India

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Issues in Private Agricultural Research

The demand for new agricultural technology is growing in India. The population continues to rapidly grow, and per capita income growth has grown even more rapidly, pushing up the demand for food. In India, the land frontier is closed, irrigation is becoming more expensive, and urban growth is pulling people out of agriculture, which leaves research as the remaining major source of growth. Wealthier consumers want higher quality food and less environmental pollution, which also increases the demands on research.

Since 1985, public sector investment in agricultural research in India has continued to grow, but at a slower rate. In many of the Indian Council of Agricultural Research (ICAR) institutes, an acute shortage of operating funds has reduced scientists' productivity. In some of the state agricultural universities, the funding crunch has been even more acute. For example, the state government of Maharashtra has been gradually reducing funding every year to the state universities. In addition, the international agricultural research centers that contributed to India's growth in earlier years have had their budgets reduced considerably.[1] (Desai, 1997; and Pal, Singh, and Jha, 1997)

The result of the shortages of funds in some states and ICAR institutes and the weakness of public institutions for distributing public technology is that new public technology has spread very slowly to farmers. Consequently, farmers have begun planting older varieties. For example, wheat varieties in India have an average age of 9 years, versus 3 years in the United Kingdom (Witcombe, Virk, and Farrington, 1998).

The private sector has held the promise of alleviating some of these problems. Private firms began funding more agricultural research in Asia and the rest of the world. In addition, private firms have been conducting certain activities, such as commercializing and marketing new varieties more efficiently than the public sector. Thus, private research has presented an opportunity for more growth for Asian agriculture. It may have been encouraged through policy changes and public research that are more responsive to private firms' needs.

Since 1985, major international trends have reshaped world agricultural input and food industries to provide more technology for developing countries through the private sector. Barriers to international trade and foreign direct investment fell. Breakthroughs in biological sciences and favorable business conditions led to a major consolidation of biotech, seed, pesticide, veterinary, and human pharmaceutical firms into a few major life-science companies. These same firms began linking with the food industry through alliances, mergers, and acquisitions. These companies have made the latest biotechnology available to developing countries with large markets and an attractive business climate.

The increasing prominence of these life-science companies is, however, raising some questions: Will the technology they provide really be appropriate for India's small farmers? Will they force Indian farmers to use seeds with terminator genes, which would prevent farmers from keeping their own seed? Will they force farmers to use certain herbicides, which fit genetically engineered crops? Will they force the price

[1]According to some estimates, the agriculture-related R&D and education expenditures (in real terms) funded by ICAR and state governments grew at the rate of about 5.7 percent during 1974-83. This rate of growth declined to 4.9 percent during 1984-93 (see, Pal, Singh, and Jha, 1997). Presumably, if agriculture education-related expenditure is excluded, the decline would have been sharper.

of seed, pesticides, or machines to increase because of their market power? Will they patent products that farmers have been using for decades and restrict their use to farmers who pay high prices? Will Indian scientists be unable to access new genes and constructs developed in Organization for Economic Co-operation and Development countries that would be useful to Indian farmers?

To fulfill the growing demand for food, fiber, and beverages, India would benefit from the private sector's playing a larger role. The international private sector appears to be ready to play a larger role, and Indian firms are increasing their investment in agricultural research. Local and international firms could fund more research and conduct research and technology transfer activities more efficiently than the public sector. The questions that this chapter answers are: What role is private research playing? What role should the private sector play? What policy instruments are available for policymakers to influence the amount and direction of private research? Finally, what policies would be appropriate for India?

Agricultural Development

The major impetus to Indian agriculture was given during the late 1960s and early 1970s, with the advent of the so-called "green revolution technology." Agricultural production in India has rapidly grown since then.

The index of agricultural production rose from about 86 in 1970-71 to 176 in 1996-97. Since the last major drought in 1987-88, agricultural growth has been good, despite marginal setbacks in 1991-92 and 1995-96. Given the limits to area expansion, the increased production has essentially been the result of rising land productivity. These higher yields in turn were achieved by the use of modern agricultural inputs, including irrigation, chemical fertilizers, as well as improved and high-yielding seeds and pesticides.

About 80 million hectares of cropped area were irrigated in the 1990s. While the area under irrigation consistently increased over the years, only about 38 percent of the gross cropped area had access to irrigation in the 1990s (Government of India, 1998, pp. 92-93). The dependence of Indian agriculture on rainfall continues to be significant. The use of high-yielding varieties (HYVs) rapidly grew during the 1970s and 1980s; the rates of growth of HYV use seem to have declined in the 1990s. Along with the use of HYV seeds, the production and distribution of certified and quality seeds and the consumption of chemical fertilizers has also increased (table B-1). The index of fertilizer consumption rose from about 40 in 1970-71 to 259 in 1996-97. Fertilizer consumption per hectare rose from about 13 kilograms to 77 kilograms (Government of India, 1998, pp. 97-98).

About 56,000 tons of pesticides (technical grade material) was consumed in 1996-97. This is a marked increase from 24,000 tons in 1970-71 (Government of India, 1998, pp. 97-98). As table B-1 shows, the 1990s experienced some deceleration in the quantity of pesticides used; the index declined from 167 in 1990-91 to 125 in 1996-97. These indices are based on official statistics. Estimates provided by industry sources suggest an increase in the consumption of agro-chemicals even during the 1990s (Unni, 1997, table 6, p. 559). The pesticide market in India was dominated by insecticides (76 percent); the share of herbicides (13 percent) and fungicides (11 percent) in the agro-chemical market was rather small (Unni, 1997, p. 560).

Tractor production in India has been rising since the early 1970s. More than 191,300 tractors were manufactured in 1995-96, while the reported production in 1990-91 was only about 138,500. No reliable estimates are available for production of diesel engines and electric motors for irrigation. According to industry sources, approximately 500,000 to 600,000 diesel engines were produced for agriculture, and the demand for such engines rose by 5 percent per year during the 1980s and early 1990s (Basant, 1997).

Recent changes in India's cropping patterns and trends in capital formation also need to be highlighted. Changes in cropping patterns can contribute to increases in agricultural yields per hectare if the area shifts from low-yielding to high-yielding crops. Such changes also have implications for the demand patterns of agricultural inputs as the use intensity of these inputs varies significantly across crops. The rate and nature of capital formation in agriculture also impinges on the rate of agricultural growth.

The share of food grains in gross cropped area declined from about 75 percent in 1971-72 to about 67 percent in 1994-95. Within the food grains category, the percentage of area under coarse cereals (maize, sorghum, and millets) declined from 28 percent to 17 percent. The share of area under pulses also marginally declined. While rice retained its share of 23 percent,

Table B-1—Trends in agricultural growth, India, 1970-97

Item	1970-71	1980-81	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97
Agricultural production (index 1982 = 100)	85.9	102.1	148.4	145.5	151.5	157.3	165.2	160.7	175.7
Area under principal crops (index)	96.3	99.7	105.2	102.6	103.1	103.8	104.2	103.8	106.8
Yield of principal crops (index 1981-82 = 100)	92.6	102.9	133.1	131.1	137.0	140.7	145.5	139.9	149.0
Irrigated area (index 1981-82 = 100)	74.3	96.8	121.5	127.8	129.9	132.8	137.4	140.9	NA
Area under HYV (index 1981-82 = 100)	35.7	100.0	150.1	150.1	151.7	155.4	164.5	167.3	NA
Fertilizer consumption (NPK, index 1980-81 = 100)[1]	39.5	100.0 (31.9)	227.4 (67.5)	230.7 (69.8)	220.4 (65.5)	224.2 (66.7)	245.9 (72.6)	251.6	259.4
Pesticides consumption (NPK, index 1980-81 = 100)	54.0	100.0	166.7	160.2	157.3	141.6	136.4	136.2	124.7
Tractor production (index 1981-82 = 100)	21.1	71.7	131.2	159.7	159.4	146.4	172.9	202.8	NA
Gross capital formation in agriculture, (index 1981-82 = 100)[2]	61.2 (71.4)	103.0 (61.3)	102.0 (74.9)	105.0 (78.8)	119.3 (80.3)	111.7 (77.1)	138.9 (79.0)	154.6 (81.8)	155.4 (83.8)
Production of breeder seeds (1,000 metric tons)		.5	3.4	3.5	3.6	3.7	4.0	4.3	4.5
Production of foundation seeds (1,000 metric tons)			34.0	38.0	39.0	41.0	47.0	48.0	57.0
Distribution of certified/quality seeds (1,000 metric tons)		250.0	571.0	575.0	603.0	622.0	659.0	699.0	700.0

NA = Not available.
[1]Figures in parentheses indicate consumption of fertilizer per hectare of gross cropped area (kilograms per hectare).
[2]Figures in parentheses indicate the share of the private sector in the gross capital formation in agriculture.
Source: Government of India, 1998.

the share of wheat increased from 11 percent to 14 percent. Oilseeds were the major gainers among nonfood grains; their share in cropped area increased from 9 percent to about 15 percent. Cotton, which suffered a bit in the 1980s, improved its share in the 1990s (Sawant, 1997, table 2, p. 235; and Government of India, 1998, p. 94). Crop pattern shifts in favor of superior cereals and nonfood grain crops, such as oilseeds, can *ceteris paribus* increase the demand for agricultural inputs as these crops consume relatively more inputs per unit of land. For example, most pesticides are used on cotton.

