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Role of Biotechnology in Stimulating Agribusiness R&D Investment in India

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Biotechnology influenced Indian R&D through three channels: Bt cotton seed sales increased seed companies' income, providing them with money to invest in R&D and increasing their expectation for future profits from R&D; biosafety regulations increased biotech and seed firms' ability to capture some of the economic benefits from research by granting them a monopoly on GM traits and providing regulators to police the monopoly; finally, biotechnology improved technological opportunities with new traits and research tools. We tested the importance of these channels using an econometric model of R&D expenditure by the Indian seed industry with a unique set of individual firm data from 1987 to 2009. Our results show that the introduction of Bt cotton greatly increased seed sales and that these sales were the major determinant of R&D. Evidence also suggests that research increased due to technological opportunities created from GM traits and public-sector research.

Key words: R&D investment, India, agribusiness, biotechnology, seed industry.

Introduction

The seed industry is the most research-intensive agribusiness in India and over the last 15 years has had the fastest growth in research expenditure of any major agribusiness. In another paper (Pray & Nagarajan, 2012), we suggested that biotechnology could have been an important cause of research and development (R&D) intensity and growth in the seed industry. Promoters of biotechnology argue that it will stimulate R&D and innovation by providing technological opportunities to produce crop varieties that are more productive and have improved quality. Critics of biotech argue that genetically modified (GM) crops have not increased technological opportunity because the new crops are not more productive or are no more productive than crops developed through convention methods. They argue that the main impact of GM crops has been to increase the ability of major biotech firms to appropriate more money from their innovations because of the protection provided new traits through patents and the regulatory system. This may or may not lead to more research. The major biotech firms may do more research, but smaller firms may reduce their research because patents may be inaccessible and it may be difficult to move new technology through the regulatory system. As far as we know, no empirical research has been done on this issue.

This article attempts to assess the impact of biotechnology on the Indian seed industry research. The next section describes the evolution of the Indian seed industry. Then we review previous literature on the determinants of Indian seed industry R&D and propose three hypotheses about how biotechnology may have influenced R&D in the Indian seed industry. Following that, we propose and test a simple econometric model of R&D using a unique R&D dataset from the Indian seed industry for the years 1987, 1994, 2005, and 2008/09. Finally, we discuss the implications of the empirical work for the issues raised in the previous paragraph and discuss the policy implications.

Seed and Biotech Industry

The seed industry grew rapidly since the Green Revolution in the 1970s, but exploded in the last 15 years. A recent article in the *Business Standard* newspaper describes the growth in the India seed industry (Mukherjee, 2012):

> At Rs 9,000 to Rs 10,000 crore (about US$2 billion), India's seed market is today one of the biggest in the world, and double the size of what it was before Bt muscled its way into the Indian agricultural terrain. Of the Rs 10,000 crore market, almost 40% is dominated by Bt cotton. In other words, the entire rise in size of Indian seed market has been because of Bt cotton. "Before 2002, cotton seeds comprised just around 10 to 15% of the Indian seed market, which now stands at almost 40%," Dr. Ramasami, chairman-cum-managing director of Tamil Nadu-based Rasi Seeds Ltd. told *Business Standard*.

Table 1. Size and structure of the Indian private seed industry with R&D (1987 to 2009).

	1987	1995	2005	2008-09
R&D expenses (2005 million US$)	1.3	4.9	26.9	88.6
Research staff (includes tech staff in seed & biotech labs)	76	297	N/A	1,500
Area of experiment stations (Ha)	408	1503	N/A	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
No. of firms conducting R&D	17	38	28	34

Sources: 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.

Growth during the Green Revolution period was led by government-owned state seed corporations. In the last two decades, the structure of the seed industry has become increasingly dominated by private-sector seed corporations. New Indian and foreign firms entered the industry and both Indian firms and multinational corporations (MNCs) expanded rapidly in the last decade by increasing their sales and through mergers and acquisitions. For example, Vibha Seeds, a new privately-owned firm founded in 1995, is now one of India's top 10 seed firms in sales and R&D, and it is expanding now into Africa. Perhaps the most important new Indian firm is Advanta, an MNC which was purchased by the Indian generic pesticide company, United Phosphorus, Ltd. in 2007. DevGen, another new and promising biotech firm based in Belgium, recently bought Monsanto's Indian rice, millet, and sorghum operations. In 2013, DevGen was purchased by Syngenta.

