Adoption and Impact of Hybrid Wheat in India

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Abstract: In the light of ongoing debates about the suitability of hybrid seeds for smallholder farmers, this paper analyzes the adoption and impact of hybrid wheat in India. Based on survey data we show that farmers can benefit significantly from the proprietary technology. Neither farm size nor the subsistence level influence the adoption decision, but access to information and credit matters. Moreover, willingness-to-pay analysis reveals that adoption levels would be higher if seed prices were reduced. Given decreasing public support to agricultural research, policies should be targeted at reducing institutional constraints, to ensure that resource-poor farmers are not bypassed by private sector innovations

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1. Introduction

Mounting population pressure, decreasing areas of cultivable land and stagnating yield growth in developing countries challenge agricultural research to shift the crop yield frontier outward, including in marginal areas that were often neglected in the past (Lipton, 2005). Hybrid seed technologies, which exploit heterosis and generally achieve higher yields than open-pollinated varieties (OPVs), are seen as one approach to address this challenge. Indeed, the area cultivated with hybrid crops in developing countries rose over the past decades (Pingali, 2001; FAO, 2004). Today, main hybrid crops include maize, sorghum, millet and rice; other species are technically more difficult or more expensive to hybridize.

Notwithstanding their yield advantage, the suitability of hybrid seeds for smallholder farmers is questioned on two main grounds (Kloppenburg, 2004). First, hybrid research and seed production is dominated by private companies, which direct their research mainly at commercial growers in well-developed regions. As the hybrid vigor gets lost when seeds are reproduced, farmers have to buy new seeds regularly to avoid yield losses. This exclusion mechanism acts as an incentive for private sector research (Pray & Umali-Deininger, 1998). Yet, the restriction on using farm-saved seeds may prove difficult especially for marginal farmers who often grow food crops with little cash income. Second, hybrid crops are claimed to require more complementary inputs, especially chemical fertilizers, pesticides and irrigation, which are more affordable to large commercial farmers. Consequently, it is often argued that a research focus on hybrid seed technologies may not necessarily be pro-poor: if disadvantaged farmers are unable to access new seed technologies or to use them productively, growth that is induced by technological change would be inequitable.

However, there are a number of studies pointing out that smallholders successfully adopt hybrid seeds (Smale, 1995; Heisey *et al*., 1998; Morris, 1998; Zeller *et al*., 1998). Although larger farmers tend to be early adopters of new seed technologies, small-scale farmers often significantly benefit from spillover effects. Heisey *et al*. (1998) illustrate this for hybrid maize in Africa. Although maize hybrids were initially directed at commercial growers, their success also spurred demand by smallholders, and private companies adjusted their marketing strategies accordingly. Today, small and large farmers alike cultivate hybrid maize in Africa. Heisey & Smale (1995) demonstrate that well-adapted hybrids can outperform OPVs even under adverse weather conditions and in situations where no additional inputs are applied. Pray *et al*. (1991), in a study on sorghum and millet in India, found that farmers benefit to a greater extent from hybrid crops than private seed companies do. Therefore, a generalization that hybrid seeds are *per se* unsuitable for small-scale farmers seems to be untenable.

This paper contributes to the discussion by analyzing the adoption of hybrid wheat in India. While hybrid wheat was commercialized in the United States and a couple of other countries in the 1970s, it was never grown on a large scale, because seed production costs were too high in relation to yield advantages (Zehr, 2001). Accordingly, most companies dropped their research programs on hybrid wheat. India is an exception: the Maharashtra Hybrid Seed Company (Mahyco) launched hybrid wheat in 2001 and reported adoption of 60,000 acres in 2005. Strikingly, the company's marketing focus is not on the irrigated wheat states of northern India, but on states like Maharashtra in the semi-arid tropics, where wheat is primarily grown for home consumption.

The objective of this paper is twofold. First, we analyze whether adopting farmers, particularly smallholders, benefit from the cultivation of hybrid wheat in a semi-subsistent environment. Second, we examine what factors determine the adoption decision. The analysis is based on a survey of 284 wheat farmers in Maharashtra, which we carried out in 2004. As farmers identified high seed prices as a major constraint for hybrid adoption, we also analyze farmers' price preferences using contingent valuation methods. Knowledge of the determinants of adoption and of price preferences is particularly important because it can be a decisive factor in the design of strategies that aim at facilitating farmers' access to new seed technologies. We are unaware of previous studies on the adoption of hybrid wheat in developing countries.