Despite the decent performance of Indian agriculture, which augurs well for the agriculture-related industry, a few disconcerting aspects need to be emphasized (see Desai, 1997 for details):

- The annual rate of growth of agricultural production (food grains and nonfood grains) was lower in the 1990s, than in the late 1980s; and
- The annual rate of growth of input use (high-yielding varieties, fertilizer, irrigation, and power) was also lower in the 1990s than in the late 1980s.

This downturn is partly due to the relatively slow growth of real plan expenditure on agriculture since the early 1990s (Desai, 1997). Estimates suggest that, after peaking in 1978-79, (52 billion rupees (Re) at 1980-81 prices), gross capital formation in agriculture declined afterwards. India's agricultural economics improved again in the 1990s, with investment going up to Re 70 billion in 1996-97 (1980-81 prices). The stagnation of the 1980s, which continued into the early 1990s, was essentially due to the decline in public sector gross capital formation. Private investment did not rise fast enough to compensate for the relative decline in state-sponsored investment. The 1990s saw a reversal of this trend with private investment rapidly rising (see Government of India, 1998, table 15, p. 8 for some estimates). In 1996-97, as much as 84 percent of the total investment came from the private sector (see table B-1).

One can view these trends in two ways. It can be argued that public investment is gradually being replaced by private investment, and one need not be concerned about the decline in the state's role in agriculture-related investment. The other view could be that given the complementarities between public and private investments (especially in irrigation), private investment would have risen even faster if the public investments had continued to grow rapidly. In fact, the decline in the rate of growth of fertilizer use, irrigation, and high-yielding varieties could have been arrested, given the complementarities of use in these inputs and the importance of state support in expanding the use of high-yielding varieties (extension), irrigation (investment), and fertilizer (subsidy). Limited availability of concessional agricultural credit could have also contributed to this process.[2]

Overall, the picture that emerges is that agriculture's growth since the beginning of the 1990s has been good enough to support the growth of agriculture-related businesses. However, there are some indications that the growth performance (and, therefore, the market for agricultural inputs, etc.) could have been better if public investment in agriculture had not declined in recent years.

Private R&D and Technology Transfer

Research: Levels, Trends, and Goals

Most agricultural research conducted in India is very applied. The types of research conducted by private firms, the amount of expenditure, and some effects of this research are shown in table B-2. Estimates of levels and growth of private research and development (R&D) expenditures by different industries (based primarily on the Department of Science and Technology (DST) data to obtain comparability in 1984-95) are presented in table B-3. These estimates are supplemented by some firm-level estimates for different agricultural subsectors from the Centre for Monitoring Indian Economy (CMIE, 1998). These estimates are reported in tables B-4 and B-5.

[2] See Desai (1997) for the role of credit in the recent experience of agricultural growth in India.

In the 1990s, the private sector spent between $39 and $43 million on food and agricultural research in India.[3] The second column of table B-2 shows our estimates of R&D expenditures based on interviews, questionnaires, and individual firm data from DST. In industries where interview data were insufficient, industry-level data for 1994-95 from DST were used. We did not include any expenditure from government-owned firms in constructing this table. The largest research expenditure was by the food industry (about $13 million), followed by pesticides ($7 million to $11 million); the seed industry and agricultural machinery were both $5 million to $6 million. The poultry, fertilizer, and feed industries made smaller investments in R&D.

Private research in India has grown rapidly since 1985. Between 1985 and 1995 (the last year for which official figures are available), private research expenditures at least doubled. This is faster than public agricultural R&D, which grew 69 percent. Table B-3 shows growth in food and agricultural research by private firms and government-owned corporations that are registered Science and Technology Firms by the DST. Table B-3 also provides data from the seed industry from a survey by Pray and Kelley (1998). The DST data underestimates growth—particularly in industries with many new entrants—because it takes a number of years for new firms to get approval. In addition, some firms do not get approval because there is little benefit from this designation—some tax reductions—and a substantial cost in paperwork. In the Pray and Kelley (1998) survey of the Indian seed industry, firms not approved by DST conducted 24 percent of the research of the firms surveyed. Similarly, the DST estimates of private R&D for firms producing chemical fertilizers and tractors (tables B-2 and B-3) are much lower than the estimates derived from CMIE data (tables B-4 and B-5): $2.2 million versus $7.6 million for fertilizers and $5.6 million versus $19.9

[3] The data compiled by these sources are not strictly comparable. For example, the estimates of R&D expenditures compiled by the DST are based on the data made available by firms having DST-recognized R&D units in different industry groups. Not all recognized firms provide this information every year and not all firms doing R&D are recognized by DST. Consequently, these data usually underestimate the R&D in the sector. The CMIE estimates are based on data compiled from company annual reports. All companies listed in the Mumbai Stock Exchange are covered. Here again, not all firms' annual reports are available to CMIE every year. At times, firms do not report R&D expenditures in their annual reports. By and large, for the organized sector, CMIE estimates are more robust than DST estimates.

Table B-2—Private research objectives, expenditures, and effect by industry, India, 1996-97

Industry	Research objectives	Amount of research	Effect of research
Seed---field crops	Increase yields, pest resistance and quality of maize, sunflower, PM, sorghum, cotton, rice, rape/mustard.	More than $5 million (survey)[1]	Higher yields of maize, sunflower, PM, sorghum, and cotton.
Seed---vegetables	Increase yields, pest resistance and quality of tomato, cabbage, okra, hot pepper.	$1 million (survey)	Higher yields of tomatoes.
Pesticides	Increase yields and quality of crop, reduce farmers' costs of production, improve human and environmental safety. New processes for active ingredients. Combinations of pesticides. Integrated pest management.	$7 million-$11 million (survey)	Reduced costs through herbicides and improved environment through safer products. Indian production of foreign technical materials.
Fertilizers	Better agronomic practices for farmers and lower costs of fertilizer production.	$2.2 million (DST)[2]	
Agricultural machinery	Increase power of tractors keeping cost low. Adjust gears, brakes for hauling on road.	$5.6 million (DST)	
Poultry breeding	Breeds adapted to Indian conditions.	$3.2 million (survey)	Increased FCR and eggs for each bird.
Dairy research	Buffalo & cow breeding and management.	$1.7 million (DST)	
Vaccines, veterinary pharmaceuticals	Produce vaccines for new diseases and testing foreign products.	$2.72 million (DST)	Vaccine for new type of hepatitis, approval of veterinary, pharmaceuticals.
Feed	New ingredients, reduce anti-nutritional factors, and identify useful additives.	$300,000 (survey)	
Food processing sugar and oilseed		$13.0 million (DST)	

[1] "(survey)" indicates data from the authors' survey.
[2] “DST” indicates data from the Department of Science and Technology.

Sources: Survey by authors and Department of Science and Technology. Research and Development Statistics, 1994-95. New Delhi, 1997.

million for tractor firms. The higher estimates from CMIE are largely due to CMIE’s including all R&D, chemicals, fertilizers, trucks, and machines of tractor firms.

The most rapid growth took place in food processing, followed by the seed industry, pharmaceuticals, and the sugar industry. Pesticides research almost doubled during 1985-95. Actually, pesticide research probably grew even more rapidly, but several firms that increased their research, such as Monsanto and DuPont, were not registered as research companies with DST. Tractor research also substantially increased: it was 75 percent higher in 1995 than in 1985, then declined the next 2 years. The industry in which R&D declined, according to DST data, was fertilizers. A comparison of tables B-3 and B-4 suggests that the decline was particularly sharp, but given the alternate estimates from CMIE, this decline may be unrealistic. For pesticides, however, the CMIE and our survey estimates are about the same.

Seed Sector

India has a large number of seed firms, but only a few have large operations. About half of seed sales are by public corporations. Since the mid-1980s, large Indian firms and multinationals have entered the Indian seed industry. According to Pray and Kelley (1998), firms with some foreign ownership in 1995 accounted for

Table B-3—Research expenditures by private firms and state-owned enterprises, India, 1984-95

Industry	Research expenditures (1995 dollars) 1984-85	1994-95	SOE in 1994-95	Increase
	----Millions----		*----Percent----*	
Seeds	1.33	4.93	0	271
Agricultural machinery	3.70	6.48	13	75
Fertilizers	6.80	6.65	67	-2
Pesticides	9.00	17.02	15	89
Veterinary pharmaceuticals	.90	2.72	5	203
Sugar industry	.90	2.49	1	177
Food processing	1.27	10.33	1	712
Vegetable oil processing	.07	.14	0	99
Total	23.97	50.75	16	112
Public research	206.22	347.90		69

Notes: Pesticides are calculated as 30 percent of chemicals (other than fertilizer) research, based on assessments of each chemical firm's research by Dr. B.P. Srivastava, former head of research at Pesticides India and Union Carbide India. Veterinary pharmaceuticals are calculated as 5 percent of pharmaceutical research. Exchange rate is Re31.4 = $1.00.

Sources: Seed expenditures, Pray and Kelley. 1998 and the Department of Science and Technology.

about one-third of the private half of the seed market, and large Indian firms accounted for 23 percent.

Most seed firms conduct breeding research to develop new hybrids based on inbred lines that have been developed in the public sector, international agricultural research centers, or parent companies. A few large programs conduct research to develop their own inbred lines.

At least three seed companies have major biotechnology labs in India conducting basic biological research. One lab spent about $700,000 in 1997, had 11 Ph.Ds out of a total of 34 scientists, and had collaborative research with some top university biotech labs in the United States. Two of these labs work on hybrid rice issues—understanding hybridization or identifying markers that can screen for grain quality. These labs are also transforming cotton and vegetables with bacillus thuringiensis and other genes. A number of companies test transgenic varieties developed either from their own programs or from foreign programs. The Department of Biotechnology, which must approve any field trials of genetically modified organisms, reports that there have been 28 field trials of transgenic crops since 1996, of which 95 percent were by private firms. These trials have been for cotton, mustard, tomato, eggplant, and cabbage. Soybean trials had been approved but were not yet in the field, and trials for potatoes and tobacco were in progress.

