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'Poverty, Equity and Growth in Developing and Transition Countries: Statistical Methods and Empirical Analysis'

Georg-August-Universität Göttingen
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Discussion Papers

No. 105

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January 2012

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Acknowledgements: The Higher Education Commission (HEC) of Pakistan provided a stipend to the first author, which is gratefully acknowledged.

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Abstract: Data from a farm survey and choice experiment are used to value the benefits of Bt cotton in Pakistan. Unlike previous research on the economic impacts of Bt, which mostly concentrated on financial benefits in terms of gross margins, we also quantify and monetize positive externalities associated with technology adoption. Due to lower chemical pesticide use on Bt cotton plots, there are significant health advantages in terms of reduced incidence of acute pesticide poisoning, and environmental advantages in terms of higher biodiversity and lower soil and groundwater contamination. These positive externalities are valued at US$ 79 per acre, of which half is attributable to health and the other half to environmental improvements. Adding average gross margin gains of US$ 204 results in an aggregate benefit of US$ 283 per acre of Bt, or US$ 1.7 billion for the total Bt cotton area in Pakistan.

Key words: *Bt cotton; Pesticide use; Health and environmental benefits; Choice experiment; Pakistan*

JEL classification: *D62, I15, Q51, Q57*

1. Introduction

Bt cotton has been genetically modified (GM) through insertion of genes from *Bacillus thuringiensis* (Bt) to make the plant resistant to cotton bollworms. Bollworms are a group of insect pest species, which cause significant crop damage and are responsible for heavy chemical pesticide applications in almost all of the world's cotton growing regions (Zehr, 2010). Over the last 15 years, Bt cotton has been adopted widely in a number of countries. Studies show that this

technology contributes to lower pesticide use, reduced crop damage, and higher farm incomes (Qaim, 2009; Carpenter, 2010). For developing countries, the most comprehensive studies on the impacts of Bt cotton are available for China and India (Pray *et al.*, 2002; Huang *et al.*, 2003; Qaim *et al.*, 2006). Furthermore, effects were analyzed in South Africa (Bennett *et al.*, 2003), Argentina (Qaim and de Janvry, 2005), and Mexico (Traxler and Godoy-Avila, 2004). While the main findings are consistent across countries, the concrete effects vary, because they depend on agroecological and institutional conditions.

The existing research concentrates on agronomic and financial impacts of Bt cotton. A few studies have also analyzed reductions in the incidence of acute pesticide poisoning among farmers, due to lower exposure to chemical pesticides (Bennett *et al.*, 2003; Hossain *et al.*, 2004; Kouser and Qaim, 2011). But these effects were not monetized,[1] which is important for inclusion into benefit-cost analysis. Furthermore, we are not aware of studies that tried to assess the environmental benefits of Bt cotton from an economic perspective. This is a research gap. As is well known, chemical pesticide use can be associated with significant health and environmental risks (Pingali, 2001; Travisi *et al.*, 2006). This is especially true in developing countries, where pesticide regulations tend to be laxer and spraying operations are often carried out manually with little or no protective clothing (Pingali *et al.*, 1994; Maumbe and Swinton, 2003). Hence, chemical pesticide reductions through Bt adoption may entail health and environmental benefits. Evaluating and monetizing such positive externalities will contribute to the research direction. It can also add to the public and policy debate about GM crops, which often concentrates more on potential environmental and health risks (Andow and Zwahlen, 2006).

[1] The only study that attempted some economic valuation of the health benefits of Bt cotton adoption is by Kouser and Qaim (2011), using a cost-of-illness approach. Krishna and Qaim (2008) used a similar approach in their ex ante impact assessments of Bt eggplant in India.

Here, we analyze possible financial, health, and environmental benefits of Bt cotton in Pakistan. Bt cotton was officially commercialized in Pakistan in late 2009. Unofficial cultivation of Bt varieties already occurred before 2009, but the Bt area has increased rapidly since then, reaching 5.9 million acres in 2010, which is equivalent to 75% of Pakistan's total cotton acreage (James, 2010). Two recent studies have looked at Bt cotton impacts in Pakistan, building on data from unofficial cultivation in 2007 and 2009 (Ali and Abdulai, 2010; Nazli *et al.*, 2010); both studies did not analyze health and environmental effects. Our research builds on a farm survey carried out in Punjab Province: The survey refers to 2010 – the first cotton season when officially approved Bt varieties were used for cultivation. Agronomic and financial impacts are analyzed by comparing pesticide use, cotton yields, and gross margins between Bt adopters and non-adopters. Health and environmental externalities are estimated and valued with data from a choice experiment, which was part of the farm survey. The results are integrated into a broader benefit-cost analysis of Bt cotton from a farmer's perspective.

The rest of this article is organized as follows. The next section describes the farm survey. Section 3 analyzes agronomic and financial effects of Bt cotton adoption. Subsequently, section 4 introduces the choice experiment, while section 5 presents the estimation results of values that farmers attribute to different health and environmental externalities. Section 6 discusses the benefit-cost analysis, and section 7 concludes.

2. Farm survey

We carried out a survey of cotton farmers in Punjab, Pakistan, between December 2010 and February 2011, immediately after the harvest for the 2010 cotton season was over. Punjab is the leading cotton growing province in Pakistan, with about 80% of the country's total cotton area

(GOP, 2009). Within Punjab, a multi-stage sampling procedure was used. First, four major cotton producing districts were purposively selected, namely Vehari, Bahawalnagar, Bahawalpur, and Rahimyar Khan. These four districts account for 42% of the total cotton area in Punjab (GOP, 2009). Then, we randomly selected two tehsils (administrative units) in each district and four villages in each tehsil, resulting in a total of 32 villages. At the last stage, a complete list of cotton farmers was prepared in each village, from which 11 farmers were randomly selected. Thus, our sample consists of 352 cotton farmers, of which 248 are Bt adopters and 104 are non-adopters. Among the 248 adopters, 75 have completely switched to Bt, while 173 were partial adopters growing Bt in addition to conventional cotton. The sample is representative of cotton farmers in this part of Pakistan.

