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Adoption and Impact of Hybrid Wheat in India

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Summary. — In the light of ongoing debates about the suitability of proprietary seed technologies 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 influences the adoption decision, but access to information and credit does. 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.

Key words — hybrid seeds, adoption, impact, IPRs, Asia, India

1. INTRODUCTION

Mounting population pressure, decreasing areas of cultivable land, and stagnating yield growth in developing countries challenge agricultural research and development (R & D) to shift the crop yield frontier outward, including in marginal areas that were often neglected in the past (Lipton, 2005; Pingali & Rosegrant, 1998). Increasing the scope for private sector investments in plant breeding, especially for food crops, is seen as one approach to address this challenge. Two stimuli for private sector research are intellectual property rights (IPRs)—such as patents or plant variety protection—and hybrid seed technologies. Both of these stimuli facilitate the appropriation of R & D investments, the first through legal restrictions and the second through technical use restrictions for seeds (Pray & Umali-Deininger, 1998; Tripp & Byerlee, 2000; Tripp, Louwaars, & Eaton, 2006). There are, however, controversial debates about the social implications of an increased privatization of plant breeding research in general, and of seed use restrictions in particular. Although WTO member countries are required to provide minimum IPR standards under the Trade-Related Intellectual Property Rights (TRIPs) agreement, IPRs in the agricultural sector are still relatively weak in the developing world. Therefore, the actual impact of legal seed use restrictions can hardly be observed empirically.

This situation is different for technical use restrictions: hybrid seed technologies, which exploit heterosis and generally achieve higher yields than open pollinated varieties (OPVs), have been globally marketed for years. In fact, the area cultivated with hybrid crops in devel-

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oping countries has risen substantially over the past decades (Food & Agriculture Organization, 2004; Pingali, 2001). 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 five main grounds (e.g., Kloppenburg, 2004; Shiva & Crompton, 1998). First, hybrid research and seed production is increasingly dominated by private companies, which direct their research mainly at commercial growers in well-developed regions with irrigation facilities or reliable rainfalls. Second, high seed prices charged by the private sector are claimed to deter smallholder farmers from buying hybrid seeds. Third, and related to high seed prices, the benefits of hybrids might be captured mostly by seed companies. Fourth, as the hybrid vigor gets lost when seeds are reproduced, farmers have to buy new seeds regularly to avoid yield losses. This may prove especially difficult for marginal farmers who often grow food crops with little cash income. Finally, it is argued that hybrid crops require more complementary inputs, especially chemical fertilizers, pesticides, and irrigation, which are often more affordable to large commercial farmers. Consequently, it is often asserted that a research focus on hybrid seed technologies may not necessarily be pro-poor: if disadvantaged farmers were 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 (Heisey, Morris, Byerlee, & López-Pereira, 1998; Morris, 1998; Smale, 1995; Zeller, Diagne, & Mataya, 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) illustrated 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-scale farmers alike cultivate hybrid maize in Africa. Heisey and Smale (1995) demonstrated that well-adapted hybrids can outperform OPVs even under adverse weather conditions and in situations where no additional inputs are applied. Pray, Ribeiro, Mueller, and Parthasaraty Rao (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. Research on hybrid wheat began as early as 1954 (Edwards, 2001). It was first commercialized in the United States and a couple of other countries in the 1970s, but 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. Due to advancements in breeding techniques, however, hybrid wheat was put back on the research agenda in the past decade. Today, it is cultivated in Australia, China, South Africa, and a number of European countries, notably France. In India, 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 examine what factors determine hybrid wheat adoption in India. Second, we analyze whether adopting farmers, particularly smallholders, benefit from the cultivation of hybrid wheat in a semi-subsistent environment. The analysis is based on a survey of 284 wheat farmers in Maharashtra, carried out in 2004. As farmers identified high seed prices as a major constraint for hybrid adoption, we also analyze farmers' potential price responsiveness using contingent valuation methods. We are unaware of previous studies on the adoption of hybrid wheat in developing countries.