Animal Feed

There are very few corporate players in the animal feed industry; the bulk of animal feed is producted in the small or cooperative sector. Besides, many farmers prepare their own animal feed. The share of the corporate sector in the animal feed industry is near 33 percent and has been rising. This market has about 40 relatively large firms; the others are small. The total estimated market size was Re 23 billion in 1995-96. We have R&D data for only three major firms (table B-4).

Godrej Agrovet and Hindustan Lever emerged as two significant corporate players in this market. Hindustan Lever increased its market share by acquiring some firms and expanding capacities. While the R&D to sales ratio for Hindustan Lever declined somewhat during the 1990s, the R&D intensity increased for the other listed companies (table B-4). Unlike the other two firms, Hindustan Lever is a large diversified firm of which their R&D estimates include expenditures on activities other than animal feed. The research arms of animal feed firms essentially test new ingredients, study ways to reduce anti-nutritional factors, and test new additives provided by other firms.

Table B-4—Market shares and R&D expenditures of major firms: Various product groups, India, 1991-92 and 1996-97

Product	Company	Market share		R&D expenditures in 1996-97 (Re million)			R&D & sales	
		1991-92	1996-97	Capital	1998	Total	1991-92	1996-97
Animal feed	Godrej Agrovet, Ltd.	NA	8.21	0.5	3.4	3.9	Negligible[1] (<0.01)	.18
	Hindustan Lever, Ltd.	1.04	10.29	120.9	227.6	348.5	.66	.45
	Western Hatcheries	.04	2.34	0	1.6	1.6	.08[2]	.10
Flour milling	NEPC Agro Foods	NA	2.32	0	.1	.1	.31[3]	Negligible (<0.01)
	DCW Home Products	NA	.37	0	0	0	.22[2]	0[4]
Flowers	Century Textiles and Industries, Ltd.	NA	12.97	.1	25.9	26.0	.14[3]	.15
	Lakshmi Machine Works, Ltd.	NA	6.25	31.1	32.0	33.1	.23	.61
Pesticides	Bayer (India)	8.39	8.27	.1	14.6	14.7	.52[2]	.33[6]
	Excel Industries, Ltd.	7.97	5.15	1.2	37.4	38.6	.96	1.06[6]
	Hindustan Insecticides	4.57	3.83	.3	7.6	7.9	0	.60
	Hoechst Schering AgroEvo India, Ltd.	NA	6.63	0	9.1	9.1	.55[4]	.40[6]
	Modipon, Ltd.	3.27	3.51	1.0	3.8	4.8	1.11[5]	.15
	PI Industries	3.54	3.41	3.3	1.4	4.7	.52	.32
	Rallis India	9.65	11.29	12.8	94.8	107.6	.77[3]	.92[6]
	Searle (India)	2.57	3.61	25.7	15.4	41.1	.66[3]	2.33
	United Phosphorus	.05	9.15	1.3	12.3	13.6	.52[3]	.35[2]
Marine products	ITC, Ltd.	.77	.67	34.5	40.4	74.9	.08[1]	.24[6]
Poultry	Venkateshwara Hatcheries	82.01	NA	0	10.7	10.7	1.94[1]	.99[4]
	Venkateshwara Research & Breeding Farm	NA	11.56	6.3	33.6	39.9	36.68[2]	39.35
	Western Hatcheries	17.99	51.41	0	1.6	1.6	.08[2]	.10
Tractors	Bajaj Tempo	NA	.01	11.0	93.8	104.8	2.34[3]	1.78
	Eicher, Ltd.	NA	7.55	133.4	42.4	175.8	.19	3.09[6]
	Escorts, Ltd.	21.02	19.41	16.0	83.8	99.8	0	.60
	HMT, Ltd.	9.04	8.25	.3	90.9	91.2	1.86	.99
	Mahindra & Mahindra, Ltd.	17.30	24.54	0	279.2	279.2	.19	.83[6]
	Punjab Tractors	7.43	13.38	2.6	23.6	26.2	.38[1]	.33[6]
	Tractors & Farm Equipment	14.52	18.55	.4	19.7	20.1	.20[3]	.23

NA = Not available.
[1]For the year 1993-94.
[2] For the year 1995-96.
[3] For the year 1992-93.
[4] For the year 1994-95.
[5] For the year 1990-91.
[6] For the year 1997-98.

Sources: Centre for Monitoring Indian Economy, 1998; and CMIE electronic database.

Flowers

This sector attracted a lot of investment in the 1990s, with multinational corporations' (MNC) establishing export-oriented units. There is no estimate of the total sales of flowers. About 15 major firms sell Re 150 million worth of flowers per year. Estimates of R&D expenditures (many of these companies are bio-tech companies) are difficult to obtain; table B-4 suggests that they have increased. The focus of R&D in this area was in testing foreign varieties and developing management techniques to grow flowers efficiently.

Agricultural Chemicals and Crop Protection

Several large firms operate in this segment, and the extent of rivalry is high. Multinational corporations also figure significantly in this sector. Many international mergers and acquisitions have impinged on the market structure of this industry. Hoechst and Schering became Agrevo in 1994. Ciba-Geigy and Sandoz agricultural chemicals merged to become Novartis in 1996. In December 1999, Hoechst and Rhone-Poulenc merged to create Aventis.

In the 1990s, between 70 and 80 firms engaged in producing agricultural chemicals. The top 10 firms had a 63-percent share of a Re 31 billion market. Only a few small firms produce active ingredients of pesticides. However, some small firms formulate the final pesticide composed of the active ingredients and inert chemicals.

Research by the crop protection industry was also almost entirely applied. The two main research activities of these industries are conducting efficacy tests on chemicals new to India and developing new methods of producing commercial chemicals. The first type of research is conducted primarily by the subsidiaries of foreign firms because they are the source of almost all new pesticides. They test the chemicals that have been commercialized elsewhere to find out how effective they are against Indian pests and diseases under Indian climatic conditions, application methods, and market conditions. These tests are required by the companies to ensure that product meets their specifications and the registration requirements of the government. In addition, the chemicals must be tested for their effect on the environment, workers' health, and animals. Foreign and local firms spend some research resources trying to develop the most effective package of practices for the use of these chemicals. Some of these packages probably qualify as integrated pest management.

The main research activity of local firms has been in developing new methods of producing the active ingredient of pesticides discovered elsewhere. This allows the local firm to produce chemicals originally produced by a method kept secret by the inventor or protected by process patents. Local and foreign firms test different formulations for their products and different combinations of their products and other chemicals that might complement them.

A few local firms are starting to develop research programs to develop new active ingredients for pesticides using standard chemical synthesis methods. A larger number of local firms and at least one foreign firm were considering natural products to use as pesticides. Local firms seemed to be concentrating on neem tree extracts, plant growth regulators, and a few other things traditionally used in Indian agriculture. One foreign firm has a program to actively collect plants that might have biological activity. They then screen these plants and send a handful of the most promising ones to Europe each year. In 20 years, this program still has not led to a new commercial product.

Tractors

About 12 firms were manufacturing tractors in the 1990s in India. The major players listed in table B-4 produce 93 percent of all tractors and in 1997 had a share of 92 percent of the estimated tractor sales revenue of Re 47 billion. Mahindra and Mahindra, TAFE, and Punjab Tractors gained in market share, while Eicher, Escorts, and HMT lost. However, all major players, except HMT, increased their R&D intensity in the 1990s. The decline in the R&D expenditures at HMT tractors is understandable since it was for sale.

The tractor industry underwent major restructuring in the 1990s. While the demand for tractors has grown consistently over the years, its rate of growth declined in 1997-98, as compared with 1995-96. It is expected to decline further.

Small tractors (below 20 horsepower) were exempted from excise taxes until 1994. Inputs used to produce these tractors were also excluded from duties. The 1994-95 budget made the final product (small tractor) excise-free, and the companies had to pay duties on raw materials. Subsequent changes in the value-added tax meant that tax advantages of making small tractors declined further. To add to the problems of small tractor manufacturers, in 1995-96 the government also extended subsidies on tractors to the high horsepower versions. This was an extremely important step as tractor demand is significantly influenced by availability of subsidies and soft loans. Larger tractors are not only more efficient in the field but are also more useful for transporting products. Over the years, the inadequacy of transportation infrastructure has resulted in the use of tractors to transport men and produce. Given these policy and market changes, it is expected that firms will try to upgrade the horsepower range of their tractor production.

Tractor firms conduct a substantial amount of research in India. A major thrust has been to develop higher horsepower tractors that are also affordable to Indian farmers. For Indian firms, this means developing tractors with higher horsepower. For example, Eicher, known for its low-horsepower tractors (less than 25-horsepower range), started selling a 38-horsepower model and hopes to produce 42- and 62-horsepower tractors in the future. A large part of R&D by almost all tractor firms is spent to gear up for the production of larger tractors (more than 50 horsepower). In anticipation of a boom in demand, the market players had enlarged their capacities. This expansion, along with the entry of new players, resulted in underused capacities. Exports are seen as a source of improving rates of capacity use. But such a strategy also requires capability to produce large tractors, as the external markets do not prefer small machines. The export markets, especially the United States and Europe, also have certain design and quality specifications that are different from those in the Indian market. Firms are also conducting R&D to conform to these standards to enlarge their export markets.