The paper proceeds as follows. Section 2 gives an overview of wheat cultivation in India and the study region Maharashtra. Section 3 analyzes the adoption and impact of hybrid wheat. In section 4, the contingent valuation model is developed and used for estimating farmers' willingness to pay (WTP) for hybrid seeds. Section 5 concludes and discusses policy implications.

2. Wheat cultivation in India and the study area

Next to rice, wheat is the most important food crop in India, in terms of consumption, production and cultivated area. Main wheat producing states are Punjab, Haryana, Uttar Pradesh and Rajasthan, which are located in the northwestern zone of India. These states account for 78% of the national wheat output (Fertiliser Association of India, 2004). Other states with relatively large wheat areas are Gujarat and Madhya Pradesh in the central zone, Bihar in the eastern zone and Maharashtra in the peninsular zone.

With the onset of the Green Revolution in 1964, when India introduced semi-dwarf wheat varieties, wheat production rose steeply. From 1964 to 2002, wheat yields more than tripled from 295 to 1,120 kg per acre (Fertiliser Association of India, 2004). These enhancements were associated with an increase in irrigation facilities and chemical fertilizer usage (Rao *et al*., 2001). Production gains, however, were unequally distributed. States in the northwestern zone realized the largest production increases, because they had assured irrigation facilities (Goldman & Smith, 1995). Wheat growing states in other zones benefited primarily from spillovers of new varieties from the irrigated environments, and later from adaptations of irrigated varieties to rainfed conditions (Pingali & Rajaram, 1997).

Despite the success of the Green Revolution, growth rates in wheat yield fell over the past decades. While yields grew on average by 3.4% per year from 1982 to 1992, growth rates had slowed to 0.6% per year from 1992 to 2002 (Fertiliser Association of India, 2004). In combination with a rising population, this decline led to lower per capita availability of wheat. Reversing this trend is a priority of agricultural research in India today (Rao *et al*., 2001). There are two ways to achieve this: the first is to breed new cultivars that outperform existing ones, and the second is to exploit the potential of areas that stayed behind during the Green Revolution. The development of hybrid wheat for semi-arid states of India, where farmers often do not have access to canal irrigation, is an attempt to combine both. Mahyco, currently the sole producer of hybrid wheat in India, launched its product in 2001. Research efforts focused on the central, peninsular and eastern regions of India. Company breeders achieved heterosis in wheat by using cytoplasmic male sterility. The resulting wheat hybrid is adapted relatively well to moisture-stress (Zehr, 2001) and was grown in six states by 2004. Adoption rates are shown in Table 1.

Table 1: Hybrid wheat diffusion in India and Maharashtra

	2001	**2002**	**2003**	**2004**	**2005**
			Hybrid wheat area (acres)		
India	18,600	22,000	55,000	40,000	60,000
Maharashtra	7,300	9,800	26,433	28,483	33,000
			Adoption (%)		
India	0.031	0.037	0.09	0.06	0.10
Maharashtra	0.39	0.52	1.41	1.54	1.78

Source: Mahyco unpublished data. Acreages are based on seed sales data. The adoption rate is defined as hybrid wheat area over total wheat area

We chose Maharashtra as our study region for two reasons: (i) Maharashtra currently has the largest hybrid wheat area in the country, and (ii) small-scale farmers with limited access to irrigation dominate wheat production in that state; more than 50% of the operational holdings are below 5 acres (Government of Maharashtra, 2005).[1] We conducted a farm survey in 2004, collecting production data for the 2003/2004 cultivation period. During this period, agricultural production was affected by adverse weather conditions: rains arrived late and were erratic, so that some districts reported drought-like conditions. We selected 284 wheat farmers using stratified random sampling methods. Maharashtra is divided into four geopolitical regions and 35 districts. These regions in order of their cultivable area are Western Maharashtra, Marathwada, Vidharba and Kandesh.[2] In each of the three largest regions; we purposively selected one important wheat-growing district (Government of Maharashtra, 2003). The three districts surveyed are Nashik, Yavatmal and Aurangabad. In each district, we randomly chose seven villages where 12 to 15 interviews were carried out with randomly selected farmers. Since the number of hybrid wheat adopters was small at this early stage of the technology diffusion process, they were over-sampled from complete seed sales lists.

In total, the dataset comprises 87 adopters and 197 non-adopters. In the case of 59 adopters, who grew both hybrid wheat and OPVs in 2003/2004, input-output data was collected for both alternatives. Thus, the sample contains observations for 87 hybrid and 256 OPV plots. Furthermore, information was collected on household characteristics and social networks. Data on village variables were obtained by interviewing the village council heads. Table 2 presents selected characteristics of the sample farmers. Although the comparison of mean values between adopters and non-adopters already shows some interesting features, determinants of adoption are analyzed more explicitly in the following section.

