovations with plant variety protection (Table 2.6). Pesticide research has the most agricultural patents, which may account for some of the growth and intensity of research in that industry.

Intellectual property rights (IPRs) started to be strengthened in India in 1995 when it joined the World Trade Organization (WTO). India had to modify its IPR laws to comply with WTO agreements. India's patent laws, as amended in 1972, had excluded chemicals, medicines, and all agricultural products from being patented. This meant agricultural machinery was not provided patent protection, although most machinery (such as auto or truck parts) could be patented. Plant varieties were also not legally protected. All this changed in 1999 when the Indian patent law was revised to comply with the Trade-Related Aspects of Intellectual Property Rights (TRIPs) agreement. Starting in 2005, chemical and agricultural products and processes could be patented for 20 years, creating stronger patent protection for biotechnology products, pesticides, veterinary pharmaceuticals, farm machinery, and new food products. A *sui generis* system of plant breeders' rights was passed and started accepting applications in 2007.¹⁴ Although excluded from coverage in the patent act, plant varieties and seeds are protected by the plant variety protection (PVP) law.

Our research indicates that changes in legal protection of intellectual property made a positive but limited contribution to growth of innovation and R&D in India. Local seed companies are using the PVP act while the multinationals dominate the patenting of pesticides and biotech tools and traits (Tables 2.3 and 2.4). In the agricultural machinery industry, MNCs have filed the most patents, but local companies also are patenting extensively. Thus, patents may help account for rapid growth in R&D investments among MNCs.

The growth of private R&D of the seed and biotech industries shows that when an Indian industry has the ability to appropriate research benefits, the industry responds with more research. This is particularly true in the seed and biotechnology industry. The explosive growth of seed industry R&D in the first decade of the 21st century was a direct result of the technological opportunity of producing genetically engineered insect-resistant hybrid cotton (called Bt cotton) coupled with strong appropriability due to the Indian regulatory regime (Pray and Nagarajan 2011). From 2002 to 2006, Monsanto and its Indian partner, Mahyco, had considerable market power in the Bt cotton seed market because, due to strict biosafety regulations (not due to patents, which could not protect biotech until 2005), they were the only companies legally authorized to sell Bt seed. They charged much higher prices and had higher profit margins than Indian seed companies had on any other major field crop (some vegetable seeds had higher margins), and the profits were obvious to everybody in the seed industry. The technology's superiority over the competing technology of hybrid seed combined with chemical pesticides forced other companies to license genes from Monsanto or somebody else, develop their own Bt genes, or do both. Pray and Nagarajan (2011) argued that the example of Bt cotton was the major factor in the rapid growth in R&D in the seed industry in all hybrid crops in the first decade of this century. This growth has slowed somewhat since 2006, when an Indian government ruling that Mahyco-Monsanto was a monopoly forced all the seed companies to reduce prices of Bt cotton seed by about two-thirds (Pray and Nagarajan 2010).

¹⁴ Due to the flexibility in Article 27.3(b) of TRIPs, "developing" and "least developed country" WTO members do not have to provide patent protection for plant varieties, nor do they have to implement the UPOV Convention (International Convention for the Protection of New Varieties of Plants). These countries have adopted a modified version of plant variety protection (PVP) systems—national *sui generis* PVP systems. So far very few and truly *sui generis* PVP systems have been developed. Notable exceptions include the Thai Plant Varieties Protection Act (1999) and the Indian Protection of Plant Varieties and Farmers' Rights Act (PVPFR Act, 2001).

Technological Opportunities and the Costs of Innovation

In addition to market size and somewhat stronger IPRs, other major factors contributing to growth of private agricultural R&D in India are rapid advances in basic biological research and information technology, and growth of public-sector R&D. The industries that have grown most rapidly and have the highest research intensity—seeds/biotech and veterinary medicine—have also benefited greatly from breakthroughs in basic biological research. Biotechnology spread to the agricultural sector in India through both private- and public-sector research laboratories, and the private seed industry sold the technology to farmers.

Public agricultural research expenditure grew by 6.4 percent annually between 1991 and 2003 (Beintema et al. 2008); 2003 is the last year for which data are available,¹⁵ although growth slowed to 2.9 percent annually from 2001 to 2003. In addition to this money, which went primarily to Indian Council of Agricultural Research (ICAR) institutes and the state agricultural universities (SAUs), there was also rapid growth in basic biotechnology research at institutes under the Department of Biotechnology, the Council of Scientific and Industrial Research (CSIR), and the general universities. Previous studies of the development of the seed industry (Pray et al. 1991) have shown that much of the hybrid sorghum and hybrid cotton was based on inbred lines developed by ICAR research programs or agricultural universities.

The international centers of the Consultative Group for International Agricultural Research (CGIAR) have had an important impact on private research in India. The International Crop Research Institute for the Semi-arid Tropics (ICRISAT), located in Hyderabad, has influenced the development of the seed and plant biotech industries in India. The hybrid pearl millet seed business depends on a regular supply of downy mildew-resistant lines from ICRISAT. The International Rice Research Institute, in collaboration with ICAR institutes, is the basis of the hybrid rice industry in India—providing important training, research, and germplasm that allowed the subtropical hybrid rice production system of China to be transferred to the tropical conditions in India and elsewhere in south Asia. The International Maize and Wheat Improvement Center (CIMMYT) has provided important germplasm to the public-sector research system and indirectly through the public sector to the Indian private-sector maize R&D programs in India.