We used a structured questionnaire, including questions on general socioeconomic characteristics of the farm household, details about input use and output in the cotton enterprise, farmer perceptions of pesticide related health and environmental effects, including concrete experience with pesticide poisoning, and a choice experiment. The face-to-face interviews were conducted by a team of four local enumerators, who were selected, trained, and monitored by the researchers. Details about cotton enterprise budgets and the choice experiment are discussed further below. Some general descriptive statistics are shown in Table 1. Bt adopters have significantly larger farms than non-adopters, although the difference in the cotton area is small and not statistically significant. In addition to cotton, both adopters and non-adopters grow wheat, rice, maize, and partly also sugarcane. Differences in the farmer's age and educational levels are not significant.

Table 1 about here

3. Pesticide use, yields, and gross margins

Table 2 shows details of input use and yields obtained on Bt and non-Bt cotton plots. For partial adopters, we collected input-output data for both Bt and non-Bt plots, so that the number of plot observations is larger than the number of farmers surveyed. Farmers use significantly lower pesticide quantities on Bt than on non-Bt plots. This is further illustrated in Fig. 1, showing the cumulative distribution functions of pesticide use on Bt and non-Bt plots. A Kolmogorov-Smirnov (KS) test confirms that the two functions are significantly different ($p < 0.01$). Table 2 also shows that Bt cotton is sprayed significantly less often, and that the pesticide cost expressed in Pakistani Rupees (Rs) per acre is lower than on non-Bt plots.

Table 2 about here

Fig. 1 about here

Cotton yields are also significantly higher on Bt than on non-Bt plots; the observed yield difference is 28%. This difference is not due to higher genetic yield potentials of Bt varieties, but due to reduced crop losses. In spite of chemical pesticide applications, bollworms cause sizeable yield damage in conventional cotton, which can be controlled more effectively with Bt technology. Again, comparison of cumulative distribution functions confirms a significant difference ($p < 0.01$) between Bt and conventional cotton yields (Fig. 2). These results are consistent with earlier studies on Bt cotton impacts in Pakistan (Ali and Abdulai, 2010; Nazli *et al.*, 2010) and other developing countries (Pray *et al.*, 2002; Qaim and de Janvry, 2005; Qaim, 2009).

Fig. 2 about here

Concerning the costs for other inputs, Bt seeds are more expensive than conventional cotton seeds (Table 2), but the difference is only 14%, which is much smaller than in other

countries where Bt cotton has been adopted. In India, for instance, during the first years of adoption, Bt seeds were three times more expensive than conventional cotton seeds (Qaim *et al.*, 2006). However, unlike India where Bt is mostly incorporated into hybrids developed by private companies, in Pakistan open-pollinated Bt cotton varieties developed by public research institutes are available, in addition to black market seeds coming in from China and India.

For fertilizer, irrigation, and labor, the costs observed are also slightly higher on Bt than on non-Bt plots. These differences are not due to higher input requirements of Bt technology, but higher yields increase the marginal input returns, thus providing incentives for intensified production. Total production costs are higher on Bt than on non-Bt plots, but this increase is overcompensated through higher revenues, so that gross margins increase significantly. The mean difference in gross margins between Bt and non-Bt plots is Rs 17300 per acre (US$ 204). This difference is larger than in most other Bt cotton adopting countries, which is largely due to the lower Bt seed costs in Pakistan. Yet it should also be mentioned that cotton prices were relatively high in 2010, contributing to above average gross margins.

During the survey, farmers were also asked about acute health problems that they had faced in connection with pesticide sprays in cotton during the last growing season. In particular, they were asked about the frequency and type of pesticide related poisonings, such as skin and eye irritation, breathing problems, nausea, faintness, and other symptoms. As Table 2 shows, cases of pesticide poisoning were reported both for Bt and non-Bt plots. This is typical situation where farmers apply highly toxic pesticides with knapsack sprayers and hardly any protective clothing. However, as can be seen, the incidence is significantly lower on Bt plots, which is plausible given the lower use of chemical pesticides. This is consistent

with research in China, India, and South Africa (Hossain *et al.*, 2004, 2003; Kouser and Qaim, 2011; Bennett *et al.*, 2003). Fig. 3 shows that the majority of Bt farmers reported zero or one case of poisoning during the 2010 cotton season, whereas non-Bt farmers reported a higher frequency for each higher count of pesticide poisonings; a chi-square test confirms that the two frequency distributions differ significantly ($p < 0.05$).

Fig. 3 about here

We also expect positive environmental effects of Bt adoption, but these were not directly observed by farmers, so that we cannot make simple comparisons based on the survey data. Instead, we used a choice experiment to learn more about farmers' health and environmental preferences. Details of this approach are explained in the following section.

4. Valuing health and environmental benefits

We want to quantify the health and environmental benefits of Bt cotton adoption. These benefits occur though a reduction in negative externalities. Hence, we estimate and quantify the negative externalities for both Bt and non-Bt cotton and interpret the difference as the external benefit of Bt adoption. As there is no market for external health and environmental costs and benefits, we use a non-market valuation approach. In particular, we build on stated preference data for estimating farmers' willingness to pay (WTP) for health and environmental improvements.

Creating a scenario that is similar to a real market situation and is easily understandable by farmers, helps to reduce hypothetical bias when eliciting stated preference data. As part of the farm survey, we designed a scenario where respondents were asked to choose between hypothetical pesticides, which all have the same effectiveness in terms of controlling bollworms,

but different health and environmental attributes. A similar approach was used by Cuyno *et al.* (2001), who evaluated farmers' attitudes towards integrated pest management in the Philippines; they directly asked farmers for their WTP for different pesticide formulations in a contingent valuation exercise. Here, we are not only interested in aggregate WTP for a "safe" pesticide, but also want to analyze farmers' preferences for different health and environmental attributes. For this purpose, a choice experiment (CE) is better suited than contingent valuation techniques (Hanley et al., 1998). Different CE approaches were used in the literature to estimate WTP for environmental quality, but also for improvements of several other non-market goods and services (Foster and Mourato, 2000; Speelman et al., 2010; Vásquez et al., 2011).

