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Liberalization's Impact on the Indian Seed Industry: Competition, Research, and Impact on Farmers

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ABSTRACT: This article attempts to measure the impact of India's limited liberalization on the seed industry and on farmers. Using a unique data set on the structure, research, and sales of private seed firms at two points in time, 1987 and 1995, we provide evidence that liberalization increased the competitiveness of the seed industry, and increased the amount of research by Indian and foreign seed firms. Then, using government district level data and data collected from these firms, we show that private hybrids increased farmers' yields. This suggests that Indian farmers are the true beneficiaries of liberalization and that policies that encourage more competition and more research will provide future benefits to farmers.

INTRODUCTION

India has reformed its technology policy as part of its liberalization process of the late 1980s and 1990s. In the seed industry, the government launched a New Seed Industry Development Policy in 1988 that was supposed to encourage the private sector to play a larger role in the seed industry. However, some groups in Indian society are now arguing that reforms have gone too far in the agricultural sector. They raise the specter of foreign corporations using terminator genes to starve

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poor Indian farmers with seed that will not germinate. So far, there has been little quantitative evidence of the impact of reform on the Indian input industry and Indian farmers.

This article attempts to start to correct that situation by analyzing quantitative data on the impact of reform in a key agricultural input industry—the seed industry. The first section summarizes the structure of the seed industry and the policies that government is including in the recent reforms in the seed industry. The second section examines the quantitative evidence on the impact of reforms on seed industry structure and R&D by the seed industry using 1987 and 1995 data from surveys of the seed industry. The third section presents the first econometric evidence that the private hybrids have had a positive impact on farmers' yields. The fourth section suggests further policy reforms that are needed in the seed industry.

Seed Industry Structure and Policy Reform

The main source of seed for most Indian farmers is still farmer-saved seed. About 10% of the seeds of self-pollinated crops such as rice and wheat are supplied by the commercial seed system; the other 90% is farmers' saved seed. Twelve percent of all the seed planted in India is provided by the commercial seed system (Agrawal, 1997). Even when they plant hybrids, maize farmers still use over a third of their own seed despite the loss in yields because of planting second generation hybrids (Singh and Morris, 1997).

Seed production and marketing are done by both state seed corporations (SSCs) and private seed firms. Most of the seed distributed by both public and private seed firms is grown by thousands of small farmers on contract with SSCs or private firms. Some of the seed for SSCs is produced by a few large government farms. Seed is processed and packaged by the SSCs and private firms. Seed imports are negligible except for vegetable seed.

Industry representatives estimate that from 1984 to 1995, 50% to 60% of the value of seed was sold by the private sector (Chopra K. R. President, Seed Association of India, personal communication May, 1989; Agrawal, 1997). The Seed Association of India reports that private firms have the largest share of the commercial market of maize, sunflower, pearl millet, and sorghum sudan grass (personal communication, R. S. Arora, President Seed Association of India, letter to authors of November 1, 1996). Private firms also make up an important and growing share of the cotton and sorghum hybrid market. SSCs dominate the wheat and rice seed sales.

Research to produce new varieties is primarily conducted by the Indian Council of Agricultural Research (ICAR) institutes, State Agricultural Universities (SAUs), and International Agricultural Research Centers such as ICRISAT. ICAR and SAUs spent about Rs.1960 million (U.S. $55 million) on crop research in 1994 (Singh et al., 1996). Our survey found that the private sector spent about Rs. 155 million (U.S. $4.4 million) on plant breeding research.

The Indian government has intervened extensively in seed markets since the colonial period. The British established a system of testing new varieties, multiplying small amounts of those varieties on seed farms, and distributing seed of new varieties through the extension system. After Independence, the first major government seed industry initiative was to establish the National Seed Corporation and State Seed Corporations to meet the demand for seed caused by the Green Revolution in the 1960s. The first seed law was passed in 1966.

Restrictions on private seed firms started in the late 1960s. The Government of India banned commercial imports of any agricultural input that was also being produced in India. This applied to seeds of field crops, which could only be imported by the government, and vegetable seeds, which could be imported by private firms with special permission from the government. The government also restricted exports of seeds. The 1969 Industrial Policy Act restricted Indian firms that had more than Rs.1 billion in assets to "core" industries. In 1979, firms which had more than 40% foreign equity were also restricted to core industries.