Government departments and government research institutes outside of ICAR and the SAUs have been very useful to certain industries. The Department of Biotechnology (DBT) has been most proactive in supporting private R&D in plant biotechnology and animal vaccines. At first it provided financial support for biotechnology research in public-sector institutions and also private foundations such as the SPIC Science Foundation, the Barwale Foundation, and others. More recently it has supported private research by building technology platforms for private research such as a genomics center and supporting research tools like the use of molecular markers and plant transformation tools. The pesticide industry has benefited over the years from the research conducted by the National Chemicals Laboratory of CSIR in Pune. Growing private research in information technology (IT) and engineering at the Indian Institutes of Technology (IITs), general universities, and a few agricultural universities has been very supportive of the agricultural machinery industry.

Another major factor in the expansion of private R&D and innovation has been the availability of highly skilled scientists who have gotten their formal degree training at the SAUs, ICAR institutes, general universities, and IITs and then received practical training by doing research in the SAUs, ICAR institutes, and CGIAR institutes like ICRISAT. Virtually all of the private-sector scientists in agribusiness research clusters like Hyderabad for seed and biotech have their training at Andhra Pradesh Agricultural University (APAU) and most of the leaders of the industry spent time as scientists at ICRISAT. Tamil Nadu Agricultural University (TNAU) plays a similar role in providing skilled scientists and engineers to South India, and Punjab Agricultural University plays a similar role in the north. In recent years this supply of human capital to private R&D and innovation has been supplemented by an increasing number of scientists coming back from abroad with PhDs and years of research experience. Sometimes these

¹⁵ A new study is underway but will not be available until 2012.

scientists come as employees of the subsidiaries of US and European firms, but in recent years we met many scientists who were recruited by Indian firms.

While breakthroughs in basic sciences and engineering, and investments in public agricultural research and education have increased the probability of innovation and reduced its cost, other factors have reduced the probability of innovation and increased its cost. Biotech regulations make it difficult to introduce genetically modified (GM) varieties. Approval of new genes in cotton and new cotton cultivars containing those genes has been possible, but so far it has not been possible to commercialize genes in any other crops. Bt eggplant was approved by the highest regulatory authority, but then the Minister of the Environment vetoed its approval.

A major market development in the last 20 years that has reduced the cost of R&D has been the development of financial markets in India. An increased willingness to finance agribusiness has been due to the liberalization of the Indian financial sector, the growth of stock markets in India, and the interest of Indian and foreign investors in investing in Indian agribusiness. As a result, large numbers of companies, both Indian and some foreign based, have been able to raise money for all types of agribusiness investment, including research—through expanding their stock offerings or through initial public offerings (IPOs). Some of the most important companies that were private and now are listed are United Phosphorus (UPL), Nath Seeds, and Kaveri Seeds. In addition, a few firms such as Mahindra & Mahindra have been able to raise money on US stock markets. In certain industries venture capital and Indian angel investors have played a role. As mentioned above, the well-known venture capitalist Vinod Khosla has invested in Praj's biofuel programs. Angel investors in the IT industry helped Metahelix get started and expand.

Industrial Policy

Changes in industrial policy are also stimulating private innovation and R&D. Earlier studies of private R&D by the seed industry in India (Ramaswami and Pray 2001) and private agribusiness R&D in seven countries in Asia (Pray and Fuglie 2001) have noted the importance of market liberalization as a factor leading to the growth of private R&D. This has continued to be an extremely important factor in the growth of R&D in India in the last decade. Table 5.2 summarizes some of the policies that have changed. Almost all of these industries, from about 1970 to the early 1980s, were restricted to the small-scale sector; to cooperatives, which were largely controlled by the government; or to state-owned enterprises. Most were protected from foreign competition by keeping foreign direct investment out; restricting imports to things that could not be made in India; and eliminating patents, which were thought to be a way that foreign companies could control the technology of essential industries like agriculture, medicine, and chemicals.

As Table 5.2 shows, policies have gradually been liberalized to allow large Indian companies and foreign firms into the food and agriculture industries. Import bans and quotas gave way to allowing imports under open general license (OGL) but often still with substantial tariffs. Many of these changes took place in the first major round of liberalization starting in the late 1980s and early 1990s. Liberalization greatly increased the role for large firms and foreign firms in the agriculture-related industries. Another set of reforms took place in the late 1990s to bring Indian policy in compliance with the WTO agreement. These reforms included changing quotas and other quantitative restrictions on trade to tariffs, replacing the restrictive 1972 Foreign Exchange Regulation Act (FERA) with liberalized foreign exchange regulations under the 1999 Foreign Exchange Management Act, and the changes in the patent act mentioned above.

These policy changes have had major impacts on the food and agricultural input industries, leading to significant investments in agricultural input industries by almost all large Indian business groups; the Tata Group, Aditya Birla Group, and DCM Shriram are examples. The liberalization of the economy has also allowed Indian agricultural input firms to expand rapidly by issuing shares on Indian and international stock markets—for example, Mahindra & Mahindra and UPL. Finally, it has allowed

MNCs to make major investments in these industries, bringing in technology and investing in R&D to develop technology in India.

There has been some concern that allowing the large Indian companies and MNCs into these industries would lead to the concentration of these industries in a few large companies. Actually their entry or expansion in most industries has resulted in more competition rather than less. For example, in the seed industry, the four-firm concentration ratio declined from 51 percent to 34 percent between 1995 and 2008 while the share of MNCs in the total market increased from 33 percent to 40 percent (Ramaswami and Pray 2001 Pray and Nagarajan 2010).