In our CE, we included the incidence of acute poisoning during or after spraying operations as an important health attribute of pesticides. As mentioned, this is a serious problem in Pakistan's cotton sector. The poisoning incidence is correlated with pesticide quantities used, but also with pesticide toxicity levels (Hossain *et al.*, 2004; Kouser and Qaim, 2011), so that considering this as a health attribute of pesticide formulations is justified. Concerning environmental attributes of pesticides, we differentiate between farmland biodiversity effects on the one hand, and levels of soil and groundwater contamination on the other hand. For farmland biodiversity, we concentrate on the loss of beneficial insects, which is an important biodiversity concern (Theiling and Croft, 1988; Perrings, 2010). Soil and groundwater contamination is a more general indicator of pesticide impacts on agroecosystems (Brethour and Weersink, 2001; Cuyno *et al.*, 2001; Travisi and Nijkamp, 2008). Finally, we include pesticide price as a product attribute. Details of the different attribute levels used in the CE are explained further below.

It should be stressed that our approach of valuing environmental externalities of pesticide use is partial. First, we chose a limited number of attributes that are easy to understand for local

cotton farmers with relatively low educational background. While the attributes included involve important aspects, they do not cover all environmental goods that may be affected through pesticide use. Categories that may not be fully captured, for instance, are birds and aquatic species. Second, we only conducted the CE with farmers, although non-farm households may have a positive WTP for environmental quality, too. Hence, our approach is conservative in the sense that we likely underestimate the negative externalities of pesticide use in cotton and thus the external Bt cotton benefits for society as a whole.

4.1. The choice experimental approach

The CE is a non-market valuation technique that makes it possible to infer respondent's preferences for a set of relevant product attributes and their levels. The methodology is derived from a combination of Lancaster's model of consumer choice and random utility theory (Louviere *et al.*, 2000). As mentioned, we model a cotton farmer's choice for pesticides that help to control bollworms but have varying levels of harmful health and environmental impacts. Farmer *i* chooses among *j* pesticide alternatives from a choice set *C* that provides different levels of utility. The utility function (U_{ij}) consists of a deterministic component (V_{ij}) and a stochastic component (ε_{ij}):

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (1)$$

Farmer *i* will choose a specific pesticide *k* (out of *j*) if and only if $U_{ik} > U_{im}; \forall m \neq k$. Assuming that ε_{ij} is independently and identically distributed with type I extreme value distribution and fixed variance, the probability (P_{ik}) of choosing *k* can be expressed with the following logit function:

$$P_{ik} = \frac{exp(V_{ik})}{\sum_{j=1}^{J} exp(V_{ij})}; \qquad k \epsilon J \quad (2)$$

which can be estimated with a conditional logit (CL) model (Maddala, 1983) as:

$$V_{ij} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \quad (3)$$

where n is the number of pesticide attributes, and X $(X = X_1 \; to \; X_n)$ is the vector of pesticide attributes. β_0 is the alternative specific constant (ASC), which captures the effects of unobserved factors not included in pesticide attributes (Louviere *et al.*, 2000), and β_1 to β_n is the vector of coefficients of their respective attributes.

4.2. Experimental design and application

The pesticide attributes included in our CE were explained above. Attribute levels were determined based on previous studies on pesticide externalities (e.g., Brethour and Weersink, 2001; Hossain *et al.*, 2004; Florax *et al.*, 2005; Arshad *et al.*, 2009; Travisi and Nijkamp, 2008) and additional discussions with agronomic and environmental experts. The attributes and their levels are shown in Table 3. For each attribute, we consider the status quo and three alternative, hypothetical levels.

Table 3 about here

The first attribute, human health effects, is measured in terms of the number of acute poisoning incidences experienced with the particular pesticide over the cotton growing season. In the pretest of the survey questionnaire, some of the farmers we interviewed reported a high number of poisoning cases, so that we decided to use six poisoning incidences as the status quo level.[2] "Safer" pesticides are assumed to cause lower numbers of poisoning incidences. Hence, for the two hypothetical alternatives we reduce the number to four, two, and one, respectively. The second attribute, farmland biodiversity, represents the loss of beneficial insects due to

[2] During the survey, we realized that the mean number of poisoning incidences is actually lower (see Table 2). As we explain further below, the benefit-cost analysis builds on the WTP per reduced poisoning incidence and the actually observed incidence numbers, so that we do not expect an upward bias in the results.

pesticide sprays. This is measured in percentage terms. Khan *et al.* (2002) showed that about 90% of beneficial insects have been lost in cotton growing areas of Punjab due to heavy pesticide use. Therefore, we use 90% loss as the reference point in the status quo, and reductions for the hypothetical alternatives as shown in Table 3. The third attribute involves the contamination of soil and groundwater with pesticide residues, which is measured in a range from 4 (extremely contaminated) to 1 (slightly contaminated). The reference in the status quo is assumed to be 4, with reductions for the hypothetical alternatives. The last attribute is pesticide price as the payment vehicle, which is important to include for WTP estimates. As status quo, we used the price of Emamectin, which is the most commonly used pesticide to control bollworms by local cotton farmers. During the time of the survey, Emamectin was sold at Rs 500 per bottle of 400 ml size. Safer pesticides with the same level of effectiveness against bollworms are assumed to be more expensive.

With four attributes and each attribute with three hypothetical levels there are 81 (3^4) possible combinations of hypothetical pesticides. However, not all of them have to be included in the CE. According to Hensher *et al.* (2006), a minimum of five degrees of freedom (corresponding to five different choice sets) is required for estimation of linear effects. Following Kuhfeld (2009) and Johnson *et al.* (2007), a D-optimal design with only the main effects was constructed using software package SAS 9.2. The goal of the D-optimal design is to generate choice sets with maximum efficiency given the assumed attributes, levels, and other properties of the experiment (Kuhfeld, 2009). Taking into account the problems of overlap, level balance, and dominance or near dominance of some choice sets (Huber and Zwerina, 1996), the 9 choice sets generated by SAS were reduced to six choice sets, which is still sufficient for linear effects estimation.