Most leading players in the market tried to obtain technology for large tractors through multinational participation. In addition, the three new entrants—New Holland, Sami-Greaves, and John Deere-L&T—are entering with more advanced foreign tractor models. For foreign firms, this means modifying large tractor models developed for the United States, Europe, and South America to be less expensive, yet efficient, and safe on the road; one of the main uses of Indian tractors is hauling crops to market.

Diesel Engines

There are about 31 manufacturers of diesel engines in the corporate sector; not all of them, however, make engines for the agricultural sector. Slow, low-horsepower (<10 horsepower) diesel engines are reserved for small firms. As a result, the bulk of the agricultural demand is satisfied by about 800 small manufacturing units spread over the country. The small sector produces about 500,000 small (up to 20 horsepower) diesel engines every year, mainly for irrigation but also for sugarcane crushers and generating power. The corporate sector contributes another 90,000 engines for irrigation. Estimates of R&D are unavailable for this segment.

The diesel engines produced by small firms are based on outdated Petter and Lister models. Concessional credit and government subsidy has been restricted to slow, low-horsepower diesel engines. As such financial support drives demand to a significant extent, policy has contributed to technological obsolescence. Small industry reservation and financial support for slow, low-horsepower engines has meant that producers did not spend on R&D to upgrade the old models (see Basant, 1997 for details).

The diesel engine story is, therefore, somewhat similar to the tractor story in which government-support for small tractors helped their persistence in the Indian market. However, unlike the tractor industry, not many new entrants have started producing new engines with multinational technologies. Field Marshall in Rajkot is one exception, which is trying to introduce HATZ diesel engines through German collaboration.

Marine Products

A significant number of large firms (more than 125) are engaged in the production of marine products. But their share of the estimated 1997 sales of Re 123 billion was only 10 percent. Most of these major players are engaged in exporting marine products. The relatively high R&D expenditure of ITC, Ltd., in this segment (table B-4) is misleading, because ITC is a large conglomerate firm, and separate estimates for R&D in the marine products sector are unavailable. Similar data are unavailable for other firms as well. Our discussions with some large firms in this sector revealed that whatever limited R&D is conducted is to meet the quality standards for exports, especially to the United States and Europe. These efforts have intensified with the European Union's banning some Indian exports. Most Indian firms export unprocessed marine products. Some firms are trying to move up the value chain and are undertaking research for this purpose. Only a few firms are trying to enter the ready-to-cook market, with research to develop such products.

Fertilizers

Tables 5a and 5b suggest that the market for all types of chemical fertilizers grew in the 1990s. It is a relatively concentrated industry, except for phosphate fertilizers. The top 10 companies accounted for more than 73 percent of sales. The industry spent about Re 310 million per year on R&D in the mid-1990s. For most firms, the R&D intensity increased or remained roughly the same during the 1990s. Any increases, however, were marginal. The DST estimates (table B-3) suggest that, compared with the private firms, the government-owned fertilizer firms do much more research. This conclusion does not seem robust given the CMIE data presented in table B-5, but the CMIE data are missing the largest component of public research, Projects & Development, Ltd.

Most of the research is engineering work to reduce costs of fertilizer production and some agronomic tests on how best to apply fertilizer to different crops. Some firms are also actively working on developing bio-fertilizers.

Poultry

India has several poultry-breeding firms—more than any country outside the United States and Europe. These firms use pure lines from the United States or European firms and breed them in Indian conditions. Therefore, the chickens must survive extreme heat and some cold, because few barns have climate controls, and they must tolerate less hygienic conditions. The firms also have to be competitive in the Indian market structure in which the commercial hatcheries are separate firms from the suppliers of grandparent stock. Therefore, the chickens must lay a large number of eggs.

The poultry industry consists largely of small firms. No estimate of the total market size is available. Including Venkateswara, the largest group, there are approximately 10 major corporate firms in the poultry market. The total sales of chickens for these firms was Re 1.6 billion in 1993-94 and 1995-96. R&D data are available for only three firms (table B-4). Since Venkateshwara Research, Venkateshwara Breeding Farm, and Western Hatcheries actually belong to the Venkateshwara group, effectively we have data for only one company. We were informed that other than the Venkateshwara group, only a few other firms undertake any significant R&D in the poultry sector.

While the market share of Venkateshwara in processed chicken (including Venkateshwara Breeding) declined a bit in the 1990s, their R&D expenditures significantly increased. In fact, the data from the firm show an even higher level and increase in R&D expenditures for the group, from Re 52 million in 1993-94 to Re 129 million in 1997-98.

Food Processing

Data on the structure of the food processing industry are difficult to compile as this sector includes a large variety of products. Therefore, only flour milling is included here. Food processing industries do a limited amount of agricultural research to improve their inputs. For example, beer companies try to improve the quality of the grain they use for malting, and tobacco firms try to reduce the cost of the tobacco they buy while retaining a certain quality standard. Pepsi has identified and popularized superior tomato varieties for the Punjab. Most research by the food industry is, however, concentrated on developing new products and manufacturing processes.

Table B-5a—Market size and shares, fertilizer industry, India, 1991-92 and 1996-97

Product	Market size (value)		Growth in market size	Market share of the top 10 companies	
	1991-92	1996-97		1991-92	1996-97
	-----Re billion-----		*-----------Percent-----------*		
Urea	40.9	84.5	106.6	67.6	72.8
Phosphate fertilizers	4.8	8.5	79.5	52.2	62.2
Ammonium nitrate[1]	.2	1.6	688.3	100.0	100.0
Other nitrogenous fertilizers	25.1	5.4	113.7	98.1	99.7
Di-ammonium phosphate (DAP)	21.3	26.8	25.7	82.2	85.0
Mixed & complex fertilizers other than DAP	11.7	27.5	135.0	95.7	98.4

[1]For all seven companies in the product group.

Source: Center for Monitoring Indian Economy, 1998.

Table B-5b—R&D expenditures of major firms, fertilizer industry, India, 1991-92 and 1996-97

Firm	R&D expenses, 1996/97	R&D/sales 1991-92	R&D/sales 1996-97
	Re millions	*------Percent------*	
Deepak Fertilisers & Petrochemicals Corporation, Ltd.	15.7	.02[1]	.54
Deepak Nitrite, Ltd.	6.5	.31	.52
Dharamsi Morarji Chemical Co., Ltd.	13.8	.33	.64
EID-Parry (India), Ltd.	42.1	NA	.49[6]
Fertilizers & Chemicals, Travancore, Ltd.	5.4	.08[2]	.05
Godavari Fertilizers & Chemicals, Ltd.	0	.06[2]	0
Gujarat Narmada Valley Fertilizers Co., Ltd.	5.4	.02[1]	.04
Gujarat State Fertilizers & Chemicals, Ltd.	54.9	.51[2]	.31
Hind Lever Chemicals, Ltd.	0	028[2]	0
Indian Farmers Fertilizer Co-operative, Ltd.	0	Negative[3]	0
Jay Shree Tea & Industries, Ltd.	1.3	.07[4]	.06
Madras Fertilizers, Ltd.	1.3	0	.02
Mangalore Chemicals & Fertilizers, Ltd.	.5	0	.02
Oswal Chemicals & Fertilizers, Ltd.	0	.11[5]	04
Rama Phosphates, Ltd.	1.2	0	.05
Rashtriya Chemicals & Fertilizers, Ltd.	10.3	.06[1]	.08
Southern Petrochemical Industrial Corporation, Ltd.	78.5	.39[2]	.39[6]
Tata Chemicals, Ltd.	51.8	.07[3]	.35
Tuticorin Alkali Chemicals & Fertilizers, Ltd.	2.6	.24[3]	.23
Vam Organic Chemicals, Ltd.	14.4	.55[2]	.58
All firms	305.7	.15	.19

[1] For the year 1993-94.
[2] For the year 1995-96.
[3] For the year 1992-93.
[4] For the year 1994-95.
[5] For the year 1990-91.
[6] For the year 1997-98.

Source: Centre for Monitoring Indian Economy electronic database.

There are about 30 relatively large firms engaged in the manufacture of flour milling products. Their share in the market was, however, very small, only 10 percent of the Re 58 billion, annual market. Very few of them report R&D expenditures.

The entry of firms in flour milling, especially wheat flour, is a recent phenomenon. By and large, the packed and branded wheat flour could not withstand competition from the small producers. Consequently, the R&D activity initiated in the early 1990s has not increased. Some respondents indicated that increasing the shelf life was the major focus of this research. Apparently, some research is also being conducted to retain the softness of the kneaded wheat flour for relatively long periods.

Technology Transfer

Even in agriculture, where new technology is often embodied in plants and animals that are very sensitive to changes in climatic, soil, and pest conditions, some technology can be transferred with very little adaptive research. Some of this technology comes in as finished or almost finished inputs and the quantities can be indicated by input imports. For other technology, the knowledge is purchased and the product is made in India. Finally, some technology is brought in as a part of direct foreign investment by foreign firms.