An additional impact of liberalization in India and abroad has been the globalization of Indian agribusinesses, led by Tata Tea, Mahindra & Mahindra, UPL, and Shree Renuka Sugars. Tata Tea formed a joint venture with Tetley Tea to market tea to the United Kingdom in 1992 and then purchased Tetley in 2000 to become the world's biggest tea company. Mahindra expanded its Indian tractor market share by buying Gujarat Punjab Tractors in 2007. It expanded gradually in the small tractor market in the United States since starting operations there in the 1994. It now has three assembly plants in the United States. Mahindra also acquired majority ownership of a joint venture with Yancheng Tractors in China—the third-biggest tractor manufacturer in China.

UPL has globalized in three directions. First, it has expanded its export sales of generic pesticides dramatically over the years. Roughly three-quarters of its production is exported. Second, it expanded into the seed business by buying Advanta, a medium-sized seed multinational based in the Netherlands. Third, it bought DuPont's main fungicide business. Shree Renuka Sugars expanded in India through acquisitions of cooperative and private sugar mills and an engineering company, through leasing mills, and through investing in green field projects to build itself into India's largest sugar producer. Then in 2009 and 2010, it invested \$350 million to acquire two large Brazilian sugar and ethanol companies, from which it sources sugar for the Indian market.

Globalization appears to affect R&D by Indian companies in three ways. First, it increases the total research investments of these companies and their research intensity, since they now must face competition from science-based international firms. Second, acquisitions of foreign firms can give Indian firms access to the technology and R&D of the acquired firms. They can transfer the technology through their company to India or elsewhere in the world or can adapt it to Indian needs. They can incorporate the R&D of the acquired companies into their R&D programs. Third, it could shift some of the research that the company is performing away from developing technology for the Indian market to focus on large international agricultural input and processing markets such as the United States, Europe, and Latin America. This may not reduce research and innovation for Indian markets since the total amount of research and innovation of the firms is larger.

These policy changes also induced investments in research facilities that are part of the global research programs of foreign-based MNCs. The investments accounted for a substantial part of the increase in investment in the seed industry (Monsanto, DuPont), pesticides (Syngenta), and the food industry (Nestlé). For example, John Deere reports (website) that it has invested \$250 million over the last five years and hired 1,200 professionals for a center in Pune that will provide information technology services for Deere's global operations but also conduct engineering research for the global company. Shell Oil has had one of its four global biofuels research facilities in Bangalore for many years, but no data are available on how much is spent there. In addition, as mentioned Section 3, there have been announcements of major investments in R&D facilities by Pfizer Animal Health, Merck, Dow Chemicals, and McDonald's (vegetarian food research).

Table 5.2—Government restrictions on large Indian firms, imports of technology, and foreign direct investment

Sector	1980s	Mid-1990s	Current
Seed/biotech	Reserved until 1986. Limited vegetable seed imports. Other seed imports prohibited.	Large Indian and foreign direct investment (FDI) allowed in joint ventures with Indian firms. Vegetable seeds open general licensing (OGL). Limited imports of coarse grain and oilseed seed. Government imports of rice, wheat seeds.	FDI allowed 100% under “non-controlled” conditions since April 2011. Import of vegetable seeds and other seeds and planting material allowed under OGL.
Pesticides	New active ingredients (AIs) allowed for limited time at 150% tariff and then must manufacture in India. 50% formulation reserved for small industry. No imports of formulated products. Product patenting abolished in 1970.	All imports with 35% tariff. No imports of formulated products. No reservation for small scale. Customs duty on imports as high as 65%.	Imports of formulated products allowed since 2004. 100% FDI allowed through automatic route since 2008. Customs duty on imports slashed to 7.5%. Maximum excise duty is 15%. Joined TRIPS–WTO regime in 2005.
Fertilizer	Restricted to cooperatives and Indian domestic firms. Imports controlled by government under Foreign Exchange Regulation Act (FERA).	Same as 1980s.	Since 2005, 100% FDI allowed.
Agricultural machinery	No imports and restricted under FERA. Equipment reserved for small-scale domestic enterprises. Foreign firms allowed in joint ventures for tractors.	No imports. No reservation on equipment. FDI allowed.	Some imports allowed, especially small equipment, including power tillers. 100% foreign ownership allowed.
Poultry	Grandparent stock imports restricted. Parent stock imports banned.	Import restrictions continued.	1999–2000 grandparent stock imports allowed under OGL. Tariffs at 25%.
Sugar	Reserved for small-scale and cooperative sectors. Sugar imports restricted.	Sugar industry de-licensed in 1998. Reserved until 1998, when deregulation started. Quantitative restrictions on exports removed. Futures trading for sugar introduced.	Large Indian companies can invest outside. FDI allowed up to 100% through the automatic route. Import duty on sugar up to 60% since April 2011 (previously removed in 2009).
Food processing and supermarkets	Reserved for small-scale sector.	Reserved until 1998.	FDI still prohibited in retail food markets.

Source: Pray and Basant 2001 for 1980s and 1990s; discussions with industry and government officials for current information.

In the development of supermarkets in India (and elsewhere) Reardon and Minten noted a pattern similar to the pattern described above in the agricultural input and food processing industries:

... India has had in fact three waves of retail transformation marking the rise of modern retail: the extensive spread of government retail chains starting from the 1960s/70s, the diffusion of cooperative retail chains starting from the 1970s/1980s, and finally at first slow then extremely rapid spread of private retail chains in the 1990s but mainly the 2000s, especially in the past 5 years (2011, Page 135).