These changes have resulted in a more competitive industry. The four-firm private-sector concentration in the industry[1] has declined from almost 70% in 1987 to 36% today (Table 1). At the same time, the share of sales by foreign-owned seed companies increased from 10% in 1987 to about 40% today.

Domestic seed firms traditionally depend on their own earnings and family funds for expansion and development. Recently, however, Indian firms have sought outside investments to establish or upgrade biotechnology laboratories or engineering facilities. A few firms raised money through initial public offerings in Indian stock markets (Advanta, Kaveri, JK AgriGenetics, and Nath), and a few obtained funding for expansion through private equity and venture capital financing. For example, Summit Partners (a US firm) has invested US$30 million in Krishidhan seeds,[2] and Blackstone Investments (also a US firm) invested in Nuziveedu seeds.

Seed and biotech industry R&D grew faster than any other agribusiness in India and now conducts more private agricultural R&D in India than any other agribusiness, with current annual investment of more than $88 million (Pray & Nagarajan, 2012). Table 1 shows that the increase in R&D expenditure was accompanied by an increase in the number of scientists and land in experiment stations.

Indian companies have increased R&D since early 2000 with 29 local firms accounting for 56% of total R&D expenditures. Although average R&D investments per firm by local firms are less than MNC investments, firms such as Krishidhan, Mahyco, JK AgriGenetics, Rasi, Vibha, Kaveri, Advanta, and Ankur now spend more than US$2 million on research annually in India. Some firms, such as Vibha 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 was also included, spending which exceeded by 5 times its expenditures in India in 2009 (Advanta, 2010).

Five US- and European-based MNCs account for about 44% 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, as both made major investments in large research facilities as part of their global R&D programs.

Seed firms have some of the highest research intensity of any agribusiness in India, with research expenditures as high as 13% of sales. Research intensity for the Indian seed industry as a whole increased to 3.8% in the

1. *This calculation includes only seed sold by private firms. It excludes seeds sold by the State Seed Corporations and farmer saved and traded seed.*

2. *See http://in.reuters.com/article/2010/04/12/idINIndia-47620620100412.*

early 2000s (from 3.0% in the 1990s; Pray & Basant, 2001) and then again to 7% in 2009. Recent growth in research intensity is mostly due to large research investments by DuPont and Monsanto, which increased MNC research intensity to 10.1% in 2009, up from 2.5% in 2000. Domestic firms kept up with growth in sales, remaining at about 5.5% from 2000 to 2009 (Pray & Nagarajan, 2012).

Seed industry research focuses almost entirely on crops such as cotton, maize, rice, and some vegetables where hybrid seed can be profitably produced. Hybrid seeds cannot be reproduced easily by other seed companies or by farmers, and they provide firms with larger markets and some protection of their intellectual property. Public sector research has produced most of the cultivars of wheat, rice, and other crops where hybrid seed is more difficult to produce. Cotton accounts for about 40% of plant breeding research, followed by maize (25%), hybrid rice (15%), and vegetables (20%; Pray & Nagarajan, 2011). These breeding programs focus primarily on improvements in product yields and quality and on pest and drought tolerance.

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 their own R&D facilities or ones in collaboration with MNCs. Companies who 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).

Conventional plant breeding is the major tool used to develop improved hybrids, but all major plant-breeding companies now complement this with biotechnology laboratories to make use of genomic information and molecular markers in their breeding programs. During the 1990s, only three companies had biotech research programs (Pray & Basant, 2001). In 2008, 35 seed companies had biotech research programs approved by the Department of Biotechnology to work on transgenic plants (Indian GMO Research Information Service [IGMORIS], 2010).

Most of the 35 companies with biotechnology research programs are developing GM hybrids 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 the major focus of this research, followed by disease resistance, herbicide tolerance, drought tolerance, and then 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 and has 10 registered with the government's Genetic Engineering Approval Committee. Patents on GM traits were not granted until after 2005 and foreign companies dominate agricultural biotech patenting—78 patents have been granted to foreign firms and one granted to an Indian company (Pray & Nagarajan, 2012). As a result, unlike in other countries, they do not provide much information on what research India is doing.