Knowledge of the determinants and impact of hybrid adoption as well as farmers' price responsiveness could be of great value for policy makers in the design of effective strategies aimed at facilitating access to new seed technologies. Furthermore, this knowledge could add to the question as to how far the public sector should be involved in the development of hybrid food crops and the establishment of related seed distribution channels. More broadly, the results of the study could contribute to the debate about the implications of proprietary seed technologies and strengthened IPRs 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, while Section 4 looks at the impact of hybrid wheat. In Section 5, the contingent valuation model is developed and used for estimating farmers' willingness to pay (WTP) for hybrid seeds. Section 6 concludes with a discussion of 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. The 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/acre (Fertiliser Association of India, 2004). These enhancements were associated with an increase in irrigation facilities and chemical fertilizer usage (Rao, Singh, & Chatterjee, 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 yields fell over the past decades. While yields grew by 3.4% per year, on average, 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 reversal: the first is to breed new cultivars that outperform existing ones, and the second is to exploit the potential of areas that fell 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 of the above strategies. 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 2005. Adoption rates are shown in Table 1.

We chose Maharashtra as the study region for two reasons. First, Maharashtra currently has the largest hybrid wheat area in the country, and second, small-scale farmers with limited access to irrigation dominate wheat production in that state. More than 50% of the operational holdings in Maharashtra are below 5 acres (Government of Maharashtra, 2005). [1] We conducted a farm survey in 2004, collecting production data for the 2003–04 cultivation period. During this period, agricultural production was affected by adverse weather conditions:

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 rate (%)		
India	0.03	0.04	0.09	0.06	0.10
Maharashtra	0.39	0.52	1.41	1.54	1.78

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

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 the order of their cultivable area, are Western Maharashtra, Marathwada, Vidarbha, and Khandesh. [2] In each of the three largest regions, we 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 12–15 interviews were conducted with randomly selected farmers. Since the number of hybrid wheat adopters was small at this early stage of the technology diffusion process, adopters were over-sampled from complete seed sales lists.

In total, the data set comprises 87 adopters and 197 nonadopters. For 59 adopters, who grew both hybrid wheat and OPVs in 2003–04, input–output data were 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 nonadopters already shows some interesting features, determinants of adoption are analyzed more explicitly in the following section.

3. ADOPTION OF HYBRID WHEAT

This section focuses on the factors that determine the adoption decision for hybrid wheat in Maharashtra. To analyze the determinants of adoption, information and adoption probit models are estimated. The underlying assumption in the adoption model is that farmers base decisions on utility, rather than profit maximization. This assumption is reasonable, because wheat is grown on a semi-subsistence basis, with an average of more than 80% of the produce kept for consumption by the farmer's household (Table 2). In addition, farmers are assumed to be risk averse, as the majority of them are smallholders who operate in a poverty-stricken environment.

Acquiring information about a new technology is acknowledged as a very important stage in the adoption process (Feder & Slade, 1984; Rogers, 2003). Therefore, Model (1) in Table 3 establishes what factors determine whether a farmer has information on hybrid wheat. The information dummy variable equals one if the farmer has received any information on hybrid wheat from either formal or informal sources, and zero otherwise. Model (2) in Table 3 analyzes what variables influence the farmers' adoption decision.

In their seminal review paper, Feder, Just, and Zilberman (1985) pointed out that individual variables like education, farm size, and experience are significant determinants of technology adoption in developing countries. Feder and O'Mara (1981), in their study on the adoption of high yielding varieties during the Green Revolution, emphasized the importance of proper access to information and credit as facilitating elements in the adoption process. We therefore define information and credit constraint dummy variables. The information constraint variable is founded on self-reported access to information on modern agricultural technologies. The credit constraint variable is based on the farmers' self-reported access to a loan from the bank or credit from the input dealer.

Later adoption studies additionally emphasized the role of networks for the adoption

Table 2. *Selected characteristics of sample farmers*

	Adopters ($n = 87$)	Nonadopters ($n = 197$)
	Mean (standard deviation)	
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 nonfood expenditure (rupees[a]/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.
[a] 47 rupees ~1 US$.