[1] The Government of Maharashtra (2005) classifies operational holdings as follows: Marginal/ small (up to 5 acres), semi-medium/medium (5-25 acres) and large (more than 25 acres). This categorisation is followed throughout the text.
[2] The cultivable areas (in thousand acres) are: Western Maharashtra (15,923), Marathwada (13,924), Vidharba (12,177) and Kandesh (5,884) (Government of Maharashtra, 2003).

Table 2: Selected characteristics of the sample farmers

	Adopters (n=87)		Non-adopters (n=197)	
	Mean	SD	Mean	SD
Farm size (acres)	5.16	5.06	3.16***	3.63
Share of wheat kept for own consumption (%)	80.65	29.11	84.65	27.89
Household food and non-food expenditures (Rupees/capita/year)	12,864.29	9,444.71	9,072.69***	5,177.43
Education (years of formal schooling)	7.54	4.30	7.70	4.82
Experience in growing wheat (years)	14.63	9.76	15.99	12.12
Number of other hybrid wheat farmers known	8.14	13.59	2.75***	8.17

Note: *, **, *** Mean differences are significantly different from zero at the 10%, 5% and 1% level, respectively

3. Hybrid wheat impact and the adoption decision

This section focuses on the question whether adopting farmers in Maharashtra benefit from hybrid wheat and what factors determine their adoption decision. Table 3 presents selected wheat cultivation characteristics of hybrid and OPV plots.

Table 3: Selected wheat cultivation characteristics (2003/04)

	Hybrid wheat plots (n=87)		OPV plots (n=256)	
	Mean	SD	Mean	SD
Wheat yield (kg/acre)	1,310.00	410.70	959.00***	464.00
Plot size (acres)	1.16	1.11	2.16***	2.18
Maturity (days)	117.93	20.70	119.25	19.38
Seed rate (kg/acre)	24.22	4.42	41.53***	12.28
Number of irrigations	6.69	2.13	6.14**	2.51
Fertilizer applied (kg/acre)	180.09	121.80	167.22	92.59

Notes:*, **, *** Mean differences are significantly different from zero at the 10%, 5% and 1% level, respectively.

Despite unfavorable weather conditions in the survey period, hybrid wheat had a significant yield advantage of 351 kg per acre. The majority of farmers grew hybrid wheat for the first time during the survey period, and they started experimenting on smaller plots in order to incur less risk. The number of irrigations and the quantity of fertilizer applied was higher on hybrid wheat plots, but the differences are relatively small and statistically significant only for the number of irrigations. Therefore, the widespread notion that hybrids always require higher input intensities than OPVs has to be qualified in our context.

In a next step, we estimated a Cobb-Douglas type production function, including the use of hybrid wheat as a dummy variable. Table 4 displays the results of the OLS regression, where the dependent variable is the logarithm of per-acre yield. The coefficient for hybrid wheat is positive and significant, indicating that the technology increases wheat yields also when controlling for other factors. The net yield effect evaluated at sample means is around 36%. Irrigation, fertilizer and better soil quality also increase wheat productivity, while the effect of labor is insignificant.[3] Farmers in Yavatmal and Aurangabad have lower average yields than farmers in Nashik, which can be explained by climatic and topological reasons. The districts are located in different agro-ecological zones (ICRISAT, 1999). To test whether hybrid wheat changes the production elasticities of other inputs, we also added interaction terms. The interaction of hybrid wheat with irrigation and labor is insignificant, whereas the interaction with fertilizer is negative and significant. This is surprising, because it suggests that hybrid wheat is less responsive to chemical fertilizers than OPV wheat. However, the effect is very small and should probably not be over-interpreted. In any case, also the production function analysis does not support the hypothesis that the successful use of hybrids requires higher input intensities.