The seed industry was not a core industry. Therefore, large Indian firms and firms with more than 40% foreign ownership were not allowed to enter the industry.

India reduced barriers to the entry of foreign firms and large Indian companies, and reduced regulations on importing new agricultural technology starting in the mid 1980s. The key reforms were: (1) seed and biotechnology industries were included in the list of core industries in 1986, which allowed foreign-owned firms and large Indian conglomerates to enter the seed industry; (2) the New Seed Industry Development Policy of 1988 allowed seed firms to import commercial vegetable seeds with no quotas, to import commercial seeds of foreign varieties of coarse grains and oilseeds for only two years (after which seed firms had to produce the seed inside India), and made it easier to import germplasm for research purposes; and (3) in 1991, regulations on technology transfer and foreign investment for the entire economy were reduced.

Impact of Reform on the Seed Industry

There is general agreement that reform allowed more foreign firms and more large Indian firms to enter the seed industry. But did they affect the amount of research? Did these reforms lead to increased imports of seed? Are foreign firms controlling the Indian seed industry? Have these changes increased or reduced competition in the seed industry?

The empirical bases of our analysis are surveys of seed firms conducted in 1988 and 1996. The 1996 data were collected through a May 1996 mail survey of private seed firms. Questionnaires were sent out to approximately 160 seed companies that either had links with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), were members of the Seed Association of India, or were identified by other firms. In all, 51 companies responded to the survey with information on these issues. These 51 included almost all of the major seed firms, accounting for about 75% of private commercial seed sales and 38% of public and private seed sales in India. <This calculation is based on total sales by the firms in our sample of Rs.3600 million, and Seed Association of India estimates of total commercial seed sales of Rs.10000 million in 1994 (Arora, 1996) of which about half were by the private sector.> In addition, we draw from a 1988 survey using a similar methodology which got responses from 28 firms including all the large private firms that were active in the mid 1980s (Pray et al., 1991). The data from these surveys are supplemented with government data when appropriate and available.

The changes in seed policies and regulations had very little impact on seed trade. Seed imports are negligible except in vegetables (Government of India, 1996). Sunflower is the only field crop with appreciable imports of commercial seed in recent years, and that was only for one year, 1991 through 1992. Even that was only about 7% of total commercial use. The volume of imports of vegetable seed, for which restrictions on trade were eliminated except a small tariff, increased much more than field crops. Seed exports were also very limited. Small quantities of maize, forage crops, and vegetable seeds are exported from time to time.

Reforms led to greater competition in the industry. After the 1986 change in the Industry Act allowed large Indian firms into the seed industry, J. K. Industries, SPIC (Southern Petrochemical Industries Corporation), Khatau–Junker Ltd., Godrej, Dunlop, and Harrisons entered the Indian seed industry for the first time. The last three soon dropped out. In addition, large, well-established firms that were partially foreign-owned such as Hindustan Lever Ltd.(HLL), ITC, ICI, and Sandoz also entered the seed industry. The other key group of new entrants was the multinational seed companies such as Cargill, DeKalb, and Monsanto, who generally came in as joint ventures or wholly own research or foundation seed companies with local distributors. The final group of new entrants was small seed companies.

The effect of these entrants was to reduce concentration and increase the competitiveness of the industry. The top half of Table 1 documents this impact. The number of firms that responded to our surveys almost doubled (Row 2, Table 1), but even more importantly the number of larger firms with research programs doubled. While the total number of firms in the sample is not a reliable measure of the growing number of firms in the industry, the number of research firms is. These firms are well known to ICRISAT and the seed industry, and with some

Table 1. Size and Structure of the Private Seed Industry 1987 to 1995

	1987	*1995*
Number of companies in responding to survey	24	51
4 firm concentration ratio (% private sales by top 4 firms)	68	51
Share of large (MRTP) Indian companies (% of private sales)	0	23
Share of firms with foreign ownership (% of private sales)	10	33
No. Firms Conducting R&D	17	38
Scientists		
Ph.D.	31	112
M.S.	45	185
Area of Experiment Stations (ha)	408	1503
R&D Expenditure (mil. 1995 Rs.)	41.7	154.9