Table 3. *Modeling information and adoption of hybrid wheat*

Explanatory variable	Description	(1) Information[a]	(2) Adoption[a]
Farm size	Land owned in acres	−3.29E−04 (−0.15)	4.69E−03 (1.59)
Irrigation	Share of farmland irrigated (%)	1.02E−03* (1.58)	−1.49E−05 (−0.02)
Soil quality	Dummy (1: high quality, 0: low quality)	0.05 (1.15)	0.05 (0.88)
Subsistence	Share of wheat output kept for own consumption (%)	1.35E−03* (1.83)	1.09E−03 (1.09)
Education	In years	−3.15E−03 (−0.76)	3.01E−03 (0.49)
Experience	Experience of growing wheat (years)	−2.81E−03 (−1.56)	−1.04E−03 (−0.40)
Expenditure	Annual per capita food and nonfood expenditure	1.30E−05*** (2.76)	1.16E−05** (2.36)
Credit constraint	Dummy (1: constraint, 0: otherwise)	−3.25E−03 (−0.08)	−0.06 (−1.02)
Information constraint	Dummy (1: constraint, 0: otherwise)	−0.32*** (−5.11)	−0.23*** (−3.07)
Hybrid wheat farmers	No. of hybrid wheat farmers known		0.02** (2.42)
Hybrid wheat farmers squared	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)
Yavatmal[b]	Dummy variable for the Yavatmal district	0.09* (1.70)	0.06 (0.80)
Aurangabad[b]	Dummy variable for the Aurangabad district	0.02 (0.41)	0.07 (0.93)
Regression statistics	Log likelihood $n = 281$	−102.71	−142.04

Note: Numbers in parentheses are z-values based on robust standard errors. *, **, *** Estimates are significant at the 10%, 5%, and 1% level, respectively. The means (standard deviations) of the dependent variables are: Information 0.81(0.39), Adoption 0.31(0.46).

[a] The probit model estimates shown are marginal effects evaluated at sample mean values.

[b] The reference variable for the district dummies is Nashik.

decision, that is, 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 studies stress that farmers do not learn from all other farmers in the village. They suggest that information flows through social networks, which are not necessarily based on geographic proximity (e.g., Bandiera & Rasul, 2002; Conley & Udry, 2001). As a measure of the size of the individual network, following the approach of Bandiera and Rasul (2002), we asked individual farmers in the survey how many hybrid wheat farmers they know. In addition, since 80% of all sample farmers stated that the seed dealer is one of their main sources of information on new seeds, [3] the geographical distance of the village to the nearest seed dealer is included, to capture village effects. District dummy variables capture 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" has been dropped from the regression. The effect of annual per capita expenditure, as a proxy for permanent income, is small but significant: [4] 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 to some extent, by using pumped groundwater (according to seasonal availability), cultivators with larger irrigated shares seem to be more interested in innovation. This might be due to the fact that the use of new seed varieties, in the past, often presupposed sufficient water availability. What is 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) demonstrates that information constraints and household income play a significant role in 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 adoption by two percentage points. Bandiera and 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 and Rosenzweig (1995) also found that farmers have the tendency to "free ride" on the acquired knowledge of other farmers. We test the free-riding hypothesis by using the square of the number of farmers known in 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 dummy variables, as well as education and experience, do not play a significant role. Interestingly, farm size and subsistence degree also do not influence the adoption decision in a significant way. Although Table 2 has shown that adopting farms are larger than nonadopting farms, the reason is apparently more related to income and associated risk considerations than to the size of the land holding itself.

4. IMPACT OF HYBRID WHEAT

Having established the main determinants of hybrid wheat adoption in Maharashtra, we now turn to the technological impact of hybrid wheat for adopting farmers. Table 4 presents selected wheat cultivation characteristics of hybrid and OPV plots.

Despite unfavorable weather conditions in the survey period, hybrid wheat had a significant yield advantage of 351 kg/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.

In a next step, we estimated a Cobb–Douglas type production function, including the use of hybrid wheat as a dummy variable. Since farmers purposely choose whether or not to adopt hybrid technology, this variable might potentially be correlated with the error term. To avoid an endogeneity bias in the estimates, we employed an instrumental variable (IV) approach, where household expenditure and social network variables, which proved significant in the adoption model, were used as instruments. Because these instruments, as such, do not influence per-acre yields, the production function is properly identified. Table 5 displays the regression results, where the dependent variable is the logarithm of per-acre yield. Two model versions are shown: one with interaction terms between the hybrid IV and other input variables, and the other without.