Table 4: Yield production function

Variable	Description	Coefficient	t-value
Hybrid wheat	Dummy	0.41	2.90***
Irrigation	Logarithm of number of irrigations	0.18	2.03**
Fertilizer	Logarithm of fertilizer amount (per acre)	0.43	6.46***
Labor	Logarithm of labor-days per acre	-0.05	-0.74
Soil quality	Dummy (1: high quality, 0: lower quality)	0.21	3.79***
Education	Formal education (years)	-0.01	-0.88
Experience	Experience in growing wheat (years)	-8.19E-04	-0.33
Yavatmal[a]	District dummy	-0.27	-3.50***
Aurangabad[a]	District dummy	-0.17	-2.25**
Hybrid-irrigation	Interaction term	0.01	0.70
Hybrid-fertilizer	Interaction term	-1.39E-03	-4.11***
Hybrid-labor	Interaction term	1.20E-03	0.62
Constant		4.52	12.24***
Regression statistics	F (12, 260)	9.17	
	R^2	0.32	

Notes: Standard errors are robust. *, **, *** Coefficients are significantly different from zero at the 10%, 5% and 1% level, respectively. [a] The Reference variable for the district dummies is Nashik

Table 5 looks at the impact of hybrid wheat on farm income. To control for unobservable factors that might influence wheat cultivation, e.g. farmer's skills, we only compare the plots of those farmers who cultivate both hybrids and OPVs. Such a within farm comparison helps to reduce a possible non-random selection bias. The hybrid yield advantage of 26% is smaller than in Table 3, but still significant. In addition, the market price for grain from hybrid wheat is on average 0.41 Rupees per kg higher than that of OPV wheat, reflecting quality differences.[4] Quality is especially

[3] Since over two-thirds of all sample farmers did not use any pesticides, a pesticide variable was not included in the production function. Zero observations would cause problems with the Cobb-Douglas specification. Other specifications with a pesticide variable included did not change the sign and significance of the other variables. Soil

relevant to smallholders who mainly produce wheat for home consumption: different studies show that crop varieties, which are not adapted to farmers' tastes, are often not widely adopted (Smale, 1995).

Table 5: Income effects of hybrid wheat (2003/04)

	Hybrid wheat (n=59)		OPVs (n=59)	
	Mean	SD	Mean	SD
Yield (kg/acre)	1,261.94	389.66	1,004.00***	377.29
Output price (Rupees/kg)	8.19	0.85	7.78***	0.79
		Rupees per acre		
Market value[a]	10,367.50	3,452.52	7,800.78***	2,969.56
Variable costs				
Seeds[b]	1,086.34	198.15	486.92***	227.89
Fertilizers	1,205.92	779.72	1,066.88	610.80
Pesticides	268.16	1,004.49	266.51	1,004.80
Family labor[c]	856.81	939.71	750.42	925.35
Hired labor	911.90	865.49	928.34	996.72
Hired machinery and contracted operations	821.38	658.30	642.68***	548.55
Total variable costs	5,150.51	2,102.86	4,435.48***	2,150.11
Net income	5,216.99	3,627.44	3,365.29***	2,707.23

Notes: *, **, *** Mean differences are significantly different from zero at the 10%, 5% and 1% level, respectively.
[a] Since the majority of farmers did not sell their produce, the value of output was approximated at the village level market price. [b] For farm-saved seeds or seeds received from neighbors, the seeding rate was multiplied with the market price of grain, to reflect the opportunity cost. [c] Family labor was valued at the prevailing village wage rate for males and females, respectively.

Seed costs per acre are considerably higher for hybrid wheat. The main reason for the price difference is the high cost of hybrid seed production. In the first year of hybrid wheat introduction, the seed price per acre was much higher (around 1,400 Rupees), but Mahyco already cut the costs and reduced the price to its current level of 1,000 Rupees. Cost differences for other inputs are not significant. Looking at the number of irrigations for this sub-sample shows that there is no significant difference. Machinery costs are higher on hybrid wheat plots, because most farmers pay for a rented thresher on a yield basis. Overall, the average net income advantage of hybrid wheat over OPVs is 1,852 Rupees per acre (40 US$/acre). Disaggregating this gain further by farm size reveals that small farms with less than five acres of land gain more (2,018 Rupees/acre) than medium farms with 5-25 acres (1,924 Rupees/acre) and large farms with more than 25 acres (1,466

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qualities correspond to farmers' own evaluation of their plot. Heavy soils are identified as high quality soil, whereby medium to light soils are soils of lower quality

[4] Indeed, when being asked about the advantages of hybrid wheat, farmers named higher yields as the main advantage, followed by the good taste and bread making quality of hybrid wheat.

Rupees/acre). Therefore, the sample does not confirm the concern that the impacts of hybrid crops are biased towards larger farms.

Having established that hybrid wheat is beneficial to adopting farmers in this sample, we now analyze the determinants of adoption. For this purpose, information and adoption probit models are estimated. Acquiring information about a new technology is acknowledged as a very important stage in the adoption process (Feder & Slade, 1984). Therefore, Model (1) in Table 6 establishes what factors determine whether a farmer has information (heard about) on hybrid wheat. Model (2) analyzes the variables that influence the farmer's adoption decision.

