Ind. Jn. of Agri. Econ.
Vol. 57, No. 1, Jan.-March 2002

ARTICLES

Dissemination of Private Hybrids and Crop Yields in the Semi-Arid Tropics of India

Bharat Ramaswami, Carl E. Pray and Timothy Kelley*

I

INTRODUCTION

Many countries in the developing world have experienced significant unprecedented increases in foodgrains output. It is well known that advances in plant breeding provided a basis for this achievement. The research that produced the new high-yielding varieties (HYVs) of seed and the extension services that disseminated it were largely financed by public funds through national and international agricultural research systems. Today, it is not so clear that plant breeding research is a predominantly public good. Technological developments, such as the development of hybrid seed, and new legal protections, such as the assignment of property rights to biological inventions, have strengthened the appropriability of private research and diminished the public good nature of, at least, certain kinds of agricultural research. As a result, in the developed countries, the private sector is an important supplier of technology even in traditional areas of public sector research like plant breeding.

Can this be so in developing countries too? The question is important in the light of current debates in developing countries about the role of the private sector in agricultural research. Should government policy acknowledge a role for the private sector? Can the private sector be expected to do research? Should governments allow foreign firms into the seed industry? For some, these are not issues at all. By unleashing another round of technological change, private plant breeding would increase agricultural productivity making better-off farmers and consumers. Others are not so sure. They fear that the products of private research would be high priced and will not be afforded by poor farmers.

Legal protections in developing countries are relatively weak and have not been the principal barriers to replication. As is well known, seed from hybrid-seeded crops

* Indian Statistical Institute, New Delhi-110 016; Agriculture, Food and Resource Economics, Rutgers The State University of New Jersey, New Brunswick, N.J. 08901-8520, U.S.A.; and Senior Agricultural Research Officer, TAC Secretariat, FAO, Rome, Italy, respectively.

The opinions expressed here are those of the authors and do not reflect the official position of any of the organisations that they are affiliated with or that helped fund this project. We thank Vasantha Mamidi for excellent research assistance. P. Parthasarathy Rao at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru (A.P.) made available to us much of the data. We are grateful to him for his time and patience. We also acknowledge the assistance of an anonymous referee for useful comments.

cannot be used without major yield reductions in future generations. Hybrid seeds therefore provide a mechanism for private technology suppliers to appropriate a significant enough share of the gains from higher yields. And this has been the principal route for private firms in the seed business. This route is, however, blocked for entry into wheat and rice - the principal food crops of Asia. Wheat hybrid seeds have not been developed and hybrid seed in rice is recent. Maize, sorghum and pearl millet are the food crops where hybrid seeds have been successfully developed. It may therefore seem that private hybrid seed promise little to the wheat and rice eating developing world. However, even in predominantly wheat and rice eating regions, such as South Asia, sorghum and pearl millet are important to a poor household's diet. In addition, in India, these crops are grown predominantly in the poorer semi-arid regions rather than in the more favourably endowed wheat and rice growing areas.

India has one of the largest private seed sectors in the developing world. While a large number of firms confine their activity to seed multiplication and distribution, there are some firms active in plant improvement through plant breeding. As a result of policy changes in the late 1980s culminating in the economy wide reforms of 1991, investments in private plant breeding multiplied three-fold (Pray *et al.*, 2001). Is private plant breeding then an important source of technology in the poor semi-arid tropical regions of India? And in particular, is this so for crops like sorghum and pearl millet? These are the questions that we seek to answer in this paper.