Each choice set consists of three different pesticides, where one was always the status quo, and the other two were hypothetical alternatives. All six choice sets were presented to farmers, one after the other, and in each round farmers were asked to choose the most preferred pesticide (contingent choice). Thus, our data contain six choices for every farmer. We used choice cards with colored pictures for the attributes and attribute levels to facilitate visual differentiation (Fig. 4). These cards were printed in national language (Urdu). Before starting the CE, we informed famers about the problem of hypothetical bias through "cheap talk" and reminded them to keep this in mind when making their choices (e.g., List *et al.*, 2006).

Fig. 4 about here

5. Estimation results

5.1. Conditional logit model

Building on the conditional logit model and the CE data, we estimated a model with the following specification:

$$V_{ij} = ASC + \beta_1 Health + \beta_2 Biodiv + \beta_3 Soil\ and\ GW + \beta_4 Price \quad (4)$$

where ASC takes a value of 1 if one of the hypothetical "safer" pesticides was chosen, and 0 if the farmer chose the status quo option. $Health$ represents the pesticide effect on farmers' health, $Biodiv$ denotes the effect on farmland biodiversity, $Soil\ and\ GW$ means the effect on soil and groundwater, and $Price$ is pesticide price per bottle.

Equation (4) was estimated using all 2112 choices elicited from 352 farmers. Results are shown in column (1) of Table 4. All the coefficients are statistically significant and have the expected signs. The ASC coefficient is positive, suggesting that farmers have a general preference for safer pesticide alternatives over the status quo. The other coefficients indicate that

farmers prefer pesticides that are associated with a lower incidence of acute pesticide poisoning, lower negative effects on beneficial insects, and lower contamination of soil and groundwater. Furthermore, holding other attributes constant, farmers prefer lower-priced pesticides, which is consistent with random utility theory.

Table 4 about here

The CL model assumes the independence of irrelevant alternatives (IIA) property, implying that the relative probabilities of two alternatives being chosen are unaffected by the introduction or removal of other alternatives. If the IIA property is violated, the results of the CL model will be biased; in that case other discrete choice models, which do not build on the IIA property, would be preferred (Hensher *et al.,* 2006). To test whether the CL model is appropriate in our case, the Hausman and McFadden (1984) test for the IIA property was employed by comparing the unrestricted model with restricted models where individual alternatives were excluded from each choice set. When excluding the status quo, the test could not produce a result, because the difference matrix is not positive definite. Yet when excluding the hypothetical alternatives, the null hypothesis of IIA could not be rejected (p = 0.55). We conclude that the CL model is appropriate in our case.

5.2. Model with interactions

The CL model as shown in equation (4) assumes homogeneous preferences across farmers. Yet, in reality preferences for safer pesticides may be heterogeneous and influenced by socioeconomic factors. To account for this, we augmented the model by including interaction terms between selected socioeconomic variables and health and environmental pesticide attributes. Farmer's age, farm size, and other socioeconomic variables were tried, their

interaction terms were statistically insignificant. For farmer's education, however, some interesting effects were found, which are presented in column (2) of Table 4. The underlying model has the following specification:

$$V_{ij} = ASC + \beta_1 Health + \beta_2 Biodiv + \beta_3 Soil\ and\ GW + \beta_4 Price + \beta_5 Edu * Health + \beta_6 Edu * Biodiv + \beta_7 Edu * Soil\ and\ GW \quad (5)$$

where Edu is the farmer's education measured in terms of schooling years. We used the Swait-Louviere likelihood ratio test (Swait and Louviere, 1993) to compare the CL model with and without interaction terms. The test results, which are shown in the lower part of Table 4, indicate that adding education interaction terms notably improves the model's significance.

Health, farmland biodiversity, and soil and groundwater effects remain significant attributes for pesticide choice. The education-farmland biodiversity interaction is negative and significant, revealing that farmers with more education have a higher than average preference for pesticides that are less harmful for beneficial insects. Similarly, the education-soil and groundwater interaction is negative and significant, indicating that more educated farmers have a higher preference for pesticides with lower negative agroecosystem impacts. The education-health interaction is negative, but statistically insignificant. This is plausible: even for less educated farmers it is easy to understand negative impacts of pesticides on their own health, so that educational levels do not influence preferences significantly. In contrast, biodiversity and agroecosystem effects are somewhat more complex and less immediately felt, so that the value that farmers subjectively attribute to reduced negative impacts is significantly correlated with education.

5.3. Willingness to pay

The results from the CL model can be used to estimate average marginal WTP for a change in different pesticide attributes. WTP represents the marginal rate of substitution between pesticide price and the health and environmental attributes. We employed a Wald procedure (Delta method) to estimate marginal WTP for the average farmer, building on the estimates from column (2) in Table 4. The results are reported in Table 5. Column (1) shows marginal WTP for each product attribute, expressed in Rs per 400 ml bottle of pesticide. The values have to be interpreted for a one unit reduction in health and environmental impacts.

For each reduced incidence of acute pesticide poisoning, farmers are willing to pay Rs 398 more. This is an 80% increase over the price of a bottle of pesticide in the status quo, which is quite high but not unrealistic, given that pesticide poisoning is often associated with a significant cost of illness, including the opportunity cost of lost labor days (Krishna and Qaim, 2008; Kouser and Qaim, 2011). Farmland biodiversity is measured in percentage terms; a one percentage point reduction in the loss of beneficial insects increases WTP per bottle of pesticide by Rs 9. Soil and groundwater contamination is measured on a 1-4 scale; per unit reduction, farmers are willing to pay Rs 303 more per bottle.