Imports of agricultural inputs are very limited for India. For example, seed imports are negligible except in vegetables. Table B-6 shows that sunflower was the only field crop with appreciable imports of commercial seed

Table B-6—Seed imports, India, 1988-95

Year	Cereals (maize, sorghum, millets)	Pulses	Oilseeds (primarily sunflower)	Vegetable seed	Total
			Tons		
1988-89	0.64		0.11	11.34	14.14
1989-90	.13	.02	.14	82.52	82.81
1990-91	.80		5.09	77.59	83.50
1991-92	3.37		373.66	51.33	428.39
1992-93	1.73	.05	22.50	121.31	148.08
1993-94	.76		58.32	170.02	235.06
1994-95	2.19	.01	33.46	414.34	459.91

Source: Ministry of Agriculture, Government of India. Unpublished data. 1997.

for only 1 year, 1991-92. Even that was only 7 percent of the total commercial use. The volume of imports of vegetable seed, for which restrictions on trade were eliminated except for a small tariff, increased much more than field crops but were still small. Imports of many other inputs, such as tractors and diesel engines, were not permitted. Pesticide inputs increased.

Imports of technology through multinational firms can be indicated by proposals approved by the Indian Government. Table B-7 provides details of the proposals approved by the Foreign Investment Promotion Board during 1991-97 for the agriculture-related product groups. Of the 8,795 approved proposals for which we have data, 1,582 (18 percent) were in the agriculture-related sectors. These approved proposals anticipated equity flows of $31 billion, 12 percent of which were to flow into agriculture-related sectors.

The proposed participation of multinational corporations in the agricultural business industry was mainly in the form of equity flows and establishing export-oriented units. Licensing of technology was the third most important MNC linkage (table B-7). Financial and technical participation of MNCs in these industry groups is likely to enhance technology flows as well.

Food processing of various kinds (instant semi-processed foods, meat preparations, and other food products), as well as vegetables, fruits, and flowers are the main sectors attracting MNC participation. Interestingly, input industries, such as fertilizers, pesticides, and agricultural machinery, have not attracted many projects. However, the input industry is not as diversified as the other product groups, and the number of firms in the input industries is also small in relative terms. Consequently, the entry of even a few MNCs may have significantly increased the competitive pressures in the input segments. That may have been the effect of MNC entry on some food processing segments as well.

Effect of Private Research

In the debates about intellectual property rights and biotechnology, critics of the private sector continually argue that private firms will drive up prices of inputs and not provide farmers any benefit from research. In contrast, most economists argue that although the price of improved inputs, such as hybrid maize, may increase, farmers' total costs of production will decrease because they need less of other inputs. The reduction in needed inputs can be measured as partial factor productivity, such as output per hectare or total factor productivity. If output per hectare increases, less land will be needed to produce the same amount of output. Thus, a farmer is saving on his costs of land by using the new technology. If total factor productivity increases, farmers' costs are reduced by using the new technology.

Measuring the effect of private research is beyond the scope of this study. However, three types of evidence indicate that private research has increased productivity and thus reduced farmers' costs of production. First, evidence is available from the companies interviewed about the effect of their R&D effort on partial productivity measures. Second, three studies measured the effect of private research on output per hectare and total factor productivity. Third, studies of industrial research and technology purchase in India show a positive effect of R&D and technology purchase on total factor productivity of industry. This suggests that research on new processes by the food industry and input industries increases productivity, which will eventually benefit farmers and consumers.

The industries interviewed provided several examples of productivity increases due to their research. One example is from Venkateshwara Hatcheries (VH): improved VH breeds increased the productivity of their layers and broilers considerably through breeding. Table B-8 shows that the number of days required to rear broilers to a marketable-size bird was reduced by 20 percent. The amount of required feed declined by 26 percent, and mortality also dropped. Table B-8 shows that the number of eggs from their layers increased by 17 percent, while the feed requirement declined by 7 percent and mortality declined. These

Table B-7—Proposals approved by Foreign Investment Board, India, 1991-97

Product category	Export-oriented units	Holdings	Licensing	Technology	Financial	Equity flows
			Number			*Million rupees*
Animal & animal products	20	0	9	2	38	445
Agricultural products (except flowers)	40	0	40	0	73	838
Flowers	157	0	11	1	111	43,236
Agricultural products (total)	197	0	51	1	184	44,074
Fats, oil, etc.	18	0	9	0	29	1,622
Food products	8	2	27	2	61	21,057
Meat preparations	41	0	14	1	74	661
Dairy products	1	0	1	0	12	5,269
Cocoa	1	0	5	0	14	1,685
Instant semi-processed seeds	47	1	11	0	71	8,316
Vegetables/fruits	108	0	9	0	124	1,327
Beverages	5	1	17	0	48	49,765
Other foods	20	3	11	0	42	10,541
Food industry (total)	249	7	104	3	475	100,243
Food processing machinery	0	0	16	0	19	362
Fertilizers	1	0	6	0	7	2,477
Pesticides	0	0	6	0	8	239
Agricultural machinery	0	0	15	0	11	2,292
Agricultural inputs (total)	1	0	27	0	26	5,008
Total (agriculture industries)	507	7	247	6	815	150,969
			Percent			
Total (agriculture industries)	32.05[1]	4.4	15.6	0.4	51.5	
			Number			
Total (all industries)	1,225	42	2,762	43	4,723	1,226,696
			Percent			
Agriculture-related/total investment	41.4	16.7	8.9	14.0	17.3	12.3

Source: SIA database, Ministry of Industry, Government of India. 1998.

data come from VH poultry operations; data were available from other commercial farms. It seems likely that the productivity increases on other commercial farms would be less.

Another success of the VH group was in producing vaccines that are less expensive than some commercial vaccines and more reliable than government vaccines. They also developed vaccines that provide protection against diseases for which no other vaccine exists. In fact, they developed one vaccine that no other country has developed. This vaccine is for a form of hepatitis that has become a serious problem for poultry in India since 1993. The commercial sale of this vaccine in recent years has greatly reduced deaths from this disease and increased industry productivity.

As mentioned earlier, several recent studies measured the effect of technology developed and introduced by the private sector. A study of maize (Singh and Morris, 1997) used farm-level data from six states in 1994-95 to show that the adoption of hybrid maize led to yield increases of about 1 ton per hectare over improved open-pollinated varieties. In total, this led to an increase

Table B-8—Increases in poultry efficiency due to poultry research, India, 1981 and 1996

Item	Unit	1981	1996
***Broilers*:**			
Days to 1.5 kg body weight	Number	47	38
Feed conversion	Percent	2.5	1.85
Mortality	Percent	3	2
***Layers*:**			
Eggs production to 72 weeks	Number	270	315
Feed efficiency	Percent	145	134
Mortality (72 weeks)	Percent	8	6

Source: Venkasteshwara Hatcheries, Limited.

in maize production of 1.1 million tons. To obtain these increases, farmers had to increase fertilizer, irrigation, and pesticide use in addition to adopting hybrids. Therefore, increased output is not entirely productivity growth.[4] Since most hybrids in 1995 were from private firms, most of this gain was due to private research.

A study by Ramaswami, Pray, and Kelley (1999) looked at the factors that influence the partial productivity index, yield per unit of land. The dependent variables were cotton, maize, sunflower, sorghum, and pearl millet yields. The independent variables included a measure of the spread of high-yielding varieties (HYVs), the spread of private varieties, the proportion of irrigated crop area, fertilizer use, the number of regulated markets, and the length of roads in the district, in addition to profitability of the crop, a trend variable, and variables measuring rainfall. The basic model is augmented by interaction variables of HYVs with private varieties, irrigation, and fertilizer use. Since private varieties have been significant in these crops only recently, their analysis was confined to the period since 1985.

Private hybrids' effects on yields are positive and statistically significant in five of the nine crops and provinces and close to significant in a sixth case. Table B-9 summarizes the results of the regressions. These estimates provide the first econometric evidence that private plant-breeding affects crop yields in developing countries. This is particularly impressive because the region examined is in the semi-arid tropics where private research is not expected to have much effect.

[4]This partial productivity index was used rather than the index of total factor productivity (TFP), because input data are available only for the entire crop sector not for individual crops. Thus, it is impossible to calculate crop-wise determinants of total factor productivity.

The only study that had considered how the benefits of private hybrids were divided was conducted by Pray et al. (1991). It examined the increases in seed prices and increases in farmers' yields of hybrid sorghum and pearl millet in Maharashtra and Gujarat. For hybrid sorghum, at most 18.5 percent of the benefits were captured by the seed companies through higher prices, while 81.5 percent went to farmers as the value of increased production minus the increased cost of seed. For hybrid pearl millet, only about 6 percent of benefits were captured by seed firms. More than 90 percent of the benefits from private pearl millet research went to farmers. Using this same data, Ribeiro (1989) estimated the social rate of return to private plant-breeding research in India to be 38 percent or more.

A study of total factor productivity of crop production, by district in 13 major states of India from the 1950s to the 1980s, also provides evidence of the effect of private research and technology transfer (Evenson, Pray, and Rosegrant, 1998). The study found that private research and technology transfer, advances in agricultural research outside India, and public research all made major positive contributions to total factor productivity growth in the crop sector. The social rate of return from investments in private research was very high—exceeding 100 percent—which suggests that most benefits from private research go to farmers and consumers rather than input companies and that society believes that there is a substantial underinvestment in private research.

Studies of the experience of Indian industry found that technology imports reduced local R&D by a small amount but increased the productivity of Indian firms (Fikkert, 1995; and Basant and Fikkert, 1996). The lost productivity from the small decline in research was more than offset by increased productivity from the imported technology. Indian firms did not need to use their own resources to reinvent technology developed elsewhere and could concentrate their research instead on new products and processes that could not be purchased from abroad.