Supermarkets are changing the food supply chain, particularly for fresh fruits and vegetables, by demanding physically appealing, high-quality, and uniform goods throughout the year. This in turn is creating more farmer demand for modern inputs like fertilizer, pesticides, mechanization, and irrigation. In addition, it is creating more demand for food safety and for organic and natural foods, which require specialized management and specialized organic fertilizer and organic pesticides.

Another trend encouraged by allowing major Indian corporations and MNCs into the input industry is the development of rural business hubs and increased information and services for farmers in the countryside. A number of large agribusiness companies such as DSCL, ITC, Murugappa Group, Tata Chemicals, and Mahindra & Mahindra are developing rural stores that sell all types of agricultural inputs, including their brands, as well as being information centers with technicians or computer kiosks available to provide technical advice and answer questions. These services are intended to make inputs more easily available to farmers and to increase the productivity of these inputs by providing advice on how they can be used most effectively. In addition, these centers sell food and other consumer products (Reardon and Minten 2011). Agricultural processors such as ITC's tobacco business and some of the sugarcane companies offer more extensive input supply, credit, and information services to their contract growers—not only for their contract crops but also for the other crops that their contract farmers grow. In addition, there is increasing competition among seed companies to build larger and more knowledgeable dealer networks that can provide more and better information to farmers (Rajendran 2011).

The increased density of dealers and sources of information to farmers can break down the rural regional market power of traditional agricultural input dealers and provide farmers with greater bargaining power. As a result, markets should work better and farmers should get lower-priced inputs and sell their output for higher prices. In addition, farmers can obtain more information, which will make these inputs more productive. If the inputs are less expensive and more productive, farmers' demand for them will increase. The input supply firms will benefit from the increased demand for their products. In addition, if market efficiency is increased by reducing regional market power, the revenue that the firms receive for each sale could go up.

Continuing Government Constraints on Innovation and R&D

Despite strengthening of IPRs, growth of public research, and the changes in industrial policy shown in Table 5.2 that have supported impressive growth in private innovation and R&D, firms and industry associations interviewed still describe government policies and regulations as important constraints that fall into four categories: (1) regulations on new technology, (2) price controls on new technology, (3) enforcement of IPRs, and (4) availability of scientists.

New products in almost all agricultural input industries face some type of regulation to ensure safety for consumers, farmers, and the environment, and to ensure they actually improve farmer well-being. The seed, biotech, and fertilizer industries in particular expressed frustration with regulations for new technology approval. Bt cotton was the first genetically modified (GM) crop approved for planting in India. The approval process was took 6 years and cost \$1.2 million (Pray et al. 2006). The first GM food crop put forward for approval was hybrid mustard, but Bayer CropScience gave up after 10 years of trying to provide regulators with sufficient biosafety data (Pray et al. 2006). Recently, all regulatory authorities approved Bt eggplant, but the Ministry of the Environment vetoed the approval in response to consumer concerns about health and environmental impacts of genetically modified organisms (GMOs)

and lobbying by groups such as Greenpeace. It is not clear whether any GM food crop will be approved for cultivation in India.

Although the fertilizer industry does not face the problem of never having its new products approved, the approval process is time consuming and expensive, taking at least three years of efficacy testing for both new products and combinations of previously approved products. Once a product is approved, companies must lobby many more years for their fertilizers to be included on the list of government-approved and -subsidized fertilizers. In 2009, the government provided subsidies for only 18 of the 90 types of fertilizers that are approved for used by farmers. Since subsidies support 60 percent of the fertilizer cost, new products are not competitive unless they are subsidized. This delays their use for several more years.

Companies also cite price controls as barriers to innovation. Until recently, fertilizer companies were not allowed to raise prices for innovative products or for improvements in current products such as adding minor nutrients to bulk fertilizers. Around 2005, the Fertilizer Authority of India began allowing firms to increase prices by 5 to 10 percent if their urea products were fortified with boron or other minor nutrients.

The seed industry also faces price controls on innovations. In 2006, the government of Andhra Pradesh forced seed companies to reduce the prices of Bt cotton seed by two-thirds and royalties to nearly nothing. Most other important cotton-producing states followed Andhra's lead. Farmers welcomed this move because they were able to obtain less expensive Bt cotton seed, but the profits of both the companies that licensed the Bt genes to seed companies and the seed companies themselves were drastically reduced (Pray and Nagarajan 2011). Several companies interviewed stated that price controls reduced their interest in bringing new GM traits into India or in conducting research to develop traits that fit specific needs of Indian farmers. In addition, they expressed concern that price controls could spread to proprietary hybrid maize and hybrid rice cultivars. At least one small Indian biotech company, Metahelix, was unable to market its Bt cotton seed because investors were unwilling to support technology scale-up when seed prices were so low (Koshy 2010).

In the area of IPR, companies are mainly concerned with how courts enforce patent and PVP laws. In addition, international pesticide companies that have invented most active ingredients would like to keep the data in the regulatory dossier of each pesticide proprietary so that Indian companies that want to produce active ingredients no longer protected by patents in the United States and Europe must either license the data or redo regulatory testing required of new pesticides. International firms argue this would provide an incentive for them to commercialize older, off-patent products that would be novel and useful in India but are not patentable in India. Indian firms argue that making such data available would reduce the cost of bringing products to market. More research is needed to assess which data policy would give farmers more access to more effective and safer pesticides.