Table 5 about here

In column (2) of Table 5, these marginal WTP values per bottle of pesticide have been divided by 400, in order to obtain values per ml of pesticide. These values still refer to a one unit reduction in health and environmental impacts. In order to derive WTP for all units of negative externality, the values in column (2) have to be multiplied with the attribute levels in the status quo. Results of these calculations are shown in column (3) of Table 5. Summing up over the three attributes, each ml of pesticide causes negative health and environmental externalities that

each farmer value at Rs 6.8. In other words, options to control bollworms with lower negative health and environmental impacts could cause significant welfare gains.

6. Benefit-cost analysis of Bt cotton adoption

In section 3, we have compared gross margins between Bt cotton adopters and non-adopters and found significant differences, suggesting sizeable benefits of technology adoption. However, gross margin analysis only captures financial benefits. Given the fact that significantly lower amounts of chemical pesticides are used on Bt than on non-Bt plots, there is also a reduction in negative externalities, entailing health and environmental benefits. Using the results from section 5, we now monetize these health and environmental benefits and add them to the financial benefits for a broader benefit-cost analysis of Bt cotton adoption.

Columns (1) and (2) of Table 6 show gross margins and the costs of negative externalities associated with chemical pesticide use on Bt and non-Bt cotton plots, respectively. The externality costs were calculated by multiplying the WTP per ml (see column 3 of Table 5) with the actual quantity of pesticide used on each plot. The average costs of negative externalities are lower on Bt plots. Column (3) shows that the differences between Bt and non-Bt plots are statistically significant. The negative differences in rows (b) to (e) imply reductions in the negative externalities, which can also be interpreted as positive externalities of Bt cotton adoption. The total external benefit of Bt cotton is Rs 6739 (US$ 79) per acre. Out of this, 47% is due to positive health effects, 20% due to higher farmland biodiversity, and 33% due to lower soil and groundwater contamination.

Table 6 about here

Total external benefits of Bt adoption are equivalent to 39% of financial benefits (gross margin difference). Adding up financial and external benefits results in a total net benefit of Rs 24039 (US$ 283) per acre of Bt cotton. Multiplying this with the total Bt area in Pakistan, which was 5.9 million acres in 2010, results in aggregate welfare gains of Rs 142 billion (US$ 1.7 billion) for technology adopting farmers.

7. Conclusion

We have used data from a farm survey and choice experiment to value the benefits of Bt cotton adoption in Punjab, Pakistan. In addition to analyzing financial benefits in terms of gross margin differences between Bt adopters and non-adopters, we also valued positive health and environmental externalities. Although previous research pointed at the existence of positive health and environmental impacts, such external benefits have never been monetized and integrated into a broader economic assessment of Bt cotton, neither for Pakistan nor for any other country. Our findings show that Bt cotton adoption results in significantly lower chemical pesticide use, higher yields, and higher gross margins, which is consistent with the results from other countries. In addition, lower pesticide use brings about significant health advantages in terms of reduced incidence of acute pesticide poisoning, and environmental advantages in terms of higher farmland biodiversity and lower soil and groundwater contamination. These positive externalities are valued at US$ 79 per acre, which adds another 39% to the benefits in terms of higher gross margins. Adding up financial and external benefits results in total benefits of US$ 283 per acre, or US$ 1.7 billion for the entire Bt cotton area in Pakistan.

Our results suggest that previous studies on the impacts of Bt cotton adoption underestimated the benefits, because positive externalities were not accounted for. Obviously, a comprehensive

evaluation should also consider negative externalities, such as possible environmental risks. Several studies have shown that high concentrations of Bt proteins can also have negative effects for non-target species, including beneficial insects and soil organisms. However, such studies are often carried out under artificial laboratory conditions, or the environmental effects of Bt are compared to zero-pesticide alternatives, which are rarely observed in real farm production. A recent meta-analysis suggests that negative environmental impacts of chemical pesticides are much larger than those of Bt crops (Wolfenbarger *et al.*, 2008).

The approach developed and used here is only a first attempt to quantify and monetize health and environmental benefits of Bt cotton technology. One limitation is that we could only include environmental effects that are relatively easy to understand for people with low educational levels. Another limitation is that we conducted the choice experiment only with farm households, so that welfare gains for non-farm households associated with improvements in environmental quality are disregarded. This may potentially lead to underestimation of the total external benefits. On the other hand, stated preference data may involve hypothetical bias, which could result in overestimated benefits. Further research is required to refine the approach and gain a deeper understanding of external effects and their monetary values.

References

Ali, A. and A. Abdulai (2010), 'The adoption of genetically modified cotton and poverty reduction in Pakistan', Journal of Agricultural Economics 61: 175-192.

Andow, D.A. and C. Zwahlen (2006), 'Assessing environmental risks of transgenic plants', Ecology Letters 9: 196-214.

Arshad, M., A. Suhail, M.D. Gogi, M. Yaseen, M. Asghar, M. Tayyib, H. Karar, F. Hafeez and U.N. Ullah (2009), 'Farmers' perceptions of insect pests and pest management practices in Bt cotton in the Punjab, Pakistan', International Journal of Pest Management 55: 1-10.

Bennett, R., T. Buthelezi, Y. Ismael and S. Morse (2003), 'Bt cotton, pesticides, labour and health: A case study of smallholder farmers in the Makhathini Flats, Republic of South Africa', Outlook on Agriculture 32: 123-128.

Brethour, C. and A. Weersink (2001), 'An economic evaluation of the environmental benefits from pesticide reduction', Agricultural Economics 25: 219-226.

Carpenter, J.E. (2010). 'Peer-reviewed surveys indicate positive impact of commercialized GM crops', Nature Biotechnology 28: 319-321.

Cuyno, L., G.W. Norton and A. Rola (2001), 'Economic analysis of environmental benefits of integrated pest management: a Philippine case study', Agricultural Economics 25: 227-233.

Florax, R.J.G.M., C.M. Travisi and P. Nijkamp (2005), 'A meta-analysis of the willingness to pay for reductions in pesticide risk exposure', European Review of Agricultural Economics 32: 441-467.