Determinants of Seed and Biotech Industry Research in India

This article attempts to sort out the impact biotechnology has had on R&D in the seed industry by developing an econometric model of R&D and testing it on the Indian seed industry. Pray and Fuglie (2001), in their paper on the growth of R&D by private seed firms in Asia, used an induced innovation framework in which the major factors determining the levels of R&D were expected demand for new technology, the ability of science-based firms to appropriate the benefits from R&D, the technological opportunities (a combination of the expected costs of research and innovation and their assessment of the probability of successful innovation), and government policies.

Past studies in India have suggested that the most important factor in the growth of private seed industry R&D between 1987 and 1995 was the government policy of seed industry liberalization—reforms in industrial policy, which allowed large Indian companies and multinational corporations to enter the seed industry. Before 1986, the seed industry was reserved for small Indian firms. After new regulations and laws came into effect in 1986 and 1988, large Indian firms and foreign firms were allowed into the seed industry. Ramaswami, Pray, and Kelley (2001) found that about one third of the growth of R&D between 1986 and 1995 could be accounted for by the entrance and expansion of large Indian and foreign-owned firms. Beginning early in

2000, the firms were allowed to import seeds of most crops and planting materials under open-general licensing (OGL). Also, the foreign direct investment policies towards investing in the seed/biotech industry relaxed, which created more opportunities for foreign and domestic firms in sourcing technologies. These policies greatly increased the availability of capital for industry expansion and R&D, effectively reducing the cost of R&D.

A second key factor explaining the growth of R&D before 1995 was the ability of firms to capture more of the value of their innovations by selling new cultivars that are hybrids. Farmers cannot multiply the seeds of hybrids themselves and hybrids are not easy for other seed companies to copy. This allowed companies to sell these seeds at higher prices than the seeds of conventional varieties and to make profits despite having to cover the extra costs of research and innovation. The commercial seeds of all of the major crops for which seed firms were developing new cultivars in India were hybrids—maize, sorghum, pearl millets, and cotton. Since the early 1990s, firms started conducting research on hybrid rice and hybrid mustard, which greatly increased investments on R&D in those crops (Ramaswami, Pray, & Kelley, 2001).

The third major factor in the growth of Indian industry R&D was new technological opportunities from breakthroughs in biotechnology and from research by the Indian and State governments, as well as international centers such as International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Maize and Wheat Improvement Center (CIMMYT), and International Rice Research Institute (IRRI).

Based on the induced innovation model, we have developed three hypotheses about the way biotechnology has affected R&D by the Indian seed industry. The first hypothesis is that biotechnology greatly increased actual and expected market size in the seed industry, which increased R&D. As mentioned above, the adoption of Bt cotton greatly increased the market size of the seed industry. Sales of Bt hybrid cotton by the leading firms increased from $56 million in 2004/05 to $336 million in 2009/10 (calculated from Pray & Nagarajan, 2010). Biotechnology increased farmer demand for seed by increasing the yields of cotton and by allowing seeds to take over markets from other industries—for example, insect-resistant Bt cotton replaced insecticides (for the latest evidence of this, see Krishna & Qaim, 2012). The superiority of this technology allowed proprietary Bt hybrids to replace public hybrids and varieties that

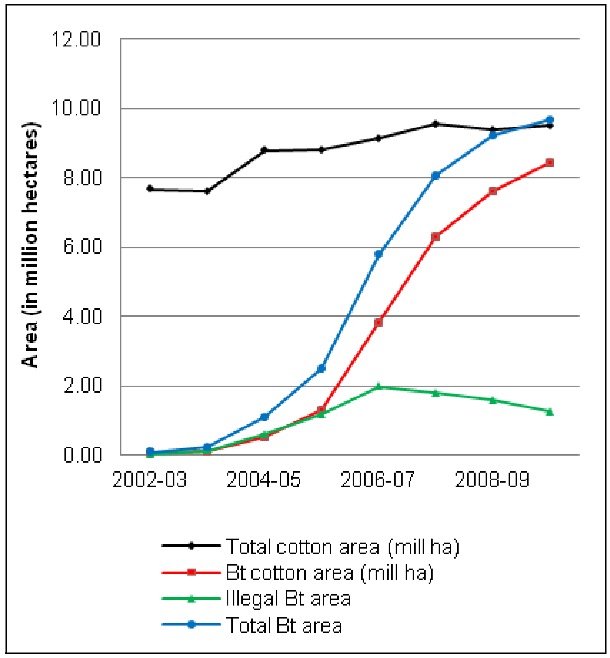

Figure 1. The spread of legal and illegal Bt cotton (in million ha).
Source: Industry estimates