II

AN EMPIRICAL MODEL

Our analyses cover sorghum, pearl millet and maize in three states of the semi-arid tropics - Andhra Pradesh, Karnataka and Maharashtra. In consumption data, sorghum, pearl millet and maize are coarse cereals. Table 1 shows the shares of rice, wheat and coarse cereals in total cereal expenditure by different income groups. In all the three states, the share of coarse cereals is the highest for the poorest 30 per cent of the population. This suggests that yield improvement in coarse cereals will benefit poor households the most. In Karnataka and Maharashtra, where coarse cereals are more important in the diet of poor households than rice and wheat,

TABLE 1. SHARE OF COARSE CEREALS IN TOTAL CEREAL EXPENDITURE OF RURAL HOUSEHOLDS IN 1993-94

Rural (1)	Andhra Pradesh (2)	Karnataka (3)	Maharashtra (4)
Bottom 30 per cent	0.12	0.53	0.55
Middle 40 per cent	0.07	0.37	0.39
Top 30 per cent	0.04	0.24	0.25
All	0.07	0.35	0.37

Source: From the National Sample Survey (NSS) on Consumption Expenditure, as tabulated in Joshi (1998).

productivity increases in coarse cereals are, at the margin, more important in increasing the welfare of the poor than productivity increases in rice or wheat. Thus even though average consumption patterns favour rice and wheat, the productivity of coarse cereals matters a great deal to the poor.

Table 2 records the share of area under private hybrids for the years 1990 and 1995. We observe large increases in Andhra Pradesh and Karnataka while more modest increases are seen in Maharashtra. Table 3 records the change in estimates of average district yields between the periods 1985-90 and 1991-95. In all cases, average

TABLE 2. SPREAD OF PRIVATE HYBRIDS

Crop and State (1)	Per cent area under private hybrids, 1990 (2)	Per cent area under private hybrids, 1995 (3)
Sorghum, Andhra Pradesh	9	29
Sorghum, Karnataka	29	46
Sorghum, Maharashtra	8	18
Pearl millet, Andhra Pradesh	10	33
Pearl millet, Karnataka	10	24
Pearl millet, Maharashtra	34	42
Maize, Andhra Pradesh	50	74
Maize, Karnataka	33	61
Maize, Maharashtra	25	30

Note: These figures are based on estimates by private seed firms.

TABLE 3. AVERAGE YIELDS DURING 1985-95

Crop and State (1)	Yield (tonne/ha), 1985-90 (2)	Yield (tonne/ha), 1991-95 (3)
Sorghum, Andhra Pradesh	0.64	0.74
	(120)	(100)
Sorghum, Karnataka	0.87	1.04
	(98)	(60)
Sorghum, Maharashtra	0.91	1.00
	(133)	(111)
Pearl millet, Andhra Pradesh	0.68	0.80
	(103)	(83)
Pearl millet, Karnataka	0.48	0.54
	(69)	(44)
Pearl millet, Maharashtra	0.45	0.63
	(120)	(97)
Maize, Andhra Pradesh	1.67	2.48
	(114)	(92)
Maize, Karnataka	2.50	2.82
	(103)	(70)
Maize, Maharashtra	1.04	1.31
	(126)	(111)

Notes: Figures for a state are averages across districts and years. Figures in parentheses are the number of observations. They differ from variable to variable because of missing observations.

district yields have increased. It is natural to ask, therefore, whether the increases in yields were associated with greater adoption of private hybrid seeds. Our objective is to examine whether variation in the area under private hybrid-seeded crops 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 hybrid seed use on the overall increase in crop yields. Our analysis is for the period 1985 to 1995.

The empirical method consists of regressing average district crop yields on the district area under private hybrid seeds after controlling for other various technology, infrastructure and weather variables. The empirical model consists of the following:

$$y_{it} = f(X_{it}, Z_{it}, V_{it}) \quad \ldots (1)$$

where i indexes district, t indexes year, f is the functional form relating the dependent variable to the explanatory variables, y is district yield, X is a vector of district level technology variables, Z is a vector of district level infrastructure variables and V is a set of other district level variables. The individual variables are defined in Table 4. The model closely resembles the models of total factor productivity analysis in the literature (Evenson and McKinsey, 1991; Evenson *et al.*, 1999; Fan and Hazell, 2000; Kumar and Rosegrant, 1994). In all cases, a measure of productivity is regressed on relevant explanatory variables. However, because the dependent variable in our analysis is a partial productivity measure, we depart from the literature in taking into account variable input use.