Sources: Pray et al. (1991) and Pray and Kelley (1998).

extra work we were able to get questionnaires back from all of them in the both surveys. The new entrants included companies with substantial amounts of capital and large rural distribution networks (SPIC and JK had fertilizer distribution networks, HLL distributed consumer products, ICI and Sandoz distributed pesticides), and biological research programs (HLL, Sandoz, and ICI). Many small companies entered the industry selling public hybrids and varieties. The effect has been less concentration in the seed market as measured by the standard measure—the four firm concentration ratio—that went from 69% of private sales in 1987 to 51% of private sales in 1995 (see Table 1).

Multinationals or large Indian companies have greatly increased their share of the market but have not been able to dominate the industry. As the table shows, the large Indian companies went from nothing to a 23% share of the private market, while firms with some foreign ownership went from 10% to 33% of the private market. Because government corporations' sales are about equal to private sales, the share of the four largest firms in the total commercial market is about 25%. Assuming the commercial market is about 12% of all seeds used by farmers, the four largest firms supplied 3% of total seed used.

Impact of Reform on Research

Between 1987 and 1995 the real expenditure on research conducted by the private sector increased from Rs.41.7 million to Rs.154.9 million (bottom of Table 1). The number of researchers with Ph.D.'s went from 31 to 111. The number of research scientists with M.Sc.'s increased from 45 to 140, and the area under experiment stations from over 400 to over 1,200 hectares. The number of firms conducting research increased from 17 to 38.

How much of that increase is because of reform? Economic theory suggests that, in addition to policy changes, major factors influencing firms' research investment decisions are expected sales of the product of R&D, the ability to capture the benefits of research through intellectual property rights or technical means, and the expected costs of research. To identify the relative importance of the reforms in increasing research it is necessary to examine the impact of these other factors.

Of the 47 firms for which we have information, 20 firms entered the industry after 1987. They account for about 44% of the increase in R&D expenditures between the two surveys. Of these 20 firms, five firms would not have been allowed entry into the industry under the old policies– that is, they were either large domestic firms or foreign firms. The R&D budgets of the five foreign and large domestic firms that entered the industry since 1987 adds up to nearly 36% of the increase in R&D.

We now turn to examining whether reforms had a role in (1) inducing the entry of the 15 small Indian firms and (2) the expansion of R&D budgets of the incumbent firms.

The small Indian firms primarily conduct pearl millet and sorghum plant breeding research –crops in which public research programs are strong, and the market for hybrid seed was increasing. Thus, the spurt of entry and research by small firms may well have been more closely related to the opportunities thrown up by the growing market for hybrids, and opportunities provided by public research than by seed policy reform.

In 1995, incumbent firms (i.e., firms that were in the industry before 1987) accounted for 61% of total R&D expenditure. The increase in the budgets of incumbent firms amounts to 54% of the increase in industry R&D budget. Was this expansion related to seed policy reforms or was it simply higher sales which led firms to expect even higher sales in future on proprietary hybrids? If future sales are a projection of current sales, we can control for this factor by comparing the ratio of R&D expenditures to current sales across the two surveys. This ratio was 3.6% in 1987 and 6.9% in 1995. In 1995, these firms almost doubled their R&D expenditure ratio, which indicates that higher sales were not the only important factor in their growth.

The second factor that may have caused an increase in R&D expenditures was the development of hybrids for rice and rapeseed. Between 1987 and 1995, it became clear that hybrid rice and rape/mustard were commercially feasible. Hybrids can enhance the private returns to research investments because seed from hybrids cannot be used repeatedly without significant quality deterioration. All of the private research by the seed industry was on crops for which production of F1 hybrids is possible (Table 2). In 1995, hybrid rice was the subject of research by 15 companies; in 1987, no companies were doing hybrid rice breeding. Only one private company had mustard and rapeseed research programs in 1987; now at least nine firms do. To control for this effect in the incumbent firms, we delete the R&D expenditures on rice and rapeseed from the total in 1996, and then compare the ratio of the resulting magnitudes to sales between the two periods. Now the growth is from 3.6% to 5.2%—still a considerable increase.