Effect of Technology in the Pipeline

Perhaps the most important technology in the pipeline is hybrid rice, which the public and private sectors are racing to commercialize. Sixteen private seed firms reported that they are breeding hybrid rice, and several of these breeding programs are quite substantial.

Table B-9—Effect of private and public hybrids on yields, India, 1998

Crop/State	Private	High-yielding variety	Estimation technique
Sorghum, Andhra Pradesh	0.0027[1]	-0.09	Random effects
	(1.92)[2]	(1.54)	
Sorghum, Karnataka	.0083[3]	.44[3]	Random effects
	2.34)	(2.99)	
Sorghum, Maharashtra	.008	.23[1]	Fixed effects
	(1.54)	(1.88)	
Pearl millet, Andhra Pradesh	.0007	-.084	Fixed effects
	(.27)	(1.1)	
Pearl millet, Karnataka	-.0002	.39[3]	Random effects
	(.11)	(3.2)	
Pearl millet, Maharashtra	.01[1]	.02	Fixed effects
	(1.91)	(.32)	
Maize, Andhra Pradesh	.023[3]	-.11	Fixed effects
	(2.27)	(.7)	
Maize, Karnataka	.005	.77[1]	Random effects
	(.48)	(1.7)	
Maize, Maharashtra	.04[3]	.13	Fixed effects
	(3.33)	(.96)	

[1] Estimates significant at the 10-percent level.
[2] T-values are in parentheses.
[3] Estimates significant at the 5-percent level.

Source: Ramaswami, B. C., and Carl E. Pray, and Tim Kelley. 1999.

MAHYCO and SPIC have biotech research programs on hybrid rice. Farmers grew hybrid rice in 1997-98. Most of the 250,000 hectares under hybrids (Indian Council of Agricultural Research, 1998) in 1997-98 was under private hybrids, with Proagro, Pioneer, and MAHYCO leading the way. These private hybrids are based on public lines from the Indian Council of Agricultural Research (ICAR), International Rice Research Institute, and China, but they are private hybrids. Yields are often 1 ton per hectare more than the best conventional varieties, and yields of hybrid seed are high enough to make the 1-ton increase commercially viable. The main problem is the grain quality of hybrid, which is low. Thus, most private firms and many public research institutes are concentrating on improving grain quality.

Another important technology that several private firms and a number of public institutes are researching is single-cross hybrids of maize. Companies reported that singlecross hybrids produce 10 to 30 percent higher yields than double-cross hybrids in trials in India. Seed of single-cross hybrids is still not being marketed in significant quantities because of the high cost of seed production and the ease with which it can be copied by contract farmers and competitors. But this technology will be supplied as intellectual property rights are strengthened.

Among the first biotechnology products likely to be approved are *Bacillus thuringiensis* (Bt) cotton, which allow farmers to reduce the number of insecticide applications from 15 or more to 3 and to achieve higher yields. Another likely early approval of a genetically engineered crop is hybrid rapeseed that yields 10 to 20 percent more than improved local varieties. Other near approvals are pest-resistant tomatoes, cabbage, and eggplant.

A new generation of pesticides were being introduced in 1998 that are effective against some pests that have grown resistant to older pesticides and are much safer for people and the environment. Several new wheat herbicides were approved for control of *Emperata* grass, which is resistant to the herbicides on the market in India. Companies estimate that use of these herbicides, which are much more environmentally friendly, will increase yields by 20 percent.

These new products will be more expensive. An International Maize and Wheat Organization survey found that the ratio of the price of hybrid maize seed to the price of commercial grain in selected developing countries in 1990 ranged from 1.3 in China to 25 in Cameroon, with India at 4.2. Single-cross hybrid seed in the United States and Europe cost more than 30 times the cost of grain (Byerlee and Lopez-Pereira, 1994). Thus, it is probable that as Indian farmers adopt better double-cross and single-cross hybrids, prices will rise. However, as of 1998, prices have been held down by intense competition among private seed companies, public seed firms, and farmers who save seed. There is no evidence that this will change soon. Even if the firms in which Monsanto has some ownership—MAHYCO, Cargill, and E.I.D-Parry—were to merge, they would have less than 14 percent of the commercial seed market, which is a small part of the total seed planted that primarily comes from farmers (Pray and Kelley, 1998).

No one in 1998 knew the price of pest-resistant hybrid cotton with Bt in it. However, the experience of China gives some indication. In China, the price of Bt cottonseed (variety not hybrid) increased from yuan 5 per kilogram to yuan 42 per kilogram.[5] However, because of the higher quality of the seed, the quantity sown could be reduced to one-quarter of the amount of traditional seed. Thus, the seed cost per unit of land doubled, rather than increased five times. In return, farmers saved 10 to 20 pesticide applications, saving money for chemicals plus the cost of labor to apply the chemicals. Bt cotton is very popular in Hebei Province where it was released.

Reasons for Increase of R&D Investments

Liberalization in India and changes in multinational firms' strategies are major causes of the increase in research and technology transfer to India. An analysis of seed industry data indicates that local and foreign companies increased their research in response to liberalization. In 1998, foreign firms, such as Monsanto and DuPont, invested in new agricultural research stations, and John Deere entered the Indian market for the first time with its latest line of tractors. The Foreign Investment Promotion Board data (table B-7) on multinational corporations' proposals for entry into different industry groups also suggest such a trend.

According to neoclassical economic theory, firms seek to maximize expected profits. The expected profits to a firm from investing in research are a function of the expected benefits and costs of research and development of a commercial product discounted by an interest rate. The expected benefits will be based on the expected size of the market, the share of the market the firm hopes to capture, and the expected price of the new product. Firms will calculate the expected market size based on current market size and growth rates for this industry. They will estimate their expected share of the market by looking at their current market share in the industry, the strength of intellectual property rights in the country, and technical means of protecting their product from copying. The expected price will be based on current prices of similar products plus their ability to keep other firms from copying the product and competing against them. Economists use the term "appropriability" to describe a firm's ability to capture economic gains from research.

The expected costs of research depend on the availability of needed technology elsewhere in the world. The environmental specificity of foreign technology will determine whether there are opportunities for adaptive research or direct material transfer. The availability of technology from public institutes, which can be adapted or modified through local research, can reduce research costs. The salaries and benefits of scientists, engineers, and technicians are important components of research costs, as are laboratories, experiment stations, and the supplies to run them.

Market Size and Growth

Increased agricultural research was partially a function of increased demand for agricultural products and modern agricultural inputs. The size of Indian markets for agricultural inputs has grown substantially since 1980, as shown in table B-1. The private sector supplies most of the equipment for minor irrigation, half of the certified and quality seed, half of the fertilizer, most of the pesticides, and most of the tractors. This table and our earlier discussion indicate that production of almost all inputs at least doubled during the 1980s. In the 1990s, rapid growth continued in tractors, power tillers, and minor irrigation. Production of seeds and pesticides, likewise, continued to grow, but that growth was in a different dimension than is captured by the measures used earlier. In the seed industry, more expensive private hybrids replaced subsidized public hybrids and public varieties. This increased the value of the seed market but is not indicated in the quantity measures in table B-1. In the pesticide industry, newer, more expensive pesticides which require only 40 to 50 grams of technical material per hectare replaced older, less expensive pesticides that required 2,000 grams per hectare. The result was more sales measured in value terms.

[5] The exchange rate in 1998 was approximately 8 Yuan = U.S. $1.00. There are 6 metric units per acre.

India is one of the largest national markets for agricultural inputs in the world. It ranks first in the number of tractors produced and sold. It is also one of the largest fertilizer and pesticide producers and consumers. Part of the increase in research in the 1990s was due to foreign input firms' deciding that the Indian market was simply too large to ignore, even if many policies were not conducive to high profits.

Like the input industries, the Indian food industry is one of the largest in the world, and it is rapidly growing. India is expected to become the world's most populated country early in the 21st century. Demand for processed foods, poultry products, dairy, and meat has also rapidly grown, increasing demand for improved livestock technology. Output by the food industry doubled between 1980-81 and 1995-96. Production of poultry products more than doubled in the 1980s and increased another 25 percent from 1990-91 to 1995-96. Milk production increased by 70 percent in the 1980s and 22 percent from 1990-91 to 1995-96 (Tata Services, Ltd., 1997). Production of livestock feed also rapidly grew from 1.2 million cubic meters in 1980-81 to 2.9 million cubic meters in 1995-96 (Compound, 1998). These increases were driven largely by increased demand created by gains in per capita income.

In addition to increased market size, the market share of large private Indian and foreign firms has increased since 1980. Very large Indian firms and firms with foreign ownership of more than 40 percent were excluded from the seed and biotechnology industries until 1986. Half of the active ingredients of pesticides had to be formulated by small firms, and all of the agricultural implements industry was reserved for the small firms until the 1990s. The elimination of those restrictive policies allowed large firms into the seed market and permitted the manufacturers of the active ingredients of pesticides to increase their market. It is also expected to induce tractor manufacturers into the implements industry.

The market shares of government-owned corporations have declined in the seed industry and in tractors as government sales grew more slowly than private sales. In addition, some public companies in this sector, like HMT tractors, have been included in the state's disinvestment program. Both factors increased the market share of private firms.