In both specifications the coefficient for hybrid wheat is positive and significant, indicating that the technology increases wheat yields also when controlling for other factors. Irrigation, fertilizer, and better soil quality also increase wheat productivity, while the effect of labor is insignificant.[5] Farmers in Yavatmal and Aurangabad have lower average yields than farmers in Nashik, which can be explained by

Table 4. *Selected wheat cultivation characteristics (2003–04)*

	Hybrid wheat plots ($n = 87$)	OPV plots ($n = 256$)
	Mean (standard deviation)	
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)

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

Table 5. *Estimated production function*

Variable	Description	With hybrid interaction terms	Without hybrid interaction terms
Hybrid wheat	Dummy (IV)	0.34* (1.78)	0.18*** (2.87)
Irrigation	Logarithm of number of irrigations	0.22** (2.40)	0.21** (2.58)
Fertilizer	Logarithm of fertilizer amount (per acre)	0.40*** (6.09)	0.36*** (6.11)
Labor	Logarithm of labor-days per acre	−0.07 (−1.32)	−0.06 (−1.23)
Soil quality	Dummy (1: high quality, 0: low quality)	0.20*** (3.38)	0.21*** (3.52)
Education	Formal education (years)	−0.01 (−0.94)	−0.01 (−1.11)
Experience	Experience in growing wheat (years)	−3.03E−04 (−0.12)	−4.10E−04 (−0.16)
Yavatmal[a]	District dummy	−0.28*** (−3.57)	−0.28*** (−3.67)
Aurangabad[a]	District dummy	−0.18** (−2.26)	−0.18** (−2.30)
Hybrid-fertilizer	Interaction term	−9.11E−04** (−2.26)	
Hybrid-irrigation	Interaction term	−1.51E−03 (−0.06)	
Hybrid-labor	Interaction term	6.42E−04 (0.42)	
Constant		4.74*** (12.29)	4.89*** (13.64)
Regression statistics	F	7.52	9.30
	R^2	0.27	0.26
	$n = 273$		

Note: The dependent variable in both models is the logarithm of per-acre wheat yields. Numbers in parentheses are t-values based on robust standard errors. *, **, *** Coefficients are significantly different from zero at the 10%, 5%, and 1% level, respectively.
[a] The reference variable for the district dummies is Nashik.

climatic and topological factors. The districts are located in different agro-ecological zones (ICRISAT, 1999). The interaction terms indicate whether or not the hybrid wheat technology changes the production elasticities of other inputs. The interactions with irrigation and labor are insignificant, whereas the interaction with fertilizer is significant and negative. This result is surprising, because it suggests that hybrid wheat is less responsive to chemical fertilizers than OPV wheat. However, the effect is small and should probably not be over-interpreted. In any case, the production function analysis disproves the hypothesis that hybrids can only be used successfully with higher input intensities, and it confirms that hybrid wheat technology has a significant net productivity-increasing effect. Based on the specification without interaction terms, the net yield effect is around 20%. [6]

Table 6 looks at the impact of hybrid wheat on farm income. To control for unobservable factors that might influence wheat cultivation, for example farmer's skills, we only compare the plots of those farmers who cultivated both hybrids and OPVs in the 2003–04 season. Such a within-farm comparison helps to reduce a possible nonrandom selection bias. The hybrid yield advantage is somewhat smaller than in Table 4, but still highly significant. In addition, the market price for grain from hybrid wheat is 0.41 rupees/kg higher, on average, than that of OPV wheat, reflecting the higher perceived quality. [7] Quality is especially 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 (Bellon & Risopoulos, 2001; Smale, 1995).

Seed costs per acre are considerably higher for hybrid wheat. In the first year of hybrid wheat introduction, the seed price per acre was much higher (around 1,400 rupees), but Mahyco 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/acre (39 US$/acre). Disaggregating this gain further, by farm size, reveals that small farms with less than 5 acres of land gain more (2,018 rupees/acre) than medium farms with 5–25 acres (1,924 rupees/acre), and they gain more than

Table 6. *Income effects of hybrid wheat (2003–04)*

	Hybrid wheat (n = 59)	OPVs (n = 59)
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)

Note: Numbers in parentheses are standard deviations. *, **, *** 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 by the market price of grain, to reflect the opportunity cost. While 36% of the nonadopting sample farmers replace their wheat seeds every year, 45% replace them every two years, 13% every three years, and 6% every four or more years.

[c] Family labor was valued at the prevailing village wage rate for males and females, respectively.

large farms with more than 25 acres (1,466 rupees/acre). Therefore, the sample does not confirm the widespread notion that the impacts of hybrid crops are always biased toward larger farms.