Table 2. Private R&D by Crop 1987 and 1995

	No. Firms with R&D		*R&D Expend. (Mil. 1995 Rs.)*	
	1987	*1995*	*1987*	*1995*
Sorghum	10	27	7	21
Pearl Millet	12	30	8	20
Maize	6	24	4	23
Sunflower	10	26	7	21
Cotton	9	27	4	27
Mustard	1	9	1	10
Rice	0	15	0	16
Others	9	20	9	16
Total	17	38	40	155

Source: Same as Table 1.

Increased technological opportunity to produce new products could also have stimulated research in the incumbent firms, but no data are available to test its impact. Advances in biotechnology had stimulated some limited research investments by 1995. The SPIC Science Foundation has had a rice biotechnology research program for a number of years. It is loosely linked to SPIC's seed firm. Proagro established a biotechnology laboratory in Gurgaon, near Delhi, which had three Ph.D. scientists working with transgenic mustard and vegetables in 1995. MAHYCO was just starting to invest in biotechnology research.

Other less dramatic advances in science have also been important sources of technological opportunity. The Indian public research system has made major contributions of inbred lines, germplasm, and breeding techniques in rice, sorghum, pearl millet, cotton, and sunflower. ICRISAT has made contributions of germplasm and techniques in pearl millet, and sorghum. IRRI is responsible for developing tropical male sterile lines and restorers that were the basis for India's hybrid rice, and CIMMYT contributed to the maize germplasm used by private breeders (Singh et al., 1995). ICRISAT produced the world's first pigeon pea hybrid in 1992, and private seed companies have been fast to follow in producing their own.

To document the importance of public research to private firms, we asked firms to rate the importance of various sources of breeding material. Firms' ratings of the importance of various sources of germplasm support the importance of the Indian public sector and international centers, and to private sector breeders. Table 3 shows the percentage of firms that rated a source of germplasm as "very important." ICRISAT is reported to be very important by 65% and 80% of the sorghum and millet breeding firms, respectively. ICAR/SAUs are very important for 66% of the cotton breeders, and joint venture partners are the most important outside source of sunflower breeding material. The importance of ICRISAT may have been overstated. The survey was sent out from ICRISAT, and the users of

Table 3. "Very Important" Sources of Breeding Material for Four Crops (% of firms which said source was very important)

	Sorghum	*Pearl Millet*	*Sunflower*	*Cotton*
ICRISAT	65	80	na	na
ICAR/SAU	29	34	0	66
Parent/JV	23	9	33	3
Foreign Co.	0	3	11	0
Other Indian Co.	10	0	22	66
Own collection	53	49	63	10

Source: Pray and Kelley (1998).

ICRISAT germplasm had more reason to respond to the survey and to respond in a way that was favorable to ICRISAT.

We conclude that reform was a very important factor accounting for the increase in private research in India. Thirty-six percent of the increase was by firms that could not have entered the industry without the reforms. Much of the increase in research by the incumbent firms is also because of reforms. The competitive pressure of new entrants that have major research programs forced local firms to invest more in research to remain competitive. In addition, greater ability to appropriate the gains from research because of the development of rice and mustard/rapeseed hybrids accounted for up to 20% of the increase. Finally, developments in biotechnology and conventional public sector breeding also encouraged growth in private research.

Impact of Private Research on Farmers

The increase in private research by the seed industry concentrated on a few crops which, in order of expenditure on research, were cotton, maize, sunflower, sorghum, pearl millet, hybrid rice, rapeseed-mustard, and others. The primary goal of most private plant breeding research in India has been to increase yields while ensuring that the new varieties are not susceptible to pests and disease, and are of at least equal quality of the current varieties. This section attempts to measure how well firms have succeeded in increasing yields, and how much of the benefits the seed firms were able to capture.