were developed by public R&D and distributed by government seed corporations. The success of Bt cotton and the pipeline of GM maize, rice, eggplant, and other crops that were being tested by public and private research institutes led to the expectation of more profits in the future.

The second hypothesis is that biotechnology increased appropriability, which is the ability of firms to capture the economic benefits of new technologies because of the regulations and the regulatory agencies and NGOs that control and monitor the use of GMOs. The difficulty of obtaining biosafety approval for new GM traits assured Monsanto and its partner MAHYCO of a monopoly on the sale or licensing of Bt genes until 2006. Likewise, it provided market power to all other companies who developed and received approval for new GM traits approved through the regulatory system. In the early 2000s some companies sold Bt cotton hybrids without going through the regulatory process, but they were gradually suppressed by the enforcement of biosafety regulations through lawsuits and fines and economic forces (Ramaswami, Pray, & Lalitha, 2012). Figure 1 shows that illegal Bt cotton spread as rapidly as legal Bt cotton until 2006-07 when economic regulations forced down the price of legal cotton seed and new types of Bt (Bollgard II and Indian Bts) came on the market.

Table 2. Cotton hybrids, biotech, and R&D productivity.

Year	Non-Bt proprietary hybrids(#)	Bt proprietary hybrids(#)	Cotton R&D expenditures (million Rs)	R&D productivity (hybrids/ million Rs lagged)
1994	8		25	
1998	19		145	
2000	20		210	1.48
2002	22		460	
2004	24	3	710	0.15
2009	25	54	3000	0.11

Sources: # of hybrids are from Francis Kanoi Cotton Database; R&D expenditures from our surveys of companies (Pray & Nagarajan, 2010)

Table 3. Variables in seed R&D models and data sources India.

Private research determinants	Variable	Measurement	Source
Dependent variable	R&D expenditures	Amount of expenditures that includes capital and recurring R&D in million Rs	Personal interviews, annual reports, and web sources
Market size and growth	Sales	Annual seeds sales turnover of the firms (million Rs)	Personal interviews, annual reports, and web sources
Appropriability/ technological opportunity	Biotech	GMO field trials conducted by firms (1 for trials, 0 for no trials)	IGMORIS (2010), Government of India; GEAC trials and DBT, India
Technological opportunity	Location	R&D headquarters in Hyderabad, which has major public plant breeding and biotech research	Company website, surveys, interviews
	Public research	Number of notified varieties from the public sector in proprietary crops	Department of Agriculture, Government of India
Control variables	Firm age	Number of years since the firm entered the market	Firm websites and surveys
	Ownership	Firms with domestic or foreign ownership (MNCs)	Firm websites and surveys
	Diversification	Firms with seed business only vs. diversified business(es)/part of business conglomerates	Firm websites and surveys

Source: Authors

Biotech traits in India were not patentable until 2005. As a result, the regulatory system provided the only way of protecting biotech intellectual property until the patent system became effective. Even if patents do become effective, regulations will continue to provide firms who can work their way through the regulatory system with market power.

The third hypothesis is that biotechnology greatly increased technological opportunities for developing new traits, although it also greatly increased the costs of research in terms of equipment, scientists, and labs. There is clear evidence from cotton that the pace of innovations has increased due to biotechnology. Table 2 shows a major jump in the number of Bt and conventional hybrids that are grown by a significant number of farmers. However, research expenditures also took a major jump. The last column compares the number of hybrids to R&D expenditures (including regulatory expenditures) 5 years earlier, which is when the research was conducted. The figures (last column in Table 2) suggest a decline in research productivity rather than the expected increase.