Finally, we look at the benefit distribution between farmers and the seed company. [8] The technology revenue that Mahyco gained from producing hybrid wheat in the 2003–04 production season was 287 rupees/acre, which shows that a large share of the market price for hybrid seeds is attributable to actual production and marketing costs. [9] Taking the average net income gain of 1,852 rupees/acre for adopters reveals that farmers are currently the main beneficiaries of hybrid wheat technology, capturing around 87% of the overall benefits. Of course, Mahyco could increase per-unit technology revenues by charging a higher monopoly price for seeds. This, however, might hinder hybrid adoption among smallholder farmers, which could potentially lead to lower overall company revenues. Issues of farmers' price responsiveness are analyzed in the next section.

5. WILLINGNESS TO PAY FOR HYBRID SEEDS

In the previous section it was pointed out that seed prices for hybrid wheat are significantly higher than for OPVs. Indeed, 43% of the nonadopters in our sample stated that the high seed price is a major adoption constraint. As mentioned above, Mahyco had reduced seed 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 (Hanemann, Loomis, & Kanninen, 1991). 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

$$U(Y - P, W^H, S) \geqslant U(Y, W^V, S), \qquad (1)$$

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. $P(\cdot)$ is defined as the bid function, which is positive and restricted by income,

$$0 \leqslant P(W^H, W^V, Y, S) \leqslant Y. \quad (2)$$

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

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

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, Eqn. (3) is specified by the constant-only bid function model,

$$P = a + e, \quad (4)$$

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,

$$a = a_0 + a_1X_1 + a_2X_2 + \cdots + a_nX_n. \quad (5)$$

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

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

To estimate the bid function, revealed and stated preferences are combined. Cooper (1997) suggested this approach; Hubbell, Marra, and Carlson (2000), Qaim and 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/acre. Assuming that adopters and nonadopters 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.

Nonadopters were asked if they would have been willing to cultivate hybrid wheat in 2003–04 at a lower price. Price bids were varied randomly across questionnaires in 50 rupee intervals from 350 rupees/acre, which is equivalent to the lowest market price for OPVs, to 950 rupees/acre. Fifty-four farmers in the sample had never heard of hybrid wheat. They received a description of the characteristics of hybrid wheat before posing 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

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

For nonadopters, there are two possible responses, for which the probabilities are

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

and

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

Accordingly, the log-likelihood function becomes

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

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. Table 7 displays the results of this maximum likelihood estimation.

In addition to the explanatory variables used for modeling adoption in Table 3, the variable "Negative own experience" is added, which captures whether a farmer grew hybrid wheat in ear-

Table 7. *Modeling the WTP for hybrid wheat seeds*

Explanatory variable	Description	WTP[a]	z-Value
Farm size	Land owned in acres	3.31*	1.85
Irrigation	Share of farmland irrigated (%)	−0.11	−0.24
Soil quality	Dummy (1: high quality, 0: low quality)	60.46*	1.86
Subsistence	Share of wheat output kept for own consumption (%)	−0.48	−0.89
Education	In years	−0.18	−0.05
Experience	Experience of growing wheat (years)	−1.41	−0.98
Expenditure	Annual per capita food and nonfood expenditure	7.45E−03***	2.58
Credit constraint	Dummy (1: constraint, 0: otherwise)	−61.26**	−1.99
Information constraint	Dummy (1: constraint, 0: otherwise)	−72.01**	−2.11
Hybrid wheat farmers	No. of hybrid wheat farmers known	2.12	0.97
Input dealer	Distance of the village to the input dealer (in km)	−0.31	−0.15
Yavatmal[b]	Dummy variable for the Yavatmal district	26.01	0.62
Aurangabad[b]	Dummy variable for the Aurangabad district	−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 $n = 280$	−259.92	

Note: z-Values are based on robust standard errors. *, **, *** Estimates are significant at the 10%, 5%, and 1% level, respectively.
[a] Model estimates can directly be interpreted as marginal effects on the WTP evaluated at sample mean values.
[b] The reference variable for the district dummy variables is Nashik.

lier seasons but stopped cultivating the crop because of negative experiences. Table 7 confirms the hypothesis that these farmers will have a lower WTP. There are also several other significant variables. Farmers who cultivate land with better soil quality are willing to pay 60 rupees/acre more for hybrid wheat. Farmers who are restricted in their access to credit are willing to pay 61 rupees less for this new seed technology. Income (approximated by annual per capita expenditures), information constraints, and farm size significantly influence the WTP in expected directions. Interestingly, neither education nor the subsistence shares of farmers seem to influence the WTP in a significant way. Evidently, farmers who obtain little or no 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 nonadopters were weighted differently, according to their share in Maharashtra's population of wheat growers. The mean WTP for all farmers equals 847 rupees/acre. [10] This value is only 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 (1,020 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, especially among smallholders, if market prices could be further reduced. One option would be for Mahyco to lower its per-unit technology revenues. However, as shown above, these are relatively low anyway, and, since they have to cover company R & D investments, a further reduction could jeopardize future levels of innovation. Therefore, the main avenue to reduce market prices for hybrid wheat will be to lower production and marketing costs through efficiency gains in seed systems.