Yields

The increase in private research led to an increase in the area under private hybrids. Our data on district level area under private hybrids based on estimates by six of the largest private firms is the first published estimate of district level area under private hybrids. The results in Table 4, columns two and three, show that the area under private hybrids increased in all states for which data are available. In Andhra, the percentage under private pearl millet and sorghum

Table 4. Spread of Private Hybrids

Crop and State	*% Area under Private Hybrids: 1990*	*% Area under Private Hybrids: 1995*	*Yield (tn/ha): 1985–1990*	*Yield (tn/ha): 1991–1995*
Sorghum, Andhra Pradesh	9	29	.64 (120)	.74 (100)
Sorghum, Karnataka	29	46	.87 (98)	1.04 (60)
Sorghum, Maharashtra	8	18	.91 (133)	1.0 (111)
Pearl Millet, Andhra Pradesh	10	33	.68 (103)	.8 (83)
Pearl Millet, Karnataka	10	24	.48 (69)	.54 (44)
Pearl Millet, Maharashtra	34	42	.45 (120)	.63 (97)
Maize, Andhra Pradesh	50	74	1.67 (114)	2.48 (92)
Maize, Karnataka	33	61	2.5 (103)	2.82 (70)
Maize, Maharashtra	25	30	1.04 (126)	1.31 (111)

Notes: Figures in first two columns are based on estimates by private seed firms. Data in last two columns for a state are averages across districts and years. The figures in parentheses are the number of observations. They differ from variable to variable because of missing observations.

tripled from the late 1980s to the early 1990s. The maize and sunflower percentages in Karnataka doubled, as did the share of private hybrid sorghum in Maharashtra. According to government statistics, yields increased in these states also (columns 1 and 2 of Table 4). Thus, it is possible that the private hybrids led to increases in yields.

The empirical model for our partial productivity analysis is similar to the model of total factor productivity analysis in the literature (Evenson et al., 1999). The independent variables in our analysis include a measure of the spread of high yielding varieties expressed as a proportion of the crop area devoted to all varieties (PHYV). This variable is taken to be a proxy for past public research expenditures, but it also includes area under private hybrids of maize, sorghum, and pearl millet. Additional variables include a measure of the spread of private varieties (PVT), the proportion of crop area that is irrigated (PIR), the fertilizer use in the entire district (N), the number of regulated markets in the district (MARKETS), the length of roads in the district (ROADS), a measure of profitability of the crop (ARP), a trend variable (YEAR), and variables measuring rainfall in June (JUNE), July and August (JULAUG) and for the entire year (ANNUAL). In the language of the Evenson, Pray and Rosegrant article, the Technology variables are HYV and PVT, the Infrastructure variables are irrigation, fertilizer use, markets, and road length while the trend and the rainfall variables are the "Other" variables.

Included here and not found in the literature is a proxy for crop-specific profitability. This is derived as a three-year moving average of the harvest price (deflated by the index of manufacturing prices). The rationale for including it is that it would be highly correlated with variable input use (including labor) for which we have no crop-specific data. The basic model is augmented by interaction variables of PHYV with PVT, irrigation and fertilizer use, and of PVT with irrigation and fertilizer use. Although much of the literature chooses a double-log functional form, we report the results for a linear model because in model selection tests the double-log form was rejected relative to the linear model. The analysis uses standard pooling techniques of estimation.

Our analysis covers maize, sorghum, and pearl millet. Because private varieties have been significant in these crops only recently, our analysis is confined to the period from 1985 onwards. Table 4 records the growth in the share of area under private hybrids between the years 1990 and 1995. We observe large increases in Andhra Pradesh and Karnataka, whereas more modest increases are seen in Maharashtra. The last two columns of Table 4 record the change in average district yields between the periods 1985 through 1990, and 1991 through 1995. In all cases, average district yields have increased. It is natural to ask, therefore, whether the increases in yields were associated with greater adoption of private hybrids. Our objective is to examine whether variation in area under private hybrids is a significant determinant of the variation in average district yields. Informed and rational agents would, of course, not adopt an innovation unless it makes them better off. We are not therefore attempting to test whether yields of private hybrids are higher than currently grown cultivars. Rather our goal here is to test for the influence of private hybrids on the overall rise in crop yields.

For our analysis, we used government data on various district level figures such as yields, fertilizer use, adoption of high yielding varieties, infrastructure availability, and weather. These data were supplemented by a variable measuring the proportion of crop area under private hybrids. This information was obtained by eliciting estimates from private seed companies. Because private hybrids have been significant in these crops only recently, our analysis is confined to the period since 1985.