Medium-sized Indian companies complain of lack of access to proprietary GM traits primarily controlled by a few multinationals even when companies are willing to pay for access. What is not clear about this issue is whether firms that own the traits are unwilling to sell to the Indian companies because the large biotech firms have licensing agreements with everybody but the Chinese, whether the Indian companies are just not willing to pay the market price for these traits, or whether the foreign firms fear that Indian patents and enforcement are not sufficiently strong to enable the Indian companies to profit from the technology and thereby be able to pay the royalties they offer.

The final constraint to R&D and innovation is availability of well-trained, experienced scientists. For example, several seed companies said that the plant breeders being produced by most SAUs were not ready for careers in private plant breeding because they do not get any practical experience doing plant breeding while they are graduate students. Only a few SAUs produced high-quality PhDs that the seed companies were willing to hire. Several firms mentioned that the ability of the fresh PhDs from SAUs who had the capacity to conduct research was declining and that the graduates that they hire require more training before they can be useful members of their research teams. This sentiment is also expressed in recent articles and books (Challa, Joshi, and Tomboli 2011).

6. THE FUTURE: LESSONS, CHANGING AGRIBUSINESS, AND POLICY IMPLICATIONS

Lessons

This research shows that agricultural innovations in India have dramatically increased since the 1980s. Quantitative data show that between the 1990s and first decade of this century, the number of new seed cultivars registered in maize, wheat, and rice grew by at least 60 percent and probably doubled if private hybrids that were not registered are taken into account. The number of pearl millet, sorghum, and cotton varieties that were registered grew slowly, but when unregistered private hybrids are added in, the number of cotton cultivars grew much faster than that—at least tripling during this period. Biotech innovations went from zero in the 1990s to 5 GM traits in hundreds of cotton cultivars by 2008. Pesticide registrations went from 174 in the early 1990s to 228 by the most recent decade. Qualitative evidence suggests similar growth in innovations in the agricultural machinery, veterinary medicine, and agricultural processing industries. Indian agribusiness laboratories and experiment stations account for much of this growth although the public sector still dominates innovation in plant varieties of important crops such as rice and wheat. Foreign companies account for most biotech traits and most new active ingredients used in pesticides.

Private investment in agricultural research grew from \$54 million in 1994/95 to \$250 million in 2008/09 (in 2005 dollars), suggesting that private-sector innovation will accelerate in the future as this research turns out technologies for farmers. Growth in private R&D was particularly dramatic in the seed and plant biotech industry, which grew more than tenfold between the mid-1990s and 2009. There was also very rapid growth in agricultural machinery, animal health, sugar, and biofuel. Pesticides; food, beverages, and plantations; and animal breeding and feed grew less rapidly—*only* doubling their real R&D. R&D by the fertilizer industry also grew especially slowly. Multinational corporations made important contributions to the expansion of research in India in the seed, biotech, pesticide, agricultural machinery, and processing industries.

Private research and innovation have had an important impact on agricultural productivity in India and promise to have more impact in the future. Our research and studies by other scholars have shown that private hybrid cotton, hybrid rice, hybrid maize, hybrid pearl millet, and hybrid sorghum increase yields over public-sector hybrids, varieties, and landraces. Private innovation and research has also helped pull people out of poverty by providing more rural employment and increasing production of small farmers in some of the poorest regions of India—the semiarid tropics of central India and the rainfed rice regions of eastern India. Research and innovation by private industry led to the boom in cotton exports and to rapid increases in exports of generic pesticides and agricultural machinery. Technologies such as hybrid crops or tractors use resources such as fertilizer and fuel, but at the same time some technology from the private sector conserves resources such as water and fertilizer through micro irrigation and *fertigation* (applying fertilizer in the irrigation water). Some innovations, such as pesticides, can harm the environment, but new innovations, such as extremely low-dose pesticides and safer pesticides, as well as biopesticides such as Bt cotton, reduce the use of chemical pesticides.

This dramatic growth in private-sector R&D and innovation appears to have five major causes:

1. **Market demand.** First, a major increase in demand for agricultural goods in India and around the globe has been reflected in higher prices for agricultural products and the modern agricultural inputs that agribusiness provides. Export markets for pesticides and agricultural machinery have stimulated R&D in those industries, and expansion of R&D for the agricultural input and food industries is also associated with market growth. Only two industries increased investments in R&D faster than their markets grew (seed and veterinary medicine) and only two had R&D that grew slower than their markets (fertilizer, and poultry breeding and feed).