6. CONCLUSION

In the light of the ongoing discussion about the suitability of proprietary seed technologies for smallholder farmers, this paper has analyzed whether farmers can benefit from hybrid wheat in a semi-subsistence environment of India, and what factors determine technology

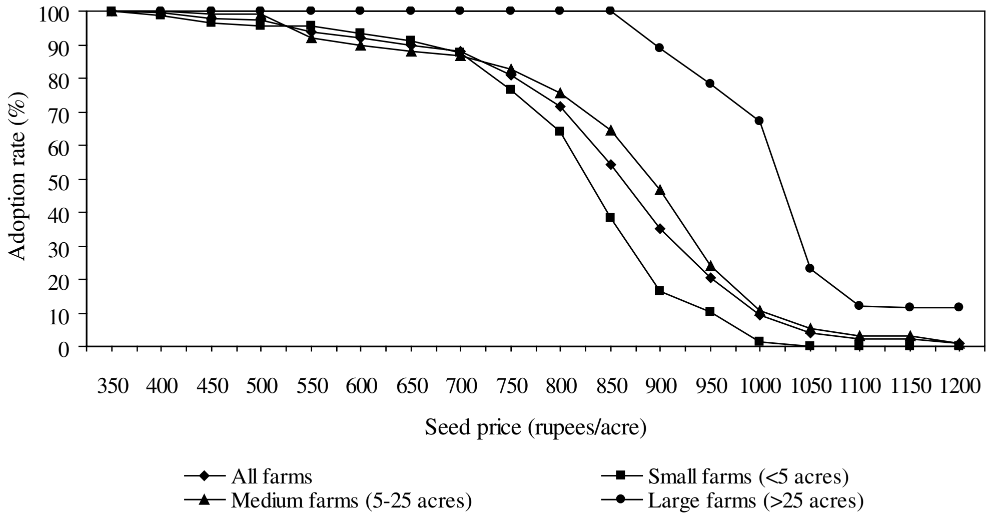

Figure 1. *Estimated percentage of hybrid wheat adopters at different price levels. Source: Own data.*

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 toward larger farms. On the contrary, despite relatively high seed prices and regular seed replacement requirements, smallholders benefit to a greater extent from the cultivation of hybrid wheat than their large-scale colleagues. In addition, when looking at the distribution of technological benefits in our sample, we found that farmers see greater gains from hybrid wheat than the seed company.

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 the 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 fairly price responsive, which indicates that if hybrid seed prices could be lowered, for instance through efficiency gains in seed production and distribution systems, 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. Yet, since the technology has only been on the market since 2001, more research is needed to assess its effects in other regions and climatic conditions.

More generally, we emphasize that the suitability of hybrid seeds for smallholders should be carefully evaluated case by case. Our findings demonstrate that hybrids can be very beneficial in a small farm environment, in spite of the fact that 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. However, institutional constraints can limit farmers' access. Consequently, more public sector involvement in promoting hybrid seed distribution is warranted. This involvement includes the establishment of physical seed market infrastructure, efficient regulatory systems, as well as the effective provision of appropriate information through the government extension service and other media. Public R & D on hybrids can complement private activities, especially related to crops that are of lesser commercial interest.

The findings are also interesting from an IPR perspective. India, like many other developing countries, only provides relatively weak IPR protection in the agricultural sector, and discussions about the pros and cons of strengthening plant breeders' rights are ongoing. The concerns of opponents are mostly related to the social implications of restricting seed use. Therefore, hybrids—with their associated technical use restriction—can offer some insights into the potential effects of legal use restrictions associated with IPRs. Our results suggest that strengthening plant breeders' rights could foster innovation and stimulate pro-poor agricultural growth in a country like India, if potential bottlenecks in seed distribution are addressed through public support. However, more research is needed in this direction, especially in countries with less developed seed industries.