In their seminal review paper, Feder *et al*. (1985) discuss factors that determine technology adoption in developing countries. Later studies additionally emphasized the role of networks in the adoption process, i.e. the role that other farmers play in the individual decision-making process. Many studies have estimated these network effects by using aggregate adoption rates at the village level (e.g. Foster & Rosenzweig, 1995; Pomp & Burger, 1995). However, more recent adoption studies stress that farmers do not learn from all farmers in the village. They suggest that information flows through social networks, which are not necessarily based on geographic closeness (Conley & Udry, 2001; Bandiera & Rasul, 2002). As a measure of the size of the individual network, following the approach of Bandiera & Rasul (2002), we asked each farmer in the survey how many hybrid wheat farmers he knows. In addition, since 80% of all sample farmers stated that the seed dealer is one of their main sources of information on new seeds, the geographical distance of the village to the seed dealer is included to capture village effects. District dummies describe regional effects.

Model (1) reveals that farmers who generally feel constrained in their access to information on new technologies are indeed less likely to know about hybrid wheat. Since all farmers who have heard about hybrid wheat know at least one hybrid wheat adopter, the variable hybrid wheat farmers is dropped from the regression. The effect of annual per capita expenditure, as a proxy of permanent income, is small but significant:[5] richer farmers are more likely to know about hybrid wheat than their poorer counterparts. Likewise, farmers with larger shares of their land under irrigation are more likely to know about hybrid wheat. Although all sample farmers irrigate their wheat, cultivators with larger irrigated shares might be more interested in the innovation, which might be because new seed varieties in the past often presupposed sufficient water availability.

[5] The household expenditure variable includes cash expenditures as well as subsistence consumption.

Table 6 Modeling information, adoption and WTP for hybrid wheat

Explanatory Variable	Description	(1) Information[a]		(2) Adoption[a]		(3) WTP[b]	
		Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
Farm size	Land owned in acres	-3.29E-04	-0.15	4.69E-03	1.59	3.31*	1.85
Irrigation	Share of farmland irrigated (%)	1.02E-03*	1.58	-1.49E-05	-0.02	-0.11	-0.24
Soil quality	Dummy (1: high quality, 0: lower quality)	0.05	1.15	0.05	0.88	60.46*	1.86
Subsistence	Share of wheat output kept for own consumption (%)	1.35E-03*	1.83	1.09E-03	1.09	-0.48	-0.89
Education	In years	-3.15E-03	-0.76	3.01E-03	0.49	-0.18	-0.05
Experience	Experience of growing wheat (years)	-2.81E-03	-1.56	-1.04E-03	-0.40	-1.41	-0.98
Expenditure	Annual per capita food and non-food expenditure	1.30E-05***	2.76	1.16E-05***	2.36	7.45E-03***	2.58
Credit constraint	Dummy (1: constraint, 0: otherwise)	-3.25E-03	-0.08	-0.06	-1.02	-61.26**	-1.99
Information constraint	Dummy (1: constraint, 0: otherwise)	-0.32***	-5.11	-0.23***	-3.07	-72.01**	-2.11
Hybrid wheat farmers	No. of hybrid wheat farmers known			0.02**	2.42	2.12	0.97
Hybrid wheat farmers^2	Square term of hybrid wheat farmers			-8.17E-05**	-2.26		
Input dealer	Distance of the village to the input dealer (in km)	-1.97E-03	-0.83	3.88E-03	1.12	-0.31	-0.15
Yavatmal[c]	Dummy variable for the Yavatmal district	0.09*	1.70	0.06	0.80	26.01	0.62
Aurangabad[c]	Dummy variable for the Aurangabad district	0.02	0.41	0.07	0.93	-14.01	-0.50
Negative own experience	Dummy (1: the farmer has made negative own experiences with hybrid wheat, 0: otherwise)					-403.05***	-5.69
Regression statistics	Log likelihood	-102.71		-142.04		-259.92	

Notes: Standard errors are robust. *,**,*** Coefficients are significant at the 10%, 5% and 1% level, respectively. The means (standard deviations) of the dependent variables are: Adoption 0.31(0.46); Information 0.81(0.39). [a] In the information and adoption model, estimates are interpreted as marginal effects evaluated at sample mean values. [b] In the WTP model, estimates can directly be interpreted as marginal effects on the WTP evaluated at sample mean values.[c] The Reference variable for the district dummies is Nashik

Somewhat surprising is that farmers with a higher subsistence share are more likely to have heard about hybrid wheat. Evidently, the notion that subsistence-oriented farms are not receptive to new crop technologies is incorrect. Education, experience and farm size, on the other hand, play no significant role in the process of information gathering.