Changes in the input markets in the United States and Europe have made the markets of countries of Asia, in general, and India, in particular, very attractive, relative to their traditional markets. From World War II to the late 1970s were boom years for agricultural input firms in the United States, Europe, and, to a lesser extent, Latin America. With the stagnant or declining growth of the 1980s, most U.S. companies reacted by reducing costs. By the early 1990s, having squeezed costs as much as they could, many of them started to look to developing countries, Eastern Europe, and the former Soviet Union for further growth. John Deere, DuPont, and Monsanto in the early 1990s expanded into developing countries, including India. In addition, due in part to developments in biotechnology, agricultural chemical and pharmaceutical companies shed their traditional chemical business and bought biotech and seed firms to transform into life-science companies. Table B-10 shows the effect of the mergers and acquisitions in the United States and Europe on the Indian seed industry. These companies invest large sums of money in basic research to develop new drugs, seeds, and agricultural chemicals, which they then try to sell worldwide to pay for their research.

Appropriability

Appropriability—the ability of a firm that owns new technology to capture some benefits that users of the technology obtain—can be due to several causes. First, laws like patent acts can give owners temporary monopolies, enabling them to raise prices and profit from selling the technology. Second, the structure of the industry may allow firms to capture some benefits. Monopoly or oligopoly power in a market can give inventors high enough prices to profit from technology. Third, the technology may allow firms to keep others from copying a technology thus giving inventors market power. Fourth, firms can simply keep inventing and stay ahead of their competition. This also would allow them to charge more.

Since 1985, there have been only a few changes in appropriability in India. The laws and enforcement of intellectual property rights have not changed since 1972, when new chemicals, pharmaceuticals, and food and agricultural products were excluded from product patent protection. However, as earlier mentioned, the markets have become more competitive.

India signed the Uruguay Round of GATT (General Agreement on Tariffs and Trade, now the World Trade Organization) and was committed to a *sui generis*

Table B-10—Effect of mergers and acquisitions on U.S. and Indian seed industries, India, 1998

Parent company (main business)	U.S. seed companies	Indian seed companies
Monsanto (agricultural chemicals, pharmaceuticals, and food additives)	Holden's DeKalb Asgrow (soybeans and corn) Stoneville Delta & Pineland, and Cargill International Seed Business	MAHYCO (50-50 cotton Monsanto; 26 percent of MAHYCO) E.I.D. Parry (corn, sorghum and sunflower with DeKalb), and Cargill
DuPont (chemicals, oil, fiber, and food)	Pioneer	SPIC (Pioneer)
Aventis---Hoechst (Agrevo), and Rhone-Poulenc (agricultural chemicals)	AgrEvo PGS	Proagro (PGS) Sunseeds
Novartis (agricultural chemicals & pharmaceuticals)	Northrup King, and Ciba seeds	Novartis (was Sandoz)
Zeneca (agricultural chemicals & human health)	Advanta	ITC/Zeneca
Empresas La Moderna (Mexican-owned conglomerate)	Seminis DNAP Peto Asgrow (vegetables) George Ball	MAHYCO (Asgrow), Nath Slius (90 percent), Indo-American Seeds

Sources: Various newspapers and trade journals.

plant breeders' rights (PBR) law and strong process patents on biotechnology products by January 1, 2000. The country also plans to issue product patents for new chemicals, pharmaceuticals, and food and agricultural products by 2005. PBR legislation and amendments to the patent act were proposed and debated by several different Indian Administrations but not passed. In addition, India must protect trade secrets and extend liability to third parties that induce breach of a trade secret, and protect test data which is submitted for obtaining marketing approval of a new product. India's signature to the GATT agreement may have raised the hopes of research-based firms for stronger intellectual property rights, but not too much.

In the seed sector, appropriability increased through technical means. Hybrid seed is becoming viable in additional crops. Developments in hybrid rice seed production after 1985 led to the commercial adoption of hybrid rice in 1997. In addition, several systems for producing hybrid rapeseed seem possible. These developments led to private investment in a number of new research programs on rice and rapeseed, increasing total seed research (Pray and Kelley, 1998).

Regulatory changes allowed foreign firms to increase their share of ownership in all sectors. This enables the foreign owner to appropriate a larger share of profits from new technology back to the firm's headquarters where much of the research is conducted. The potential for enhanced profitability will increase the interest of foreign firms to invest in research in India.

The increased entry of foreign firms and some large Indian firms into agricultural input and agricultural processing industries has increased the competitive pressure on all firms in these industries. Firms have to innovate more rapidly to keep their market share. They try to appropriate the gains from their research by staying ahead of the competition.

Cost of Innovation

Firms must weigh the expected benefits, which are based on market size and appropriability, against the cost of innovation and the possibility that the innovation will fail to generate the expected sales. The cost of innovation and probability of success are a function of the state of basic science, quantity and price of scientific inputs such as scientists and labs, and agroclimatic differences between the place for which a new product was designed and India.

Advances in basic science can lead to new possible products from applied research. One major breakthrough since 1980 has been in biotechnology. Profits from plant biotechnology products are no longer a dream, but rather a reality in the United States, Canada, and Argentina. This has drawn a number of seed firms and agricultural chemical firms to invest in biotechnology research in India. In 1985, the first survey found that Hindustan Lever and a few other firms had started to work on plant biotechnology. Now Hindustan Lever, Tata Tea, and at least three seed firms have substantial plant biotech labs in India.

The output of more applied public research can also stimulate private research. During 1985-98, public research institutes in India and international centers provided considerable stimulus to private plant-breeding research. Participants of a study of the Indian seed industry (Pray, Ramaswamy, and Kelley, 1998) reported that the International Center for Research in the Semi-Arid Tropics (ICRISAT) was a very important source of germplasm by 65 and 80 percent of the sorghum and millet breeding firms, respectively. The Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAU) were very important for 66 percent of the cotton breeders. Sunflower was the only major crop for the international centers and ICAR/SAU were reported not to be important sources; joint venture partners are the most important sources of sunflower breeding material. Singh, Pal, and Morris (1995) documented the importance of ICAR and CIMMYT germplasm as the basis of private maize research.

The downsizing of ICRISAT and SAU and weak funding of ICAR meant that many well-trained and experienced scientists were available to private firms to lead and staff their administrative and research positions. The negative side of weak funding is that less public science and technology is available from these institutions in the long run. Some effect of declining funds can be seen at ICRISAT, which has stopped having the sorghum and pearl millet field days, at which ICRISAT scientists displayed and distributed samples of their latest hybrids, varieties, and inbred lines.

Another way to reduce the cost of research is to learn from ideas and innovations elsewhere in the world. Since 1985, several types of innovations have become more accessible to private firms. The reforms of the seed industry in the late 1980s made inbred lines and earlier generation germplasm more easily accessible. The reforms made it easier to import varieties for research and finished varieties for a few years to try them on a commercial basis. The admitting of foreign-owned firms meant that they brought in germplasm and new ideas that spilled over to local firms. Some of our survey respondents expressed the fear that new intellectual property rights (IPRs) might result in less sharing of germplasm and other research materials.

Regulatory reforms that reduced the time for new chemicals to be approved (from 7 or 8 years to 3 or 4) influenced pesticide companies to bring in more products, which stimulates local research on these products. Research by the agricultural chemical industry depends primarily on the number of new chemicals introduced. Each new chemical needs a minimum amount of research to ensure that it works well in India and that it is registered.

Policy

Most key government actions that may have stimulated private research are described in earlier sections and in the sub-sections in this chapter on markets, appropriability, and cost of research in this paper. But the key set of policy changes was the liberalization of the policies and regulations on the input industries. Table B-11 lists some policies before and after liberalization. Reforms allowed foreign firms more control over their Indian operations—as majority owners or wholly owned subsidiaries. Inputs in the production of the finished agricultural inputs—such as the active ingredients of pesticides, grandparent stock of poultry, and germplasm for the seed industry—were easier to import. Requirements for licenses to build new plants or expand old ones were eliminated. In addition, although most of the safety, environmental, and efficacy regulations did not change, their implementation became more efficient. For example, in the past, it took 7 to 8 years, on average, to register a new pesticide, while it now takes 3 to 4 years.

Summary

The two major forces behind the increase in private research are the size and growth in the Indian agricultural input and food market and the liberalization of restrictions on Indian and foreign firms that wish to invest in the food and input industries. Liberalization also resulted in an increase in the competitive pressures faced by the firms in the market. Other important factors, but less important than the first two factors, were developments within the international food and agricultural input industries—declining growth rates in demand in Organization for Economic Co-operation and Development (OECD) countries and mergers and

Table B-11—Key policies before and after reforms, India, 1998

Industry	Before	After
Seed	MRTP & FERA companies not allowed. Vegetable seed restricted. Other seed imports banned.	All firms allowed. Vegetable seeds open general license. Limited imports of commercial seed of coarse grains and oilseeds. Imports of wheat and rice only by government.
Agricultural machinery	No imports. Equipment reserved for small industry Licenses required for production and expansion.	No imports. Anyone can produce equipment. Licenses not required for production and expansion.
Pesticides	Active ingredient (AI) could be imported for limited time with 150 to 180% tariff, then had to be manufactured in India. 50 percent of AI must be formulated by small sector. No imports of formulated products except emergency. Licenses required for production and expansion. New product registration took 5 to 10 years.	AI imports with 35% tariff. No imports of formulated products, except emergency. No reservation of AI for small sector. No licensing requirement for expansion. New product registration takes 3 to 4 years.
Poultry	Grandparent imports restricted, and parent imports banned.	Grandparent stock imports open general license. Parent imports banned.

acquisitions in the food and input industries. Finally, breakthroughs in plant research and biotechnology, as well as an increase in applied research by the Indian Government and international nonprofit institutions, were important for some industries, particularly seed and biotech firms.