The technology variables include a measure of the spread of HYVs 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 seeded to private hybrid seed of maize, sorghum and pearl millet. The second variable in this set is a measure of the proportion of crop area planted to private hybrids (PVT).

Infrastructure variables consist of the proportion of crop area that is irrigated (PIR), the fertiliser use in the entire district (N), the number of regulated markets in the district (MARKETS), and the length of roads in the district (ROADS). Although irrigation and fertiliser use are inputs, they are often used as explanatory variables in total factor productivity analyses (cited above). The rationale is that these inputs are supplied by the public sector, are not competitively priced and are, in practice, rationed. Hence, their classification as infrastructure variables. Since we are estimating the effects on yields, we are not constrained by this interpretation although for reasons of data availability, we continue to use fertiliser use rather than fertiliser price. Since the information is about aggregate use for all crops and is not crop-specific, the impact of fertiliser use is likely to be under-estimated.

Other variables consist of a trend variable (YEAR), and variables measuring rainfall in June (JUNE), July and August (JULAUG) and for the entire year

(ANNUAL). Our only departure from the literature is to also include a measure of crop profitability (ARP). We do not have any information, whether cropwise or for the entire district on the use of variable inputs (including labour). We therefore construct 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 for which we have no crop-specific data.

Table 5 presents the matrix of correlations among explanatory variables for the case of sorghum in Maharashtra. To conserve space, we do not report the tables for the other eight cases. However, Table 5 is representative of the correlations in data.

TABLE 4. VARIABLES IN THE EMPIRICAL ANALYSIS

Variable (1)	Type of variable (2)	Definition (3)
Crop yield	Dependent variable	District crop output divided by district crop area (tonnes/ha)
PHYV	Independent variable: Technology variable	Proportion of district crop area seeded by HYVs
PVT	Independent variable: Technology variable	Proportion of district crop area seeded by private hybrids
PIR	Independent variable: Infrastructure variable	Proportion of district crop area that is irrigated
N	Independent variable: Infrastructure variable	District usage of nitrogen fertiliser
MARKETS	Independent variable: Infrastructure variable	Number of regulated markets in the district
ROADS	Independent variable: Infrastructure variable	Length of roads in the district
YEAR	Independent variable: Other variable	Trend
JUNE	Independent variable: Other variable	June rainfall (mm) in district
JULAUG	Independent variable: Other variable	Sum of rainfall in July and August (mm) in the district
ANNUAL	Independent variable: Other variable	Annual rainfall (mm) in the district
ARP	Independent variable: Other variable	Three-year moving average of district harvest price deflated by the wholesale price index of all manufacturing prices

TABLE 5. CORRELATION MATRIX OF EXPLANATORY VARIABLES FOR SORGHUM, MAHARASHTRA, 1985-1995

Variable (1)	PHYV (2)	PVT (3)	PIR (4)	N (5)	MARKETS (6)	ROADS (7)	JUNE (8)	JULAUG (9)	ANNUAL (10)	ARP (11)
PHYV	1									
PVT	0.06	1								
PIR	-0.11	0.13	1							
N	0.002	-0.04	0.13	1						
MARKETS	0.03	-0.09	0.03	0.40	1					
ROADS	-0.17	0.04	0.34	0.20	0.38	1				
JUNE	0.17	-0.22	0.002	-0.15	-0.13	-0.15	1			
JULAUG	0.13	-0.27	-0.15	-0.04	-0.13	-0.25	0.59	1		
ANNUAL	0.07	-0.22	-0.15	0.16	-0.08	-0.20	0.60	0.75	1	
ARP	-0.08	0.07	0.29	0.16	0.19	0.34	0.04	-0.04	0.018	1

Note that except for the correlations between the various rainfall measures, none of the other correlations are large.