2. **Policy liberalization.** The second factor in increased private research and innovation is liberalization of policies governing investment in agriculture and agribusiness by large Indian corporations, business houses, and foreign firms. Liberalization of import and export policies governing agricultural inputs and products also contributed to growth of innovation and R&D. Liberalization began gradually in the late 1980s and accelerated in the 1990s. The private sector responded with innovations from foreign and local research. Government-controlled industries such as the fertilizer industry were the least innovative, with very low research intensity. The private sector has also responded to the changes in government policy with institutional innovations such as globalization of Indian corporations, location in India of the global R&D labs of multinational corporations (MNCs), and development of supermarkets and rural business hubs.
3. **Advances in basic science and engineering.** The third factor that was particularly important for industries in which R&D growth was faster than sales growth (seed, biotech, and veterinary medicine) is advances in the basic sciences and engineering that form the basis for private technology development. Biological and information technology advances were particularly important in the seed, biotech, veterinary medicine, and pesticide industries. The growth of pharmaceutical research in India has had positive spillovers of biotech knowledge and research tools in the Indian seed and veterinary pharmaceutical industries. Contract research organizations originally devoted to pharmaceuticals are now conducting research for agribusiness, and pharmaceutical firms are investing directly in veterinary medicine. Information technology and the development of the Indian software industry have been important to research in all of these industries.
4. **Intellectual property rights.** The strengthening of intellectual property rights (IPRs) is probably not as important as the first three causes of growth, but it has provided greater incentives for innovation and encouraged growth of research in biotech and veterinary medicine. Key milestones were the 1999 amendment to the patent act to allow product patents for new chemicals, medicines, agricultural inputs, and biotechnology, and the resulting granting of patents, which started in 2005. These changes have been particularly important to MNCs based in the United States, Europe, and Japan, which have invested heavily in R&D in veterinary medicine, seeds and biotechnology, pesticides, and agricultural machinery in India.
5. **Government investment in research and education.** Finally, the Indian government's investment in agricultural research and higher education, along with research conducted within international agricultural research centers, provided the foundation for many developments and achievements in private R&D. The public research system produced the scientific advances companies used to develop their new commercial technologies and served as the training grounds for the scientists who moved into the private sector to manage private research labs and science-based agricultural input and food companies.

Policy Options

This study shows that government actions can influence amount and type of private-sector investment in research and innovation. If central and state governments in India wish to encourage more research investment, they can consider the following:

1. Continue policy liberalization in the agribusiness sector but ensure against market failures with policies that support competition and effective, efficient, and science-based environmental and safety regulations. Both central and state governments need to have clear, less time-consuming, and relatively inexpensive regulatory approval paths for new technologies such as fertilizers, biotech plants, and crop protection chemicals. These governments should also avoid counterproductive policies such as price controls on

innovations. For example, the state government price controls placed on Bt cotton, although they reduced prices for farmers, probably also reduced biotech research and led to the takeover of at least one innovative small Indian biotech firm by a large chemical company. Policy that ensures competition in agricultural input and output markets is very important, but price controls on innovations are a counterproductive way to enforce competition.

2. Invest in public research and higher education, and make scientists available to private research. The number of state agricultural universities (SAUs) and the students they produce have increased; however, the number of scientists at SAUs has declined, along with research funding per scientist (Jha and Kumar 2006; Ramaswamy and Selvaraj 2007). Drastic reforms and more resources are needed in graduate education and research at SAUs to train the young scientists that private firms are asking for. These reforms could include expanding government support for graduate education and research beyond Indian Council of Agricultural Research (ICAR) institutes and SAUs to nonagricultural institutes that have strong basic science programs. ICARs and SAUs should also re-examine research priorities to avoid duplicating research now conducted in the private sector and to concentrate on research for public goods. Where applied private research is strong, public research centers should shift their research focus to basic research that supports private applied research. At the same time, the private sector should contribute more financial and political support to public strategic research.
3. Strengthen IPRs to provide greater incentives for research and innovation. Patent laws and plant variety protection now in operation must be enforced by the courts and state governments. In addition, there may be possibilities of specific changes in the laws and regulations could encourage innovation. One example is the regulations protecting confidentiality of regulatory data on active ingredients of pesticides could encourage development of new pesticides. MNCs claim this change would encourage them to introduce pesticides too old to be patented but new and useful to India.
4. Carefully target subsidies, incubators, and tax breaks for innovation and research. These actions can stimulate private-sector innovation and R&D, but if not carefully targeted and structured may also dampen innovation. If subsidies are too large and continue for long periods, as they have in fertilizer, there is likely to be little innovation. A good example of a targeted subsidy is the agribusiness incubator of the International Crop Research Institute for the Semi-arid Tropics (ICRISAT), subsidized by city and state funds combined with the Indian government's Small Business Innovation Research Initiative grant program, which has launched new, science-based seed companies and new lines of business for seed, biopesticide, and biofuel firms. Subsidies and special export zones to develop agricultural products and inputs to compete in export markets may also be an effective use of public funds.
5. Encourage the growth of rural business hubs and supply chains established by supermarkets and the agricultural processing industry, which supply technology and market opportunities to poor farmers and job opportunities to landless laborers. Private innovation, research, and marketing of innovations can reduce poverty and improve the environment. Thus, government agencies should consider incentives for firms to develop technologies that improve health and the rural environment, such as subsidies for drip irrigation, vitamin-enriched tea, or the Bt technology that replaces dangerous insecticides.

APPENDIX: DATA SOURCES AND ASSUMPTIONS USED TO CALCULATE SALES, R&D EXPENDITURES, AND INNOVATIONS

When we initiated this project, we planned to use three major sources for data on R&D and innovations and for economic information about the individual firms, all of which we had used in past studies: Department of Science and Technology (DST) data, data on R&D and sales from the Center for Monitoring the Indian Economy (CMIE), and a survey of the firms in the Indian seed industry. The first and last sources of data were less successful this year than in the past, but much more data are now available from annual reports of individual companies in India.

For R&D data, we relied much more heavily than in the past on the audited annual reports of companies listed on the Indian stock exchanges, for several reasons: First, more agribusiness firms are listed on Indian stock markets and are therefore required to report R&D. Second, DST now only publishes R&D expenditure data, not the full reports on individual firms that contained data such as number and qualifications of scientists. Published R&D data from DST are limited because they are updated at best every three years, but often not for six years, and some do not change for a decade. Also, DST collects data only from firms that are recognized as R&D centers by the Department of Scientific and Industrial Research (DSIR), which leaves out new firms, small firms, and many multinationals.