Policy Options

The government has a number of policy options that could improve the supply and prices of technology from the private sector. First, if the government is concerned about prices of inputs for farmers, the government could eliminate the bans on the importation of most agricultural inputs. The best way to keep prices down is through competition; protecting local industry behind import bans or quotas is counterproductive. No agricultural input industry is any longer an infant industry. If India is afraid that its local industries, such as the pesticide industry or diesel pumps, might face unfair competition or dumping from subsidized Chinese or other foreign firms, then India's anti-dumping legislation may be more useful than its blanket import bans. Under the World Trade Organization (WTO), India is committed to removing bans and quotas or at least turning the quotas into tariffs, but it is not clear when this will happen. If India wants to produce world class seed, machinery, or pesticide firms, then supporting those industries with public research, loans, and intellectual property rights in their home market might be more beneficial than using current trade barriers. A sensible competition policy must accompany deregulation, trade liberalization, and more stringent intellectual property rights so that monopolistic and unfair trade practices do not adversely affect consumers.

Second, strengthening patents and plant breeders' rights (PBR) is very important. Revised patent legislation to align these laws with the WTO passed Parliament in the spring of 1999. PBR legislation is still in Parliament. Effective enforcement of patents is still lacking. Thus, it seems likely that India will wait until the last moment, 2005, to produce stronger patent laws. In the meantime, Brazilian, Mexican, Turkish, and Chinese inventors and plant breeders have had stronger IPR protection since the mid-1990s.

We asked seed firms to speculate about the effect of potential policy changes on the availability of technology. In our 1997 survey of seed firms, we asked "Would stronger intellectual property rights, changes in the regulatory regime, and trade in agricultural inputs really lead to more technology for farmers?" There was considerable variation in firms' answers. Of the seed firms surveyed by Pray, Ramaswamy, and Kelley (1998), 19 of 33 respondents reported that PBR legislation would encourage them to do more research, while 12 said that it would have no effect on their research, and 2 thought they would do less research. In interviews with the major seed firms, it was clear that they would not start major breeding programs on self-pollinated crops, even with PBRs. It would be impossible to keep farmers and small traders from multiplying and selling protected seed of protected varieties. They did suggest that further research would be done on cross-pollinated crops to protect key inbred lines. A major effect of PBR legislation might be the release of single-cross hybrids of maize. Companies reported that single-cross hybrids produce 10 to 30 percent higher yields than doublecross hybrids in trials in India. No one has released them, however, because they are concerned that they would be immediately copied by their competitors.[6]

The pesticide industry claims that a lot of technology is unavailable to farmers because of weak intellectual property rights, barriers on imports of formulated products, and regulatory hurdles. For example, sulfonylurea herbicides were being introduced in 1985. DuPont's sulfonylurea soybean herbicide "Classic" was first sold in the United States in 1986. It was marketed in Brazil in 1987 but was not to be marketed in India until 1999, at the earliest. Cyanamid's new class of herbicides called IMIs (imidazolinones) were first sold in the United States in the late 1980s. They were first released in India in 1998 as part of the MOA's emergency wheat herbicide program. Several firms reported that they were not bringing in their latest insecticides. A few, however, argued that high competitive pressures and the need to quickly introduce new products for first-mover advantages in such a scenario, may force multinational corporations (MNCs) quickly to bring in new products.

The major questions that remain unanswered are: (1) With stronger IPRs and lower barriers to entry—e.g., allowing the importation of formulated products—would the MNCs come in with new products? and (2) Is the absence of these pesticides really reducing yields? Some pesticides will not be introduced because their superiority over the previous pesticides is not enough for farmers to pay higher prices for the new pesticides. The increase in yield may be small or the main advantage may be the environmental effect or health benefits, for which farmers are not willing to pay. For the first question, only a few major pests seem to have no solutions—the imperata grass problem in wheat and insect pests for cotton are two important ones. The government has a special wheat program that reduced the time for registering a new product from 3 or 4 years to 1 year, allowing them to import more advanced herbicides. Insect pests for cotton are a problem, but it is unclear whether new chemicals would be greatly more effective than the current ones. What India mainly seems to be missing is safer and more environmentally friendly products (see the later discussion of Bt cotton). Stronger IPRs will probably not help much, but allowing formulated products to be imported may. Until farmers or the government are willing to pay a price premium for environmentally friendly products or they can be imported less expensively, they will be unavailable.

In the poultry-breeding, feed, fertilizer, and machinery industries, stronger IPRs will have little, if any, effect on private investments in R&D. However, allowing imports of these inputs would probably reduce the prices farmers pay for some of these products. For example, Chinese diesel engines and power tillers are very inexpensive. We assessed how much prices might be lowered for these commodities. The diesel engine manufacturers in India feel that the Chinese Government provides a lot of hidden subsidies to their producers. Otherwise, exports of engines at the current prices would not be impossible. It is very difficult to check the veracity of these claims.

Third, a change that would increase technology to farmers from the seed industry is less regulation on transgenic plants. At the earliest, genetically engineered crops were expected to be in commercial use in India in 2000, but pressure by environmental groups and bureaucratic inertia easily could cause further delays. In 1998, China produced 200,000 acres of cotton with the *Bacillus thuringiensis* (Bt) gene inserted for bollworm resistance. Monsanto (Achievements: Plant Biotechnology, 1997 *www.monsanto.com*) estimates that in 1997 Mexico was growing 200,000 acres of Bt cotton; Argentina, 10 million hectares of herbicide-resistant soybeans; Canada, 2 million acres of herbicide-resistant canola; and the United States, 25 million acres of herbicide-resistant soybeans, 2.6 million acres of Bt cotton, 10 million acres of Bt corn, and other crops.

Among the first crops likely to be approved are Bt cotton, allowing farmers to reduce the number of insecticide applications from 15 or more to 3 and achieve higher yields. Another likely early approval is hybrid rapeseed, which yields 10 to 20 percent more than improved local varieties. The other crops near approval are tomatoes, cabbage, and eggplant.

[6] With double-cross hybrids, contract seed growers are given seeds from single-cross hybrids, which they cannot reproduce. With single cross hybrids, they are given seeds of two inbred lines, which they can reproduce. Thus, it is easy for them to sell some of the inbreds to a competitor or reproduce the new hybrid themselves.

Fourth, the government passed some tax packages to assist private firms. The new government passed a law allowing R&D firms to write off 120 percent of their total R&D expenditure as costs on their corporate income taxes. These and other R&D-related policies, however, have not been stable. Besides, the implementation of many such schemes requires that the firm register its R&D center with the Department of Science and Technology (DST). The procedures to do this are tedious and time consuming. If this changes from a year-to-year policy into a consistent long-term policy, it might give some firms incentive to do more research.

Fifth, public research has successfully supported private research in the seed industry in the past. However, the reduction in funding of the International Center for Research in the Semi-Arid Tropics (ICRISAT) and other international centers and the poverty of some Indian public agricultural research systems are starting to hurt private research. The public research system is attempting to become more responsive to the needs of private firms, but leading firms are still dissatisfied with public research performance. They reported that part of the problem is that the public sector is perennially short of funds and a scientific culture that rewards basic research more than research that actually solves agricultural problems.

Finally, a number of foreign companies selected infrastructure—particularly roads and communications—as a major constraint to further investment in India.

Conclusions

Private research is rapidly growing—more rapidly than public research—but the total R&D expenditures in the private sector still amounted to only 16 percent of the total funding of Indian research in 1998. According to our estimates, based on our surveys and DST data, about $347.9 million (Re 31.4 = US $1) were spent in 1994-95 on R&D for the development of agriculture, forestry, and fishing, only 14 percent of which was contributed by the private sector. Empirical studies, noted earlier in this chapter, suggest that private research is contributing to agricultural productivity growth and that farmers capture more benefits of research than input firms. There is no immediate threat of Indian or foreign firms' gaining monopoly power over any agricultural input industries in India. There is simply too much competition, not only from other private firms but also from public firms, and, for the seed industry, from farmers. Even if there were a threat, the way to deal with it would be with a competition policy, not a technology policy.

The factors behind this growth in private food and agricultural research fall into four groups. The first factor is the size and growth in the Indian agricultural input and food markets. The second factor is the liberalization of restrictions on Indian and foreign firms that wish to invest in the food and input industries and the associated increase in levels of competition. A third factor is developments within the international food and agricultural input industries—declining growth rates in demand in OECD countries and mergers and acquisitions in the food and input industries. A fourth set of factors important for some industries, particularly the seed industry, is the breakthroughs in plant biotechnology and the applied research by Indian government and international nonprofit institutions such as ICRISAT.

Based on the history of recent growth and the responses of the surveyed firms, we believe that private food and agricultural research can be strengthened and farmers' access to new technology can be improved by further liberalization, continued support for public research, and stronger intellectual property rights:

- Liberalization includes continuing to liberalize rules on foreign investments in the input industries, replacing the bans on imports of inputs with tariffs that will gradually be lowered, and continuing to rationalize regulations on the release of new pesticides and biotech products. Then, farmers and consumers are protected against health and environmental dangers, and the input companies will not be burdened with unnecessary requirements.
- Continued public financing of Indian and international public research will support the growth of competitive modern food and inputs industries. Public research can give private firms opportunities to grow and compete with multinational firms.
- Stronger IPR legislation and enforcement will enable farmers to access the most advanced technology and will give local and foreign firms incentives to conduct research on the problems of farmers.

Most of these policies are not new. India is committed to continued liberalization and stronger IPRs by becoming a member of WTO and is committed to increasing government research. The real question is: How long will it take India to fully realize these commitments?

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