With one exception, the district level figures for all the variables used in the analysis are sourced from official publications. The exception relates to the variable measuring the proportion of crop area planted to private hybrid seed (PVT). This information was obtained by eliciting estimates from private seed companies, which was collected as part of a survey that was done to obtain information on research and development (R & D) expenditures of private seed firms in India. The results of this survey are reported in Pray *et al.* (2001). However, the information relates to only two time points: 1990 and 1995. To generate a continuous series, we need to extrapolate figures for the intervening years. We assume that the 1990 values characterise the period from 1985 to 1991 while the 1995 values are valid for the period 1993-95. For 1992, an intermediate value (the average) is chosen to mark the transition. Since the extrapolation procedure keeps constant the area under private hybrids in periods of rising yields, the procedure under-estimates the impact of private hybrids on yields.

III

FUNCTIONAL FORM, ESTIMATION METHOD AND RESULTS

Equation (1) is estimated using standard pooling techniques of estimation. By accounting for district-specific effects, the analysis controls for differences in agro-climatic environments. The district-specific effects can be modeled as fixed effects or as random variables. Given the limited variability across time of the variable measuring the spread of private hybrids, its impact would be better estimated in a random effects model. However, as is well known, the random effects model assumes orthogonality of the random errors with the explanatory variables. We report the random effects regression whenever there is evidence, summarised by the Haussman-Wu test, for orthogonality (Johnston and DiNardo, 1997, p. 338). Otherwise, we present estimates of the fixed effects model.

Although much of the literature chooses a double-log functional form, we report the results for a linear model because in model selection tests using the J test of Davidson and MacKinnon the double-log form was rejected relative to the linear model (Greene, 1997, p. 365). However, it is questionable whether the impact of private hybrids should be modeled linearly as large differences (between districts and across time) in the proportion of private hybrids are more likely to have an impact than small differences. This is so for at least two reasons. First, the measure of spread of private hybrids is based on estimates elicited from private seed firms. While it is hard to assess the accuracy of these estimates, it is clear that it would be easier for an observer to distinguish between districts with large rather than small differences in adoption rates of private hybrids. Secondly, even if small differences are accurately estimated, the effects of private hybrids on *average* district yield may not show up unless the adoption is above a critical threshold. For both these reasons, it might be preferable to approximate the relationship by a step-function rather than a linear relationship. Our empirical strategy is to present estimates from a linear specification as well as from a model where we use dummy variables to distinguish among districts that have markedly high presence of private hybrids from other districts.

As an illustration of the different specifications, consider the relationship between sorghum yields and the area under private hybrids in Maharashtra. Figure 1 presents the scatter of these variables as value as the fitted value from a linear regression. Figure 2 also presents the scatter of these variables as well as the fitted value from a

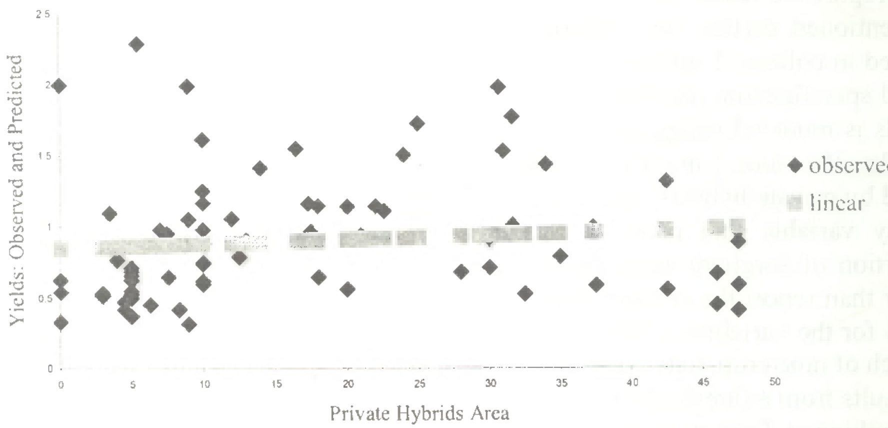

Figure 1. Fit of Linear Model, Sorghum, Maharashtra

Note: The above graph is an illustration of a simplified linear model where the explanatory variable is private hybrid area alone.