The regression analysis analyzed private hybrids by individual crops and states. Table 5 provides an example—a maize regression in Maharashtra. Table 6 summarizes the results of the regressions. Private hybrids' impact on yields is positive, and statistically significant in 5 of the 9 crops and provinces, and close to significant in a 6th case. In addition, the HYV variable is statistically significant in 4 of the 9 regressions. These estimates provide first econometric evidence that we know of in which private hybrids have had a positive impact on crop yields in developing countries. This is particularly impressive because the region examined is in the semiarid tropics, where private research is not expected to have much impact. In addition, the results support the continued importance of the public sector research which is producing the HYVs.

Maize and sunflower are the crops that should be most important to private foreign research because multinationals and local firms can draw on large research programs on these crops in temperate regions of the world. The private maize variable is positive in all three states, and is significant in Maharashtra and Andhra Pradesh. In Karnataka, the impact of private varieties is not significantly different from zero. The HYV variable is significant.

Table 5. Maharashtra: Maize Yield Function

	Continuous Private Variable
Private Varieties	.04 (3.3)
HYV	.13 (.96)
Irrigation	−.14 (.99)
Average Real Price	.75 (2.26)
Fertilizer	−.000000008 (.001)
Roads	−.000006 (.7)
Markets	.021 (1.7)
Rainfall, July-August	−.001 (3.20)
Rainfall, June	−.0005 (1.3)
Rainfall, Annual	.0007 (3.24)
Trend	−.006 (.21)
Number of Observations	191
Number of Districts	24
R square	0.27
	Fixed Effects

Interviews with seed companies suggest that sorghum and pearl millet have not benefited much from recently imported germplasm, but have benefited from private breeding based on strong public research programs. Thus, one might expect to see private and HYVs statistically significant. What we found was that both were positive and significant in sorghum in Karnataka, and close to significant in sorghum in Maharashtra. Elsewhere the results were mixed.

Table 6. Summary of Impact of Private and Public Hybrids on Yields

Crop & State	*PVT*	*HYV*	*Estimation Technique*
Sorghum, Andhra Pradesh	.0027* (1.92)	−.09 (1.54)	Random Effects
Sorghum, Karnataka	.0083** (2.34)	.44** (2.99)	Random Effects
Sorghum, Maharashtra	0.008 (1.54)	.23* (1.88)	Fixed Effects
Pearl Millet, Andhra Pradesh	0.0007 (.27)	−.084 (1.1)	Fixed Effects
Pearl Millet, Karnataka	−.0002 (.11)	.39** (3.2)	Random Effects
Pearl Millet, Maharashtra	.01* (1.91)	.02 (.32)	Fixed Effects
Maize, Andhra Pradesh	.023** (2.27)	−.11 (.7)	Fixed Effects
Maize, Karnataka	.005 (.48)	.77* (1.7)	Random Effects
Maize, Maharashtra	.04** (3.33)	.13 (.96)	Fixed Effects

t-values in parentheses. *Denotes estimates significant at the 10% level and **denotes estimates significant at the 5% level.

Distribution of Benefits

Many people argue that the only beneficiaries of plant breeder rights, hybrid seed, or plant biotechnology will be the seed companies and Life Science companies, not farmers. This does not make much sense unless you believe that Indian farmers are so irrational or misinformed that they would adopt a technology that does not give them any benefit. Nevertheless, it seems useful to look at the quantitative evidence that is available. It supports the argument that Indian farmers are rational and are adopting proprietary hybrids because they, not the seed companies, capture most of the benefits.

The only study that has looked at how the benefits of private hybrids were divided in India is Pray et al. (1991). In 1986 and 1987, yields of private pearl millet and sorghum hybrids were higher than public hybrids and public open pollinated varieties in the All India Coordinated yield trials run by ICAR and in farmers fields. In the ICAR pearl millet trials, a MAHYCO private hybrid, MBH 110, out-yielded the check hybrid, BJ 104, by an average of 23%, and yields of Pioneer hybrids were 7% to 10% higher than MBH 110. In the ICAR sorghum trials, yields of private hybrids were approximately 15% higher (AICSIP and AICMIP 1987 and 1988). Farm level yields from surveys carried out by ICRISAT and Rutgers University in nine districts of Maharashtra and Gujarat found similar yield increases in 1986 and 1987.