Model (2) discloses that information constraints and household income play a significant role for the adoption decision. The social network variable is positive and significant. It suggests that for an average farmer knowing one more hybrid wheat adopter increases the probability of own adoption by two percentage points. Bandiera & Rasul (2002), in their analysis on sunflower seed adoption in Mozambique, found that the relationship of adoption and number of farmers known is shaped like an inverse U. Farmers who know many adopters might, out of strategic considerations, delay their adoption to learn from the experiences of the other farmers in their network. Foster & Rosenzweig (1995) also find that farmers have the tendency to free ride on the acquired knowledge of other farmers. We test the free-riding hypothesis by entering the square term of the number of farmers known into the regression. This variable is negative and significant which supports the hypothesis of an inverse U-shaped relationship between adoption and the number of adopters known. Village and district dummies as well as education and experience do not play a significant role. Interestingly, also farm size and subsistence degree do not influence the adoption decision in a significant way. Although Table 2 has shown that adopting farms are larger than non-adopting farms, the reason is apparently more related to income and associated risk considerations than to the size of the land holding itself.

4. Willingness to pay for hybrid seeds

Table 5 revealed that seed prices for hybrid wheat are significantly higher than for OPVs. Indeed, 43% of the non-adopters in our sample stated that the high seed price is a major adoption constraint. As mentioned above, Mahyco reduced seed production costs and prices over time. Although seed sales increased, it is unclear at this early stage of adoption how much of this increase was due to the price changes. In order to analyze farmers' price responsiveness and WTP in detail, we use the contingent valuation method. The results might help to better understand farmers' preferences and constraints and to adjust pricing and marketing strategies accordingly.

Adapting the Bateman *et al*. (2002) framework, the farmer's decision to adopt hybrid wheat is modeled in a random utility framework. We assume that wheat is primarily considered a subsistence crop, so that $U(\cdot)$ is the farmer's utility function, which depends on cash income Y, the amount of wheat produced *W* and household characteristics *S*. Abstracting from quality differences, W^H is the hybrid wheat output, while W^V is the lower output of OPVs. The farmer will adopt hybrid wheat only if

$$U\,(Y\text{-}P,\, W^H,\, S) \geq U\,(Y,\, W^V,\, S) \qquad (1)$$

where *P* is the maximum price mark-up for hybrid wheat seeds that the household is willing to pay. *P* can be rewritten as a function of the other variables. *P* (·) is defined as the bid function, which is positive and restricted by income.

$$0 \leq P\,(W^H,\, W^V,\, Y,\, S) \leq Y \qquad (2)$$

Since the exact form of the utility function is unknown, an error term *e* is added to capture the randomness of the bid function.

$$P = p\,(w^H,\, w^V,\, y,\, s,\, e) \qquad e \sim N\,(0,\sigma^2). \qquad (3)$$

Bateman *et al*. (2002) outline two approaches to specify this bid function: the utility difference approach and the bid function approach. Here the latter is preferred because estimated parameters can be interpreted directly as marginal effects of farm and household characteristics on the WTP. Rather than deriving the bid function from a utility difference problem, the bid function approach assumes that the true bid function P(W^H, W^V, *Y*, *S*) is the result of an underlying utility difference problem solved by the farmer (Bateman *et al*., 2002, p. 189). McConnell (1990), who compared both approaches, states that they are dual to each other. With the bid function approach, equation (3) is specified by the constant only bid function model

$$P = a+e \qquad (4)$$

where *a* captures the observable part of the model and can be further parameterized to include all the variables that are expected to influence the WTP.

$$a = a_0 + a_1X_1 + a_2X_2+\ldots+a_nX_n\,. \qquad (5)$$

The constant only bid function is assumed to be normally distributed with a cumulative distribution function

$$F(P;a,\sigma^2) = \Phi\left(\frac{P-a}{\sigma}\right). \qquad (6)$$

The normal distribution is symmetric about the location parameter. Therefore, *a* defines both the mean and median of the distribution.