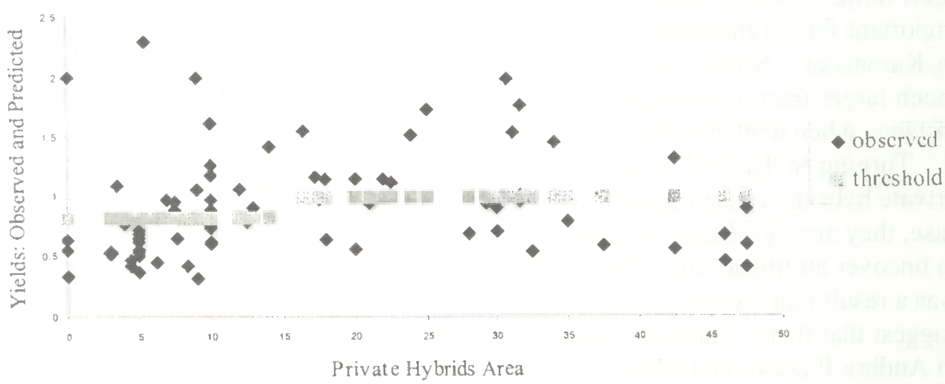

Figure 2. Fit of Threshold Model, Sorghum, Maharashtra

Note: The above graph is an illustration of a simplified threshold model where the explanatory variable is a dummy variable that is 1 whenever the area under private hybrids is greater than 15 per cent.

threshold regression where the adoption dummy is 1 for districts with adoption rates in excess of 50 per cent and zero otherwise. Note the threshold analysis picks up the effect of private hybrids better than a linear regression analysis. This could be because of either or both the reasons discussed above. In the estimates of the threshold model presented below, minimising the standard error of the model chooses the dummy for the threshold.

Equation (1) is estimated for each of the nine crop-state combinations (maize, pearl millet and sorghum in Andhra Pradesh, Karnataka and Maharashtra). Tables 6 and 7 report the results of this exercise for sorghum in Karnataka and Maharashtra. As mentioned earlier, two specifications are estimated. In the first specification, reported in column 2 (of both the tables), all variables impact yields linearly. In the second specification, reported in column 3 (of both the tables), the impact of private hybrids is modeled using dummy variables. In Table 5, D 40 is a dummy variable that takes the value 1 in all Karnataka districts where the proportion of sorghum area seeded by private hybrids is greater than 40 per cent. Similarly, in Table 6, D 15 is a dummy variable that takes the value 1 in all Maharashtra districts where the proportion of sorghum area seeded by private hybrids is greater than 15 per cent. Rather than report the entire regressions for the other cases, Table 8 summarises the results for the variables of interest, namely, the impact of private hybrids and HYVs for each of nine crop-state combinations and for a linear specification. Table 9 reports the results from a threshold analysis.

Looking at Table 8 first, we see that the proportion of area under private hybrids is a significant determinant of average district yields at 5 per cent or 10 per cent level in five cases. In sorghum, private hybrids have had a measurable impact in Andhra Pradesh and Karnataka but less so in Maharashtra. In maize, the significant impacts are in Andhra Pradesh and Maharashtra. Private hybrids have had least success in pearl millet. Only in Maharashtra, do they show some impact. The HYV variable is important for sorghum in Karnataka and Maharashtra, and for maize and pearl millet in Karnataka. Notice whenever significant, the impacts of the HYV variable are much larger than those of private hybrids. Pearl millet in Andhra Pradesh is the only instance when neither of the technology variables are important.