NOTES

1. The Government of Maharashtra (2005) classifies operational holdings as follows: marginal/small farms (up to 5 acres), semi-medium/medium farms (5–25 acres), and large farms (more than 25 acres). This categorization is followed throughout the text.

2. The cultivable areas (in thousand acres) are Western Maharashtra (15,923), Marathwada (13,924), Vidarbha (12,177), and Khandesh (5,884) (Government of Maharashtra, 2003).

3. In fact, when asked about their main reliable sources of information on new seeds and agricultural technologies, the large majority of farmers named the seed dealer as the primary source. Other sources of information, in the order of importance, are fellow farmers (including the most progressive farmer in the village), seed companies, and public media. Government extension agents ranked relatively low in that list.

4. The household expenditure variable includes cash expenditures, as well as subsistence consumption.

5. 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 that included a pesticide variable did not change the sign and significance of the other variables. Soil qualities correspond to farmers' own evaluation of their plot. Heavy soils are identified as high quality soil, whereas medium to light soils are soils of lower quality.

6. In specifications with a logarithmic dependent variable, the exact effect of dummy variables is calculated as $\{\exp(\mathit{coefficient}) - 1\} \times 100$.

7. 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.

8. We ignore consumer benefits, because the current low adoption rates are not associated with a measurable consumer price effect. This effect might change in the future when technology adoption rates increase.

9. Based on Mahyco records, the technology revenue for the 2003–04 season was calculated as follows: contract farmers for seed production received 18.80 rupees/kg, seed handling (including treatment and packaging costs) was priced at 8.00 rupees/kg, and marketing costs were 2.92 rupees/kg. The total cost is 29.72 rupees/kg, or 713.28 rupees/acre, using the average seeding rate for hybrid wheat of 24 kg/acre. Seeds were sold at 1,000 rupees/acre, which generates technology revenues of 286.72 rupees/acre.

10. 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/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.

REFERENCES

Bandiera, O., & Rasul, I. (2002). *Social networks and technology adoption in northern Mozambique* (Working Paper No. 3341). London: Centre for Economic Policy Research.

Bateman, I. J., Carson, R. T., Day, B., Hanemann, M., Hanley, N., Hett, T., *et al.* (2002). *Economic valuation with stated preference techniques: A manual.* Cheltenham, United Kingdom: Edward Elgar Publishing.

Bellon, M. R., & Risopoulos, J. (2001). Small-scale farmers expand the benefits of improved maize germplasm: A case study from the Chiapas, Mexico. *World Development, 29*(5), 799–811.

Conley, T., & Udry, C. (2001). Social learning through networks: the adoption of new agricultural technologies in Ghana. *American Journal of Agricultural Economics, 83*(3), 668–673.

Cooper, J. C. (1997). Combining actual and contingent behavior data to model farmer adoption of water quality protection practices. *Journal of Agricultural and Resource Economics, 22*(1), 30–43.

Edwards, I. B. (2001). Hybrid wheat. In A. P. Bonjean, & W. J. Angus (Eds.), *The world wheat book* (pp. 1019–1045). Paris: Lavoisier.

Feder, G., Just, R. E., & Zilberman, D. (1985). The adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change, 33*(2), 255–298.

Feder, G., & O'Mara, G. T. (1981). Farm size and the diffusion of Green Revolution technology. *Economic Development and Cultural Change, 30*(1), 59–76.

Feder, G., & Slade, R. (1984). The acquisition of information and the adoption of new technology. *American Journal of Agricultural Economics, 66*(3), 312–320.

Fertiliser Association of India (2004). *Fertiliser statistics 2002–2003*. New Delhi, India: Author.

Food and Agriculture Organization (2004). Hybrid rice for food security. *FAO Factsheets, 6*.

Foster, A. D., & Rosenzweig, M. R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of the Political Economy, 103*(6), 1176–1209.

Goldman, A., & Smith, J. (1995). Agricultural transformations in India and northern Nigeria: Exploring the nature of Green Revolutions. *World Development, 23*(2), 243–263.

Government of Maharashtra (2003). *Statistical abstract of Maharashtra State 1995–96 and 1996–97*. Mumbai, India: Government Press.

Government of Maharashtra (2005). *Economic survey of Maharashtra 2004–2005*. Mumbai, India: Government Press.

Hanemann, M., Loomis, J., & Kanninen, B. (1991). Statistical efficiency of double-bounded dichotomous choice contingent valuation. *American Journal of Agricultural Economics, 73*(4), 1255–1263.