To estimate the bid function, revealed and stated preferences are combined. Cooper (1997) suggested this approach, and Hubbell *et al*. (2000) and Qaim & de Janvry (2003) applied it to estimate the WTP for transgenic cotton technologies. In our context, a clear price mark-up of hybrid over OPV seeds is difficult to define, because many OPV farmers use farm-saved seeds. Therefore, we define *P* simply as the market price the farmer is willing to pay for hybrid wheat. Adopters in our sample had revealed that they were at least willing to pay the current seed price of 1,000 Rupees per acre. Assuming that adopters and non-adopters have the same utility function allows for combining revealed and stated preferences to enlarge the available information and thereby increase the reliability of the results.

Non-adopters were asked if they would have been willing to cultivate hybrid wheat at a lower price. Price bids were varied randomly across questionnaires in 50 Rupee intervals from 350 Rupees per acre, which is equivalent to the lowest market price for OPVs, to 950 Rupees per acre. 54 farmers in the sample had never heard of hybrid wheat. They received a description of the characteristics of hybrid wheat before answering the question. Formally, P_U is defined as the upper price bound, that is, the market price of 1,000 Rupees. P_L is the lower price bound, that is, the bid offered to the farmer. Thus, for current adopters the probability of observing the "yes" response is

$$\text{Prob(yes)} = \text{Prob}(\text{WTP} \geq P_U) = 1 - \Phi\left(\frac{P_U - a}{\sigma}\right). \tag{7}$$

For non-adopters, there are two possible responses for which the probabilities are

$$\text{Prob}(\text{no/yes}) = \text{Prob}(P_L < \text{WTP} < P_U) = \Phi\left(\frac{P_U - a}{\sigma}\right) - \Phi\left(\frac{P_L - a}{\sigma}\right)$$

$$\text{Pr}(\text{no/no}) = \text{Pr}(\text{WTP} < P_L) = \Phi\left(\frac{P_L - a}{\sigma}\right).$$

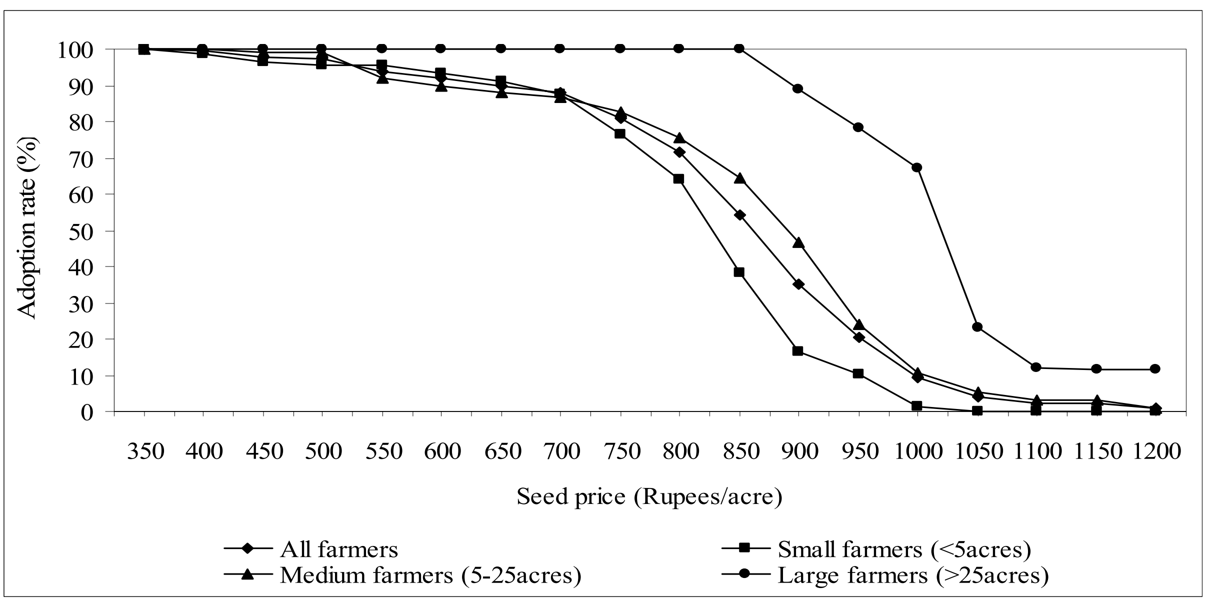
Accordingly, the log-likelihood function becomes

$$\ln L = \sum_{i=1}^{N} d^{NN} \ln\left[\Phi\left(\frac{P_L - a}{\sigma}\right)\right] + d^{Y} \ln\left[1 - \Phi\left(\frac{P_U - a}{\sigma}\right)\right] + d^{NY} \ln\left[\Phi\left(\frac{P_U - a}{\sigma}\right) - \Phi\left(\frac{P_L - a}{\sigma}\right)\right] \tag{8}$$