Turning to Table 9, it may be noted that the threshold dummies associated with private hybrids reflect impacts that are comparable with the impact of HYVs. In each case, they are significant at 5 per cent level. Using threshold dummies also allows us to uncover an impact of private hybrids in the case of sorghum in Maharashtra. This was a result that did not come through strongly in the linear specification. The results suggest that there is no one threshold level that is uniform across crops. For sorghum in Andhra Pradesh and Maharashtra, the threshold levels are low. Districts where the area under private hybrids is greater than 15 per cent of the total area under the crop have markedly higher average yields than districts that have not reached this level. On the other hand, the impact of private hybrids on maize yields in Andhra Pradesh does not show up unless the adoption of private hybrids is in excess of 80 per cent.

TABLE 6. SORGHUM, KARNATAKA

Variable (1)	Estimates (t-ratios) (2)	Estimates (3)
PVT	0.0083** (2.393)	-
D 40	-	0.38** (3.472)
PHYV	0.44** (2.999)	0.47** (3.275)
PIR	-0.291 (-0.342)	-0.28 (-0.332)
ARP	-0.243 (-1.38)	-0.33* (-1.934)
JULAUG	0.00007 (0.547)	0.00008 (0.579)
JUNE	0.0009** (2.109)	0.0007* (1.738)
ANNUAL	3.43e-06 (0.022)	0.00003 (0.156)
N	5.12e-07 (0.106)	2.01e-06 (0.417)
ROADS	0.00003 (0.866)	0.00003 (0.960)
MARKETS	-0.0065 (-1.148)	-0.009 (-1.531)
YEAR	-0.00006 (-0.003)	0.0015 (0.085)
R^2	0.37	0.37
Haussman-Wu test statistic: $\chi^2(11)$	11.66	15.6
Observations	127	127
Time period	1985-1994	1985-1994
Number of districts	17	17
Estimation technique	Random effects	Random effects

Notes: The variables are defined in Table 4. D 40 is a dummy variable that takes the value 1 whenever PVT ≥ 0.4 and is zero otherwise. t-values in parentheses. * and ** Significant at 10 and 5 per cent level respectively.

TABLE 7. SORGHUM, MAHARASHTRA

Variable (1)	Estimates (t-ratios) (2)	Estimates (3)
PVT	0.008 (1.541)	-
D15	-	0.23** (3.209)
PHYV	0.23 (1.886)*	0.24** (2.042)
PIR	-0.771 (-1.870)*	-0.794** (-2.017)
ARP	-0.527 (-3.010)**	-0.590** (-3.504)
JULAUG	-0.0007 (-3.320)**	-0.0006** (-3.065)
JUNE	-0.00004 (-0.151)	-0.00002 (-0.069)
ANNUAL	0.00028 (2.167)**	000025* (1.892)
N	5.33e-06 (1.503)	5.64e-06 (1.627)
ROADS	-0.00001 (-0.264)	-0.00001 (-0.320)
MARKETS	0.0067 (1.193)	0.00697 (1.276)
YEAR	0.0277 (1.832)*	0.02315 (1.647)
R^2	0.34	0.35
Observations	216	216
Time period	1985-1994	1985-1994
Number of districts	22	22
Estimation technique	Fixed effects	Fixed effects

Notes: The variables are defined in Table 4. D15 is a dummy variable that takes the value 1 whenever PVT ≥ 0.15 and is zero otherwise. t-values in parentheses. * and ** Significant at 10 per cent and 5 per cent level respectively.

We should point out that these results should not be taken as an indication that private hybrids in sorghum have had greater impact on the average district yields than on maize hybrids. Indeed, the picture could be quite the contrary. In Andhra Pradesh, private hybrids of maize are used in 16 of the 20 districts. In the late 1980s, the 16 districts that used private hybrids recorded adoption rates between 50 per cent and 70 per cent. By the mid-1990s, the adoption rates were in the range 80 per cent - 100 per cent. It is therefore quite clear that the estimated threshold level of 80 per cent reflects