Econometric Model and Results

The basic induced innovation model has investments in agricultural research by profit-maximizing firms as a function of four main determinants: market size, appropriability, technology opportunity, and the cost of research inputs. Government policies and other factors can influence each of these factors. In Table 3 we have classified the factors affecting seed and biotech industry R&D for which we could obtain data.

The basic model we have estimated has the specification

$$\textit{R\&D expenditures}_{(i,t)} = f(\textit{market size, appropriability, technological opportunity, cost of research inputs}), \quad (1)$$

Table 4. Factors influencing the R&D by seed and biotech industry from 1994 to 2009 in India.

Log R&D expenses (million Rs)—Dependent variable	Random effects—GLS regressions from 1994, 2000, 2005, and 2009				Log-linear regressions for the year (2009 only)			
	Coef.	Std. err.	z	P>z	Coef.	Std. err.	t	P>t
Log of sales (million Rs)	0.8490	0.1111	7.64	0.000***	1.128	0.180	6.250	0.000***
# of public varieties notified for proprietary crops	0.0019	0.0009	2.06	0.040**				
GMO trials (0=No trials; 1=trials)	0.3258	0.2593	1.26	0.209	1.735	0.416	4.170	0.000***
Firm age (years)	-0.0158	0.0165	-0.95	0.340	-0.029	0.016	-1.870	0.071**
Location code (1=Hyderabad; 0=others)	0.3367	0.2630	1.28	0.200	0.010	0.300	0.030	0.974
Firm ownership (1=MNC; 0=domestic)	0.0642	0.3124	0.21	0.837	0.282	0.465	0.610	0.100
Diversification (1=diversified; 0=only seeds)	-0.4653	0.2001	-2.33	0.020**	-0.373	0.287	-1.300	0.203
Constant/intercept	-2.8346	0.6594	-4.30	0.000***	-5.028	1.310	-3.840	0.001***
Number of observations for all time periods (1994, 2000, 2005, & 2009)			113		**Number of observations (seed firms)**			37
Wald chi^2(7)			254.600		**F(6, 31)**			15.0400
Prob > chi^2			0.000		**Prob > F**			0.0000
Group variable			Firm wise		**R-squared**			0.7360
R-sq: within			0.7386		**Root MSE**			0.7917
Between			0.8287					
Overall			0.7870					

where i = firm; t = time period/year. For empirical estimation, we have derived the reduced form of the basic model (Equation 1) as defined by the variables in Table 1 as

$$\begin{aligned} R\&D\ expenditures_{(i,t)} &= Sales_{(i,t)} + GMO\ trials_{(i,t)} \\ &+ Location_{(i,t)} + Public\ varieties_{(i,t)} \\ &+ Age\ of\ the\ firm_{(i,t)} + Ownership_{(i,t)} \\ &+ Firm\ diversification_{(i,t)} \end{aligned} \quad (2)$$

Here i denotes the firm and t for time periods viz., 1994, 2000, 2005, and 2009.

The private research variable is a continuous variable for each firm in each time period. We have data for the seed firms for four different periods of time; the number of firms surveyed in each time period differs, from 16 to 37. This allowed us to set up the data for panel type of data estimation. After testing whether a fixed or random (time) effects model was more appropriate, it was concluded that with more time-invariant variables (location, firm ownership, and diversification) involved in the empirical estimation, random effects will provide the best estimates for the specified Equation 2. Hausman tests also indicated that a random effects model should be used rather than a fixed effects model. In addition, we ran the model for 2009 alone because we had R&D data from the maximum number of firms in that year.

The results from the random effects—generalized least-squares regression using panel data estimation—are given in the left side of Table 4. The results indicate that a firm's log of sales is an important determinant of the firms' research expenditures. The firms with the largest seed sales spend more on R&D. In recent years, firms have realized that biotechnology provides important new technological opportunities and firms have responded to these opportunities with more R&D as we have argued above. Unfortunately, the only variable we have on biotech research is whether they were conducting field trials on GM traits. This variable does have a positive impact on seed firms' R&D, but it is not significant at the 5% or 10% level. The public agricultural research in India measured by approved plant varieties is positive and significant, suggesting that public R&D complemented private seed sector R&D growth in India. The public varieties provide lines that can be used to develop proprietary hybrids and also act as a proxy for other types of research and the training of scientists who become private-sector scientists and managers. The coefficient on firm age is negative but not significant. The dummy variable for MNCs suggests that—controlling for sales—their R&D expenditure is no greater than Indian firms. Diversified firms spend less than firms which specialize only in seed and seed-related activities—the diversification dummy was negative and significant. Location of R&D headquarters in Hyderabad does have a positive impact on R&D, although it is not significant.