Heisey, P. W., Morris, M. L., Byerlee, D., & López-Pereira, M. A. (1998). Economics of hybrid maize adoption. In M. L. Morris (Ed.), *Maize seed industries in developing countries* (pp. 143–158). Mexico, D.F: CIMMYT.

Heisey, P. W., & Smale, M. (1995). *Maize technology in Malawi: A green revolution in the making?* (Research Report No. 4). CIMMYT: Mexico, D.F.

Hubbell, B. J., Marra, M. C., & Carlson, G. A. (2000). Estimating the demand for a new technology: Bt cotton and insecticide policies. *American Journal of Agricultural Economics, 82*(1), 118–132.

ICRISAT. (1999). *Typology construction and economic policy analysis for sustainable rainfed agriculture*. Pantancheru, India: Author.

Kloppenburg, J. R. (2004). *First the seed: The political economy of plant biotechnology*. Cambridge University Press.

Lipton, M. (2005, November 11). *What priorities for improved agricultural technology?* Presentation at the Future Agricultures Consortium on Achieving propoor growth through agriculture: The challenges. London.

McConnell, K. E. (1990). Models for referendum data: The structure of discrete choice models for contingent valuation. *Journal of Environmental Economics and Management, 18*(1), 19–34.

Morris, M. L. (1998). Overview of the world maize economy. In M. L. Morris (Ed.), *Maize seed industries in developing countries* (pp. 13–34). Mexico, D.F.: CIMMYT.

Pingali, P. L. (Ed.) (2001). *CIMMYT 1999–2000 World maize facts and trends. Meeting world maize needs: Technological opportunities and priorities for the public sector*. Mexico, D.F.: CIMMYT.

Pingali, P. L., & Rajaram, S. (1997, May 28). *Technological opportunities for sustaining wheat productivity growth*. Paper presented at the Illinois world food and sustainable agriculture program conference, Urbana-Champaign, IL.

Pingali, P. L., & Rosegrant, M. W. (1998). Supplying wheat for Asia's increasingly westernized diets. *American Journal of Agricultural Economics, 80*(5), 954–959.

Pomp, M., & Burger, K. (1995). Innovation and imitation: Adoption of cocoa by Indonesian smallholders. *World Development, 23*(3), 423–431.

Pray, C. E., Ribeiro, S., Mueller, R. A. E., & Parthasaraty Rao, P. (1991). Private research and public benefit: The private seed industry for sorghum and pearl millet in India. *Research Policy, 20*(4), 315–324.

Pray, C. E., & Umali-Deininger, D. (1998). The private sector in agricultural research systems: Will it fill the gap? *World Development, 26*(6), 1127–1148.

Qaim, M., & de Janvry, A. (2003). Genetically modified crops, corporate pricing strategies, and farmer's adoption: The case of Bt cotton in Argentina. *American Journal of Agricultural Economics, 85*(4), 814–828.

Rao, S., Singh, G., & Chatterjee, M. (2001). Indian wheat pool. In A. P. Bonjean, & W. J. Angus (Eds.), *The world wheat book* (pp. 773–816). Paris: Lavoisier.

Rogers, E. M. (2003). *Diffusion of innovations*. New York: Free Press.

Shiva, V., & Crompton, T. (1998, September 26). Monopoly and monoculture. Trends in the Indian seed industry. *Economic and Political Weekly* (pp. 137–151).

Smale, M. (1995). Maize is life: Malawi's delayed green revolution. *World Development, 23*(5), 819–831.

Tripp, R., & Byerlee, D. (2000). Public plant breeding in an era of privatisation. *ODI Natural Resource Perspectives, 57*, 1–4.

Tripp, R., Louwaars, N., & Eaton, D. (2006). Intellectual property rights for plant breeding and rural development: Challenges for agricultural policymakers. *Agricultural and Rural Development Notes, 12*(6), 1–4.

Zehr, B. (2001). Emerging biovision: Hybrid wheat. In: M.S. Swaminathan Research Foundation (Ed.), *MSSRF-FAO expert consultation on science for* *sustainable food security, nutritional adequacy, and poverty alleviation in the Asia-Pacific region* (pp. 226–230). Chennai, India: Editor.

Zeller, M., Diagne, A., & Mataya, C. (1998). Market access by smallholder farmers in Malawi: Implications for technology adoption, agricultural productivity and crop income. *Agricultural Economics, 19*(1–2), 219–229.