where $d^{NN} = 1$ if the individual answer is no/no and 0 otherwise, $d^{Y} = 1$ if the answer is yes, and $d^{NY} = 1$ if the answer is no/yes. Model (3) in Table 6 displays the results of this maximum likelihood estimation. In addition to the explanatory variables of Models (1) and (2), the variable negative own experience is added, which captures whether a farmer grew hybrid wheat in earlier seasons but stopped cultivating the crop because of negative own experience. We hypothesize that these farmers will have a lower WTP. Table 6 confirms this hypothesis. Moreover, farmers who cultivate land with better soil quality are willing to pay 60 Rupees per acre more for hybrid wheat. Farmers, who are restricted in their access to credit, are willing to pay 61 Rupees per acre less for this new seed technology. Income, approximated by annual per capita expenditures, information constraints and farm size significantly determine the WTP. Interestingly, neither education nor the subsistence shares of farmers seem to influence the WTP in a significant way. Evidently, also farmers who obtain no or little cash income from their wheat crop are generally willing to pay for suitable new technologies.

In a next step, we calculated the mean WTP at average values of the sample data. Assuming that the sample is representative for wheat-cultivating farmers in Maharashtra, WTP values for adopters and non-adopters were weighed differently according to their share in Maharashtra's population of wheat growers. The mean WTP for all farmers equals 847 Rupees per acre.[6] This is 15% below the current market price and indicates that farmers' price responsiveness is high. Small-scale farmers have a lower mean WTP (809 Rupees/acre) than their medium (864 Rupees/acre) and large-scale colleagues (1020 Rupees/acre). Figure 1 illustrates the share of adoption at different price levels by farm size. The results suggest that adoption rates are likely to increase in the future to about 10% at current seed price levels. Yet adoption would still be remarkably higher if market prices could be further reduced, e.g. by lowering hybrid seed production costs.

Figure 1: Estimated percentage of hybrid wheat adopters at different price levels



Source: Own data

[6] We also ran the regression only with those farmers who had heard about hybrid wheat. The weighted average WTP for this sub-sample of farmers is 870 Rupees per acre, which is 23 Rupees higher than the WTP of all farmers. The relatively small difference suggests that the information given to unaware farmers during the interviews did not cause any significant bias

5. Conclusion

In the light of the ongoing discussion about the suitability of hybrid seeds for small-scale farmers, this paper has analyzed whether farmers can benefit from the adoption of hybrid wheat in a semi-subsistence environment of India and what factors determine their adoption. We found that hybrid wheat has a significant yield advantage over OPVs and that its grain quality is well adapted to farmers' tastes. Against widespread beliefs, hybrid wheat technology does not require higher input intensities, and the technology is not biased towards larger farms. On the contrary, despite relatively high seed prices, smallholders benefit to a greater extent from the cultivation of hybrid wheat than their large-scale colleagues.

Access to information and income significantly influence the adoption of hybrid wheat. Individual networks, as opposed to village networks, also play a role in the adoption process. Larger networks, however, lead to free-riding behavior. Although it is difficult for policies to influence farmers' networks, emphasis should be on the distribution of sufficient and concise information through multiple channels to raise the adoption of hybrid wheat. In a last step, the factors that determine the farmers' WTP for hybrid wheat seeds were analyzed. Income, experience and soil quality positively influence the WTP, while credit and information constraints have a negative effect. The demand for hybrid wheat is price responsive, which indicates that if hybrid seed prices could be lowered, for instance through efficiency gains in seed production, adoption rates could increase significantly.

The results suggest that hybrid wheat could be one important option to tackle today's challenges faced by agricultural research in India. The extent to which farmers will be able to benefit from this new seed technology will depend on factors like access to information and credit. Since hybrid wheat has been on the market only since 2001, more research is needed to assess its effect in other regions and climatic conditions.

More generally, we emphasize that the suitability of hybrid seeds for smallholders should be carefully evaluated on a case-by-case basis. Our example demonstrates that private research activities can be beneficial for small farms, also if farmers have to buy fresh seeds for every crop season. This holds true even in less favorable semi-subsistence environments where farmers hardly derive any cash income from staple food crops. Neither farm size nor the subsistence level of farm households seem to be obstacles for the adoption of hybrid seeds. However, institutional constraints can limit farmers' access. Given decreasing public support to agricultural research and the increasing role of the private sector, policies should be targeted at reducing such constraints, in order to ensure that resource-poor farmers are not bypassed by proprietary seed technologies.

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