Seed prices were considerably higher for private hybrids than for public hybrids or varieties. Farmers paid Rs.28/kg for private pearl millet hybrids compared to Rs.12/kg for public hybrids, and Rs.7/kg. for public varieties. Farmers paid Rs.24/kg for private sorghum hybrids, Rs.14/kg for public hybrids, and Rs.5/kg for public varieties. Nevertheless, the value of increases in farmers' yields of hybrid sorghum and pearl millet greatly outweighed the increase in cost of seeds. Seed companies had increased costs for producing private hybrids over public hybrids, and over open pollinated varieties. We calculated the increased net income of seed firms and of farmers from the sale and use of private hybrids, rather than public hybrids, as the total benefits of private research. For hybrid sorghum, the seed companies captured at most 18.5% of the benefits as higher net income, while 81.5% of benefits went to farmers (the value of increased production minus the increased cost of seed). For hybrid pearl millet, seed firms captured only about 6% of benefits. More than 90% of the benefits from private pearl millet research went to farmers.

A recent study of the maize seed industry (Singh and Morris, 1997) contains evidence that supports the conclusions of the earlier pearl millet and sorghum study. ICAR and CIMMYT designed and carried out a survey of 480 farmers in six states from 1994 through 1995. They found that hybrid maize yields were higher than open pollinated varieties by about 1 metric ton per ha. Most of these hybrids are private, and private hybrids have seed prices that are six times the price of grain. If we use Rs.2800/ton (the 1994–1995 procurement price) as the price of maize grain and the price of open pollinated varieties of seed, and 20kg/ha as the planting rate, the increased cost of seed will be Rs.560/ha. The increased value of output is about Rs.2800, out of which Rs.560 has to be subtracted for increased cost of seed. In addition, small amounts should be subtracted for increased costs for fertilizer and perhaps herbicide. Clearly, the seed firms are not capturing all the benefits from adoption of the private hybrids, and farmers, along with fertilizer and herbicide suppliers, are getting most of the benefits. It is also important to remember that the increase in seed prices is not pure profit for the seed firm because it now has to pay for R&D, processing, transportation, and quality control. To the extent that maize prices are pushed down by farmers' increased productivity, consumers rather than seed firms will be the main beneficiaries of using private hybrid maize seed.

Policy Implications for the Seed Industry

Policy reforms have so far increased competition and research in the seed industry. There are more firms in the seed industry. Seed sales are less concentrated. Policy changes have also increased the amount of research by foreign owned firms and by local firms. The article also provides evidence that the greater ability of firms to capture benefits from their research through hybrids, the greater the research. This suggests that stronger legal protection of intellectual property would also increase private research. In addition, new technological opportunities based on biotechnology and public plant breeding research contributed to the growth in private research in India.

The second major finding of this article is that farmers in some of the poorest regions of India capture the benefits from private research. Our regression results show that private research has a positive impact on yields of crops in the semi-arid tropics. Data from our 1988 survey and research by CIMMYT indicate that farmers, rather than seed companies, get most of the benefits from these new hybrids, despite the higher prices of seeds.

We believe that the policy implications of the analysis in this article for India and for other developing countries are as follows:

- Reduce the regulatory barriers to investment and trade by large local firms and foreign firms in the agricultural input markets. This increases competition based both on product quality, as well as research and prices. The gains could be especially great in countries such as China that are still closed to foreign seed firms.
- Reduce regulations with which governments try to choose the most efficient technologies for farmers—such as mandatory government testing of varieties to ensure that they are higher yielding than current varieties—and focus govern-

ment regulatory efforts on preventing negative externalities—for example, plant quarantine to reduce disease. India has had voluntary registration of new varieties and voluntary testing of these varieties throughout this period. This policy, which allows firms to start selling their new varieties without going through three or more years of government testing and bribery, could greatly reduce the cost of research and the arbitrariness of the testing system in many developing countries.

- Continue government investments in public goods and goods that have large positive externalities. These include basic research in areas such as biotechnology, and applied research such as plant breeding of crops, in which weak intellectual property rights lead to suboptimal levels of private research.
- Stronger intellectual property rights on plant varieties and genes will lead to more private research. Developing countries that continue to resist stronger intellectual property rights—including India—are missing out on research that can help their farmers.

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