The R&D data from annual reports were supplemented by data from CMIE on some firms that are not listed on the stock exchange and some publicly listed firms that did not have easily available annual reports. The annual report data were also supplemented by data from surveys in the seed industry and personal interviews of key companies and industry associations in other industries. For almost all the sectors, we gathered R&D expenses along with sales beginning in 2000 and going up to 2008 or 2009. We could not develop a continuous time series for all the sectors from 2000 to 2005, but it was possible for us to develop a time series of R&D and sales expenditures for all sectors from 2005 to 2008/09.

For the seed and biotechnology sector, we obtained R&D and sales information from 37 firms. We met with officials of the National Seed Association of India (NSAI), and they agreed to send out our questionnaire by email to all of the association's members. We received 6 questionnaires back from the members after several reminders. Then we started interviewing firms that were identified by NSAI officials as having R&D. We were able to interview 15 more firms, for a total of 21 firms that provided data through personal interviews or surveys. For 5 more firms that primarily focus on seeds and biotechnology, we obtained R&D and sales data directly from their annual reports (Advanta and Kaveri) or the CMIE database (Pallishree, Green Gold, and Mahyco). Finally, 7 publicly listed firms (Camson Bio Technologies, Shriram Bioseed, Monsanto, Basant Agro Tech, Syngenta, Bayer CropScience, and Zuari Seeds) are all part of larger business conglomerates that have both seed and nonagricultural lines of businesses, with annual reports that report total R&D, not just seed and biotech R&D. To obtain estimates of their seed R&D, we calculated the share of sales from the seed segment as a percent of their total sales and then multiplied this percentage by the total R&D to get the estimated R&D for the seed and biotech sectors. Finally, for 4 firms (Vibha, Metahelix, Devgen, and Indo-American Hybrid Seeds) that we knew had R&D but for which we had no R&D data, we estimated their R&D based on the average R&D research intensity of the seed sector multiplied by the firm's seed sales. We then checked our company R&D estimates against the most recent DSIR data for 25 firms that DSIR does list, to make sure that our estimates were reasonable.

In the case of the agricultural machinery sector, most of large tractor and irrigation equipment firms are listed on the stock exchange, and their annual reports publish total R&D expenses. All of the 8 major machinery firms engaged in the manufacture of tractors and other agricultural equipment are diversified businesses with sales of other machinery, such as automobiles, irrigation equipment, road equipment, and other machines. The firms report tractor and other farm equipment sales of between 45 and 90 percent of their total annual sales. Some of these firms reported their R&D expenses on agricultural machinery (Mahindra, Escorts, Jain Irrigation, Punjab Tractors, and VST Tillers); for others, which only reported their total R&D, we derived agricultural machinery R&D using the proportion of

their sales in agricultural machinery (International Tractors, TAFE, KSB Pumps). To include the large international firms for which no R&D data were available (John Deere, CN Holland, and Same Deutz-Fahr) we used the average Indian tractor machinery industry R&D intensity, which was 1.3 percent, and multiplied that by their sales.

For the fertilizer, pesticide, and food processing industries, most of the data were collected from company annual reports, since most companies are publicly listed in stock exchanges. This was supplemented with the CMIE database for firms. For the companies with diversified lines of business—food, agricultural, and nonagricultural—we calculated R&D expenses by using the shares of sales in fertilizer or food to apportion the total R&D expenses of the conglomerate. For example, only 56 percent of Tata Chemicals' total sales turnover is from fertilizers (urea and mixed fertilizers)—hence 56 percent of its R&D was apportioned to fertilizer R&D. Similarly, Coromandel International has 65 percent of its sales revenue from fertilizers and specialty nutrients, and the rest from agrochemical sales. Other firms reported research intensity for the entire firm and sales of fertilizer or food. For example, the annual reports of Mangalore Chemicals and Zuari Chemicals both reported that R&D was 0.2 percent of net sales of all their businesses. We calculated their R&D by multiplying their fertilizer sales by 0.002.

In the case of pesticide industries, again we gathered most of the information from the R&D expenses reported in annual reports and from CMIE. For MNCs such as BASF, Bayer, and Syngenta, which are involved not only in agrochemicals but in chemicals in general, we used the percent share of sales on agrochemicals as reported in their annual reports to apportion their total R&D expenditures.

By comparing our list of firms with the list of firms included in the DSIR data, we are confident that we have included all of the major firms that conduct R&D in India except a few of the multinational firms. DSIR's annual reports, which are also missing many of the multinationals with R&D in India, provide data on the R&D expenditure of about 72 private agribusiness firms for at least one year after 2000. We identified and collected data from 99 firms with some R&D.

Table A.1 compares our study's coverage of agribusiness in different sectors with the total industries' sizes. Column 2 has the estimates of industry size from industry sources, and column 3 has the sales of the firms that are in our sample. In sectors such as seed/biotech and pesticides, our firms made most of the sales. For the agricultural machinery sector, especially for tractors and farm equipment, our estimates cover nearly 90 percent of the industry estimates (Mahindra & Mahindra 2010). But the industry estimates also includes sales of threshers, harvesters, small equipment (unorganized, small scale), agricultural pumps, irrigation equipment, and post-harvest equipment. Companies that sell these products produce and sell a lot of equipment but do very little formal research.