TABLE 8. SUMMARY OF IMPACT OF PRIVATE HYBRIDS AND HYVs ON YIELDS

Crop and State (1)	PVT (2)	HYV (3)	Estimation technique (4)
Sorghum, Andhra Pradesh	0.0027* (1.92)	-0.09 (1.54)	Random effects
Sorghum, Karnataka	0.0083** (2.34)	0.44** (2.99)	Random effects
Sorghum, Maharashtra	0.008 (1.54)	0.23* (1.88)	Fixed effects
Pearl millet, Andhra Pradesh	0.0007 (0.27)	-0.084 (1.10)	Fixed effects
Pearl millet, Karnataka	-0.0002 (0.11)	0.39** (3.20)	Random effects
Pearl millet, Maharashtra	0.01* (1.91)	0.02 (0.32)	Fixed effects
Maize, Andhra Pradesh	0.023** (2.27)	-0.11 (0.70)	Fixed effects
Maize, Karnataka	0.005 (0.48)	0.77* (1.70)	Random effects
Maize, Maharashtra	0.04** (3.33)	0.13 (0.96)	Fixed effects

Notes: t-values in parentheses. * and ** Significant at 10 and 5 per cent level respectively.

TABLE 9. IMPACT OF PRIVATE HYBRIDS AND HYVs ON FARM YIELDS: THRESHOLD ANALYSIS

Crop and State (1)	Coefficient of threshold dummy (2)	Threshold level (3)	HYV (4)	Estimation technique (5)
Sorghum, Andhra Pradesh	0.12** (2.52)	15 per cent	-0.085 (1.42)	Random effects
Sorghum, Karnataka	0.38** (3.47)	40 per cent	0.47** (3.28)	Random effects
Sorghum, Maharashtra	0.23** (3.20)	15 per cent	0.24** (2.04)	Fixed effects
Pearl millet, Maharashtra	0.16** (2.30)	50 per cent	0.03 (0.50)	Fixed effects
Maize, Andhra Pradesh	0.54** (2.67)	80 per cent	-0.10 (0.65)	Fixed effects
Maize, Maharashtra	0.60** (2.92)	30 per cent	0.11 (0.80)	Fixed effects

Notes: t-values in parentheses. * and ** Significant at 10 per cent and 5 per cent level respectively.

the narrow variation of the PVT variable at the higher end. Similarly, we identify a low threshold level of 15 per cent in the case of sorghum in Maharashtra because adoption rates even by the mid-1990s were bunched at the lower end, in the interval 5 per cent - 35 per cent. The tendency for adoption rates to be clustered in a narrow interval is the reason why threshold analysis throws up bigger impacts than a linear specification.

Interviews with seed companies suggest that sorghum and pearl millet have benefited from private breeding based on strong public research programmes rather than imported germplasm.[1] This is confirmed by the strong impact of HYVs in the case of sorghum in Karnataka and Maharashtra as also in pearl millet in Karnataka. On the other hand, the HYV variable fails to make an impact on sorghum yields in Andhra Pradesh and on yields of pearl millet in Maharashtra where private hybrids are significant. This cannot be ascribed to correlation with the private hybrid variable because in both these instances, the sample correlation between the HYV and PVT variables is close to zero. The finding suggests that the private sector is better than the public sector in finishing and distributing varieties based on publicly funded research.

Maize is the crop that private foreign research would favour because multi-nationals and local firms can draw on large research programmes on these crops in temperate regions of the world. In line with this supposition, private hybrids in maize have registered strong impacts on average district yields in Andhra Pradesh and Maharashtra. On the other hand, it is surprising to find the absence of an impact in the case of maize in Karnataka because the area under private hybrids has increased rapidly. The coefficient of the HYV variable is, however, large and is significant at 10 per cent level, suggesting that this variable is capturing the effect of private hybrids. This can be true only if our information on the spread of private maize hybrids is erroneous since the correlation between HYV spread and private hybrids is less than 0.1.

More generally, the correlations between the spread of HYVs and private hybrids in our data have not been such as to prevent identification of their separate impacts. The estimated coefficients changed very little when either one of the variables was dropped.