Foster, V. and S. Mourato (2000), 'Valuing the multiple impacts of pesticide use in the UK: a contingent ranking approach', Journal of Agricultural Economics 51: 1-21.

GOP (2009), 'Agricultural Statistics of Pakistan 2007-2008', in, Islamabad: Government of Pakistan, Ministry of Food and Agriculture.

Hanley, N., R. Wright and V. Adamowicz (1998), 'Using choice experiments to value the environment', Environmental and Resource Economics 11: 413-428.

Hausman, J. and D. McFadden (1984), 'Specification tests for the multinomial logit model', Econometrica 1219-1240.

Hensher, D.A., J.M. Rose and W.H. Greene (2006), 'Applied choice analysis: a primer', Cambridge: Cambridge University Press.

Hossain, F., C. Pray, Y. Lu, J. Huang, C. Fan and R. Hu (2004), 'Genetically modified cotton and farmers' health in China', International Journal of Occupational and Environmental Health 10: 296-303.

Huang, J., R. Hu, C. Pray, F. Qiao and S. Rozelle (2003), 'Biotechnology as an alternative to chemical pesticides: a case study of Bt cotton in China', Agricultural Economics 29: 55-67.

Huber, J. and K. Zwerina (1996), 'The importance of utility balance in efficient choice designs', Journal of Marketing Research 33: 307-317.

James, C. (2010), 'Global status of commercialized biotech/GM crops: 2010', in ISAAA Brief No.42, Ithaca, NY: International Service for the Acquisition of Agri-biotech Applications.

Johnson, F., B. Kanninen, M. Bingham and S. Özdemir (2007), 'Experimental design for stated-choice studies', in Kanninen, B., (ed.), Valuing Environmental Amenities Using Stated Choice Studies, Dordrecht: Springer, pp. 159-202.

Khan, M.A., M. Iqbal, I. Ahmad and M. Soomro (2002), 'Economic evaluation of pesticide use externalities in the cotton zones of Punjab, Pakistan', The Pakistan Development Review 41: 683-698.

Kouser, S. and M. Qaim (2011), 'Impact of Bt cotton on pesticide poisoning in smallholder agriculture: A panel data analysis', Ecological Economics 70: 2105-2113.

Krishna, V.V. and M. Qaim (2008). 'Potential impacts of Bt eggplant on economic surplus and farmers' health in India', Agricultural Economics 38: 167-180.

Kuhfeld, W.F. (2009), 'Marketing research methods in SAS: experimental design, choice, conjoint, and graphical techniques', http://support.sas.com/techsup/technote/mr2010title.pdf, Cary: SAS Institute Inc.

List, J.A., P. Sinha and M.H. Taylor (2006), 'Using choice experiments to value non-market goods and services: evidence from field experiments', Advances in Economic Analysis and Policy 6: 1-37.

Louviere, J.J., D.A. Hensher and J.D. Swait (2000), 'Stated Choice Methods: Analysis and Applications', Cambridge: Cambridge University Press.

Maddala, G.S. (1983), 'Limited-Dependent and Qualitative Variables in Econometrics', Cambridge: Cambridge University Press.

Maumbe, B.M. and S.M. Swinton (2003), 'Hidden health costs of pesticide use in Zimbabwe's smallholder cotton growers', Social Science & Medicine 57: 1559-1571.

Morse, S., R. Bennett and Y. Ismael (2006), 'Environmental impact of genetically modified cotton in South Africa', Agriculture, Ecosystems & Environment 117: 277-289.

Nazli, H., R. Sarker, K.D. Meilke and D. Orden (2010), 'Economic performance of Bt cotton varieties in Pakistan', Selected paper at the Agricultural and Applied Economics Association Annual Meeting, 25-27 July 2010, Denver, CO.

Perrings, C. (2010), 'The economics of biodiversity: the evolving agenda', Environment and Development Economics 15: 721-746.

Pingali, P.L. (2001), 'Environmental consequences of agricultural commercialization in Asia', Environment and Development Economics 6: 483-502.

Pingali, P.L., C.B. Marquez and F.G. Palis (1994), 'Pesticides and Philippine rice farmer health: A medical and economic analysis', American Journal of Agricultural Economics 76: 587-592.

Pray, C., J. Huang, R. Hu and S. Rozelle (2002), 'Five years of Bt cotton in China–the benefits continue', The Plant Journal 31: 423-430.

Qaim, M. (2009), 'The economics of genetically modified crops', Annual Review of Resource Economics 1: 665-694.

Qaim, M. and A. de Janvry (2005), 'Bt cotton and pesticide use in Argentina: Economic and environmental effects', Environment and Development Economics 10: 179-200.

Qaim, M., A. Subramanian, G. Naik and D. Zilberman (2006), 'Adoption of Bt cotton and impact variability: Insights from India', Review of Agricultural Economics 28: 48-58.

Speelman, S., S. Farolfi, A. Frija, M.D. Haese and L.D. Haese (2010), 'The impact of the water rights system on stallholder irrigator’s willingness to pay for water in Limpopo province, South Africa', Environment and Development Economics 15: 465-483.

Swait, J. and J. Louviere (1993), 'The role of the scale parameter in the estimation and comparison of multinomial logit models', Journal of Marketing Research 30: 305-314.

Theiling, K.M. and B. Croft (1988), 'Pesticide side-effects on arthropod natural enemies: a database summary', Agriculture, Ecosystems & Environment 21: 191-218.

Traxler, G. and S. Godoy-Avila (2004), 'Transgenic cotton in Mexico', AgBioForum 7: 57-62.

Travisi, C. and P. Nijkamp (2008), 'Valuing environmental and health risk in agriculture: A choice experiment approach to pesticides in Italy', Ecological Economics 67: 598-607.

Travisi, C.M., P. Nijkamp and G. Vindigni (2006), 'Pesticide risk valuation in empirical economics: a comparative approach', Ecological Economics 56: 455-474.