We have R&D and sales data on all the major Indian producers of fertilizer. They all have R&D units that are approved by DSIR. These firms account for 90 percent of the fertilizer sold in India (Coromandel 2010). The poultry and feed sector is dominated by a few firms—as mentioned above, Venkateshwara has 80 percent of the broiler market and 60 percent of the layer market and also sells feed and food supplements. Likewise, Godrej is the major producer of manufactured animal feed and supplements. The sugar industry used to be dominated by farmer and government cooperatives, but in recent years private firms have started investing in the sector. We have included all the major private sugar firms in India.¹⁶ In the case of the food processing, beverage, and tobacco sector,¹⁷ we were able to compile information from all of the market leaders, which account for about half of sales.

¹⁶ The firms included in our sample are Renuka, EID Parry, Godavari, KCP, Andhra, Dhampur, Sakthi, and DCM Shriram.

¹⁷ The firms included in our sample are Nestlé, Hindustan Unilever, Britannia, GlaxoSmithKline, Dabur, ITC, Tata Global Beverages, and Goodricke.

Table A.1—Survey coverage and market estimates

S No.	Sector	Market size 2009 (in millions of 2005 US\$)		# of firms covered in our study
		Industrial estimates ^a	Authors' study estimates	
1	Seeds and biotechnology	1,300–1,500	1,286	37
2	Pesticides	3,600	3,206	20
3	Fertilizers	-	13,732	11 private, 6 public
4	Agricultural machinery	7,680	2,200	11 (9 tractors + 1 irrigation + 1 pump)
5	Poultry and feeds	2,500–3,000	1,010	3
6	Animal health	325	114	6
7	Food, beverages, processing, and plantations	9,500–10,000	5,650	8
8	Sugar	-	1,560	8
9	Biofertilizers and biopesticides	~250	42	6

Sources: ^a Industry estimates were obtained from the following sources:

- Seeds and biotechnology: International Seed Federation (ISF), August 2010
- Pesticides: Pesticide Manufacturers and Formulators Association of India (PMFAI), June 2010
- Fertilizers: The Fertilizer Association of India provides data only on quantities of fertilizer sold, and because of the huge subsidies involved it is difficult to calculate the market size based on this.
- Agricultural Machinery: Projected by Zinnov Research 2008 and FICCI 2008 with 5 percent annual growth rate.
- Poultry and feeds: Venkateshwara Annual Report 2009/10
- Animal health: Dr. P. P. Rao, CEO, Novartis South Asia, September 2009
- Food, beverages, processing, and plantations: India Brand Equity Foundation (IBEF) 2010 for food processing; Tea Board of India 2009 for plantations
- Sugar: We were not able to find an estimate of the total value of sugar produced.
- Biofertilizers and biopesticides: EID Parry (I) Ltd Annual Report 2009

Data Sources and Assumptions on the Measurement of Innovations

We measured innovations in different ways depending on the availability of data in each sector. The innovation indicators included patent counts, plant variety certificates, cultivars developed, number of active ingredients of pesticides registered, and unique inventions or innovations specific to certain sectors. In addition, we collected supplementary data through interviews, articles in the press, and surveys of key firms.

We measured innovations in the seed and biotech industry in five ways: first, by a count of number of varieties registered with the government for cultivation; second, hybrids and varieties reported by the firms;¹⁸ third, plant variety certificates issued by the plant variety authority of India; fourth, patents obtained by individual firms for *new inventions*, especially for biotech-based events, from the Patent Authority of India website; and fifth, varieties derived out of genetic modification. The latter holds true only for cotton cultivars, which are the only genetically modified crop approved by the Indian government and extensively used by private firms.

In the case of the pesticide industry, we measured innovations in two ways. Since India did not have product patents to protect new pesticides until 2005, most of the innovations in the pesticide industry were either imported active ingredients, new formulations of imported active ingredients, or new processes for producing foreign pesticides. So we used the number of active ingredients and formulations registered by the government since the introduction of the insecticides act in the late 1960s. The second measure of innovations was the number of pesticide-related patents—process patents before 2005 and

¹⁸ All government institutes had to register their new cultivars with the government, but private firms could until recently sell their cultivars as truthfully labeled. The number of these cultivars can be obtained only from the companies, most easily from their websites. Note that private firms, through their websites, advertise their most recent and popular varieties; hence the total count we have given here does not represent their total research products.

product patents from 2005 onward—from the Patent Authority of India. Our procedure for identifying patents in this industry was to search the online database of the Patent Authority by the company names of international and national research companies and then to search by keywords such as *insecticides*, *pesticides*, and so on. We then read the titles and abstracts of the selected patents to ensure that they were pesticide-related. We tried to search the Patent Authority’s website by international patent categories (IPCs). The website says that it is possible, but we were not able to do so.

Our only quantitative indicator of innovations in other industries was patents. We used the same procedure as described in the previous paragraph. In the fertilizer industry, we ran into special difficulties. A few foreign diversified chemical firms, such as Bayer and BASF, had some patents that were clearly in the fertilizer category. However, from the online patent database of the Patent Authority of India, it was difficult to distinguish the fertilizer chemicals from the general chemicals. So the patent numbers here include only “most popular forms of straight and mixed fertilizers” used in agricultural operations.

For other sectors, such as agricultural machinery and poultry, we used patents as a measure of innovation. In the case of food processing, beverages, and animal health, we could not identify the patents in these sectors, since most of the patents were for chemical processes and we did not have the expertise to know which industry these processes were applicable to.

We take some comfort that this ad hoc procedure for identifying patents worked fairly well (except in the cases of the chemicals for fertilizers and of the processing industries), because our patent numbers for the period before 2005 match fairly closely the agricultural patent counts of Mittal and Singh (2006).

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