IV

POLICY IMPLICATIONS

In sum, in six of the nine cases considered here, average district yields are significantly higher in districts with higher spread of private hybrids, after controlling for the effects of weather, infrastructure variables and HYVs. Private hybrids seem to have had little impact on yields of pearl millet in Andhra Pradesh and Karnataka as also on maize yields in Karnataka. These estimates provide the first econometric evidence of the contribution of private hybrids to agricultural productivity in developing countries. The significance of this finding is that it means that the private sector has been successful in finishing and distributing improved varieties. The scale of this effort has been large enough to affect aggregate productivity measures.

These results are particularly striking because they have been obtained in the regions of semi-arid tropics where the Green Revolution based on HYVs of wheat and rice has not had much of an impact. Given that the semi-arid tropics tend to be poorer than the favourably endowed growing regions of the Punjab and the Indo-Gangetic plains and given the crops in which private hybrids have had an impact, it is likely that poor farmers in SAT areas have gained from the spread of private hybrids.

The seed policy reforms of the late 1980s led to a substantial increase in R & D investments in the seed industry (Pray *et al.*, 2001). Because such investments typically take more than a few years to bear fruit, the spread of private hybrids upto 1995 was probably based on past research investments. We can therefore expect private hybrids to become increasingly important in the future.

Policies and regulations in developing countries, whether by design or otherwise, may not be supportive of private plant breeding. While this was unimportant in the past, our study suggests that the costs of neglecting incentives to private research could be significant especially to the predominantly poor consumers of sorghum, pearl millet and maize. A second lesson of this study has been the contribution of public research systems, whether national or international, to private plant breeding efforts. Public research has provided advanced lines and other germplasm that are used extensively by private plant breeders working on sorghum and pearl millet. By reducing the costs of basic research, public research has sustained the interest of private plant breeders in coarse cereals. This factor may be even more important in the future where there may be greater competition for the resources of private plant breeders. Thirdly, even when based on public genetic materials, private hybrids have often been more successful than public hybrids. The success of private seed companies in finishing and marketing their hybrids suggests that the public sector, in the case of coarse cereals, can place more of its emphasis on germplasm enhancement and basic research and reduce its presence in the production and distribution of finished varieties.[2]

Received April 2001. *Revision accepted December 2001.*

NOTES

1. As a referee has pointed out, imported germplasm might still be important because of its effects on public plant breeding.
2. These observations are inapplicable to rice and wheat.

REFERENCES

Evenson, Robert E. and James W. McKinsey Jr. (1991), "Research, Extension, Infrastructure and Productivity Change in Indian Agriculture", in Robert E. Evenson and Carl. E. Pray (Eds.) (1991), *Research and Productivity in Asian Agriculture*, Cornell University Press, Ithaca, New York.

Evenson, Robert E.; Carl E. Pray and Mark W. Rosegrant (1999), *Agricultural Research and Productivity Growth in India*, Research Report 109, International Food Policy Research Institute, Washington, D.C., U.S.A.

Fan, Shenggen and Peter Hazell (2000), "Should Developing Countries Invest More in Less-Favoured Areas?: An Empirical Analysis of Rural India", *Economic and Political Weekly*, Vol. 35, No. 17, April 22.

Greene, William H. (1997), *Econometric Analysis*, Third Edition, Prentice-Hall, New Jersey.

Johnston, Jack and John DiNardo (1997), *Econometric Methods*, Fourth Edition, McGraw Hill, New York.

Joshi, P. D. (1998), *Changing Pattern of Consumption Expenditure in India and Some Selected States*, Sarvekshana Analytical Report Number 2, National Sample Survey Organisation, Government of India, New Delhi.

Kumar, Praduman and Mark W. Rosegrant (1994), "Productivity and Sources of Growth for Rice in India", *Economic and Political Weekly*, Vol. 29, No. 53, December 31.

Pray, Carl E.; Bharat Ramaswami and Timothy Kelley (2001), "The Impact of Economic Reforms on R & D by the Indian Seed Industry", *Food Policy*, Vol. 26, No. 6, pp. 587-598.