Vásquez, W.F., D. Franceschi and G.T. van Hecken (2011), 'Household preferences for municipal water services in Nicaragua', Environment and Development Economics, in press.

Wolfenbarger, L.L.R., S.E. Naranjo, J.G. Lundgren, R.J. Bitzer and L.S. Watrud (2008), 'Bt crop effects on functional guilds of non-target arthropods: a meta-analysis', PLoS One 3: e2118.

Zehr, U.B., Ed. (2010). 'Cotton: Biotechnological Advances', Heidelberg: Springer.

Table 1 Descriptive statistics of sample households

Variables	Bt adopters (N = 248)	Non-adopters (N = 104)
Age (years)	40.56	42.44
	(12.26)	(13.28)
Education (years of schooling)	8.15	7.52
	(3.87)	(3.96)
Family members (No.)	5.85	5.73
	(1.85)	(1.79)
Farm size (acres)	25.39***	12.42
	(32.09)	(14.62)
Cotton area (acres)	9.12	8.07
	(16.27)	(11.77)

***, **, * Mean values are significantly different at the 1%, 5%, and 10% level, respectively.
Note: Mean values are shown with standard deviations in parentheses.

Table 2 Comparison of pesticide use, yields, and gross margins at plot level

Variables	Bt plots (N = 248)	Non-Bt plots (N = 277)
Pesticide quantity (ml/acre)	2724.89***	3458.08
	(1067.81)	(1398.66)
Number of sprays	6.22***	7.06
	(2.09)	(2.05)
Number of pesticide poisoning incidences	1.42***	1.96
	(1.68)	(1.90)
Yield (maunds[a]/acre)	24.31***	18.98
	(6.63)	(5.93)
Crop enterprise budget (Rs/acre)		
Seed cost	1371.62**	1208.29
	(833.97)	(702.71)
Pesticide cost	2243.24***	2641.67
	(1213.27)	(1225.79)
Fertilizer cost	5565.73***	4355.38
	(2244.76)	(1821.33)
Farm yard manure cost	804.34	783.85
	(925.61)	(869.56)
Other chemicals cost	710.38	629.42
	(687.70)	(644.18)
Land preparation cost	2704.68	2560.18
	(1038.86)	(973.37)
Sowing cost	551.94	524.55
	(228.99)	(194.19)
Irrigation cost	3383.93**	2726.51
	(3515.30)	(2706.40)
Other labor cost	4466.57*	4260.49
	(1459.93)	(1167.76)
Total variable cost	21802.42***	19690.33
	(6672.36)	(4850.93)
Total revenue	88563.17***	69150.96
	(25123.18)	(24043.85)
Gross margin	66760.75***	49460.63
	(23063.17)	(23262.06)

***, **, * Mean values are significantly different at the 1%, 5%, and 10% level, respectively.

[a] One maund is equal to about 40 kilograms.

Note: Mean values are shown with standard deviations in parentheses.

Table 3 List of pesticide attributes and attribute levels used in the choice experiment

Attributes	Current level (Status quo)	Hypothetical levels		
		Level 1	Level 2	Level 3
Human health effects *(No. of acute pesticide poisoning incidences during cotton season)*	6	4	2	1
Farmland biodiversity effects *(Loss of beneficial insects in %)*	90	70	50	20
Soil and groundwater effects *(Contamination level: 4=extreme, 3=high, 2=moderate, 1=slight)*	4	3	2	1
Price *(Rs per bottle of 400 ml)*	500	700	900	1100

Table 4 Determinants of farmers' pesticide choices (conditional logit models)

Variables	(1) Without interaction terms	(2) With interaction terms
ASC	0.74**	0.80**
	(0.37)	(0.37)
Health effects	-0.68***	-0.62***
	(0.04)	(0.06)
Farmland biodiversity effects	-0.02***	-0.01**
	(0.002)	(0.004)
Soil and groundwater effects	-0.51***	-0.41***
	(0.04)	(0.07)
Price	-0.002***	-0.002***
	(0.0003)	(0.0003)
Education*Health effects	-	-0.01
		(0.01)
Education*Farmland biodiversity effects	-	-0.001**
		(0.0004)
Education*Soil and groundwater effects	-	-0.02**
		(0.01)
Number of observations	2112	2112
Log likelihood	-1243.87	-1239.97
McFadden's ρ^2	0.16	0.17
Likelihood ratio test	-	7.80
Prob>χ^2	-	0.02

***, **, * Significant at the 1%, 5%, and 10% level, respectively.
Note: Coefficient estimates are shown with standard errors in parentheses.

Table 5 Average willingness to pay (WTP) for pesticide attributes

Variables	(1) WTP per unit reduced (Rs/bottle)	(2) WTP per unit reduced (Rs/ml)	(3) WTP for complete reduction from status quo (Rs/ml)
Health effects	398.17*** (238.76)	1.00*** (0.13)	1.96[a]
Farmland biodiversity effects	9.33*** (1.52)	0.02*** (0.004)	1.80
Soil and groundwater effects	302.69*** (48.68)	0.76*** (0.12)	3.04

***, **, * Significant at the 1%, 5%, and 10% level, respectively.

[a] While for the choice experiment we used six poisoning incidences as the status quo value, the survey results showed that the actual number of incidences is 1.96 for non-adopters of Bt technology (see Table 2).

Note: Standard errors are given in parentheses.

Table 6 Benefit-cost analysis (Rs/acre)

Variables	(1) Bt plots (N = 248)	(2) Non-Bt plots (N = 277)	(3) Difference (1) – (2)
(a) Gross margin	66760.75 (23063.17)	49460.63 (23262.06)	17300.12***
(b) Cost of negative health externality	4144.41 (5453.69)	7334.65 (8827.68)	-3190.24***
(c) Cost of negative farmland biodiversity externality	4904.80 (1922.06)	6224.54 (2517.58)	-1319.73***
(d) Cost of negative soil and groundwater externality	8283.67 (3246.15)	10512.55 (4251.92)	-2228.88***
(e) Total cost of negative health and environmental externalities (b+c+d)	17332.88 (8960.37)	24071.74 (13608.94)	-6738.86***
(f) Net benefit (a-e)	49427.86 (21143.81)	25388.89 (22884.45)	24038.98***

***, **, * Significant at the 1%, 5%, and 10% level, respectively.
Note: Mean values are shown with standard deviations in parentheses.