Like the results for the whole sample, the regression results using 2009 data indicate that firm size as measured by firms' annual sales is a major factor that increases R&D expenses of firms (left side of Table 4). For every unit increase in sales, we can expect to see about a 13% increase in R&D investment by firms. Older firms spent less on R&D than younger firms. The main important difference from the pooled data is that the GMO field trials dummy is positive and significant. If firms conduct GMO field trials, their research expenditure is about 67% higher than firms that do not. The location of the firm headquarters did not impact the firms' investment in R&D. The ownership of the firm did not have any significant impact on the R&D expenditures, as the domestic firms invest as much in seeds and biotech research and development as MNCs.

Impact of Biotechnology and Policy Implications

The econometric results provide support for our argument that market size and technological opportunity are major determinants of Indian R&D but by themselves do not clearly indicate the impact of biotechnology. The extra revenue that the seed and biotech industry earned from the sale of Bt cotton was Rs 4.3 billion in 2009 compared to about Rs 2.7 billion in 2004 (and would have been higher in the absence of price controls on Bt seed). Our regression estimates of the elasticity of R&D with respect to sales (revenue) suggest that Rs 300 million of R&D expenditure in 2009 was due to the increase in sales accounted for by Bt cotton. What we do not have is a measure of how much of that increase in sales is due to a shift in the demand for cotton seed due to higher cotton productivity and higher quality fiber or how much is due to the more appropriability as a result of the regulatory system. We do have overwhelming empirical evidence that Bt cotton increased cotton yields (Raney & Matuschke, 2011). We also have willingness to pay studies (Ramaswami, Pray, & Lalitha, 2012) that show farmers were willing to pay much higher prices for Bt hybrids than conventional hybrids due to their higher productivity and reduced pesticide use. Thus, we can reject the critics' argument that all of the increased sales is due to increased appropriability rather than increased demand by farmers due to the productivity of the Bt hybrids.

We did not find strong evidence that biotechnology increased R&D because research was more productive. There certainly was an increase in the number of cotton hybrids after Bt was introduced, but there was also a major increase in research expenditure. Our only biotech variable in the regression analysis—biotech research or not—is positively related to R&D and significant only when the model is run with the 2009 data.

Several findings about the structure of the seed industry are worth noting. The share of multinationals in the market has increased. Unlike the global seed industry, however, the Indian seed industry is now less concentrated than it was in the past. Both types of firms are investing in R&D and when one controls for sales, biotech, public research, and other variables, Indian firms spend about as much on R&D as multinationals.

Policies that increase the size of private firms' sales will increase private R&D, while policies that reduce the value of sales (such as the price controls imposed on Bt cotton seed) will have an important negative impact on private-sector R&D. Thus, if the government wants to encourage private research, it could remove price controls on Bt cotton hybrids. Allowing the use of GM technology (such as GM maize and brinjal) would increase seed-industry revenues in those crops and stimulate R&D spending both through revenues and expectations that there will be more GM seed sales in the future. Recent public policies that provide subsidies for the production of hybrid rice seeds in Eastern India and elsewhere could also be helpful if they provide private hybrids that are well adapted to regions in which they are being sold.

Other policies that are suggested by the regression results are investments in public-sector R&D. These expenditures produce public cultivars, which so far induce more private research. Finally, there is evidence that younger firms (measured by years in the Indian market) invest more in research than older firms. This suggests that programs such as the Small Business Innovation Research Initiative of the Indian Department of Biotechnology to develop new firms that have spun off from public research or from other companies may also increase research. Also, programs to encourage new firms and existing agribusiness to enter the seed business such as the Agri-Business Incubator at ICRISAT in India could be useful.

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