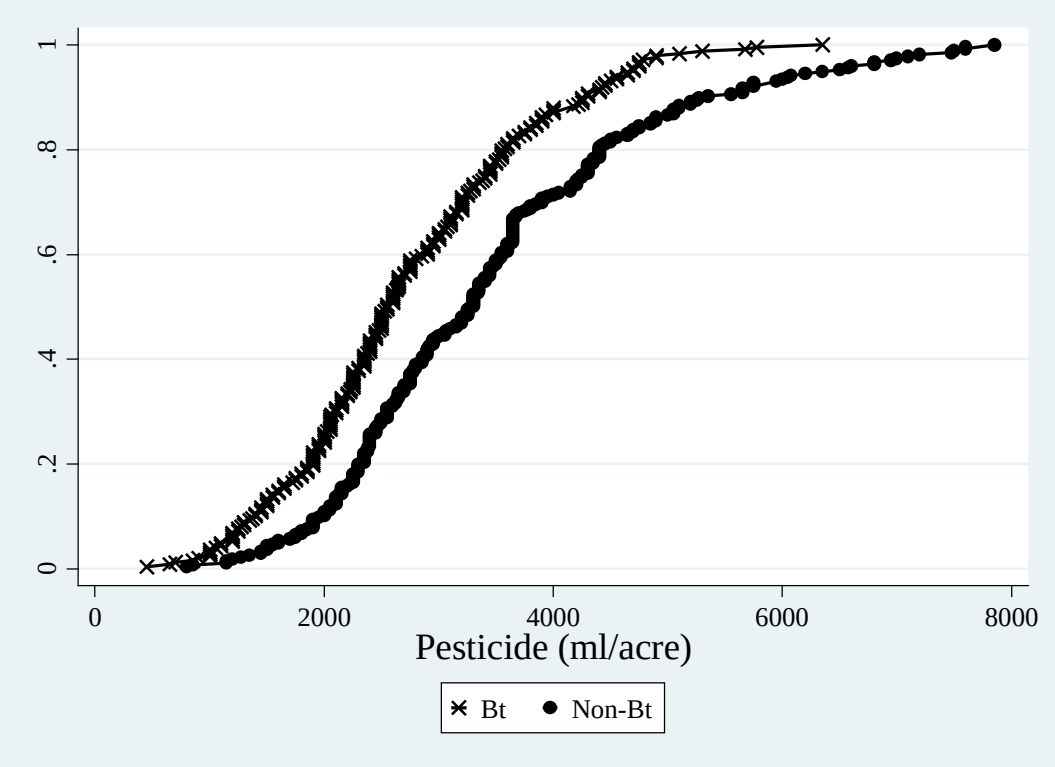

Fig. 1 Cumulative distribution of pesticide quantity used on Bt and non-Bt cotton plots

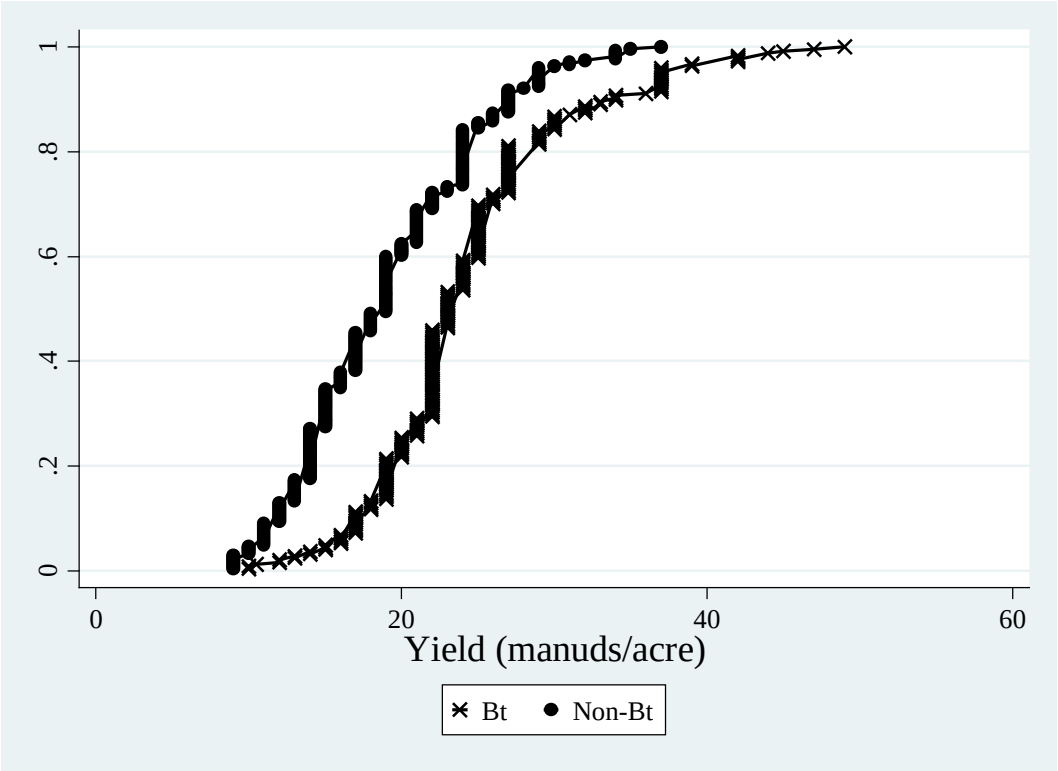

Fig. 2 Cumulative distribution of yield on Bt and non-Bt cotton plots

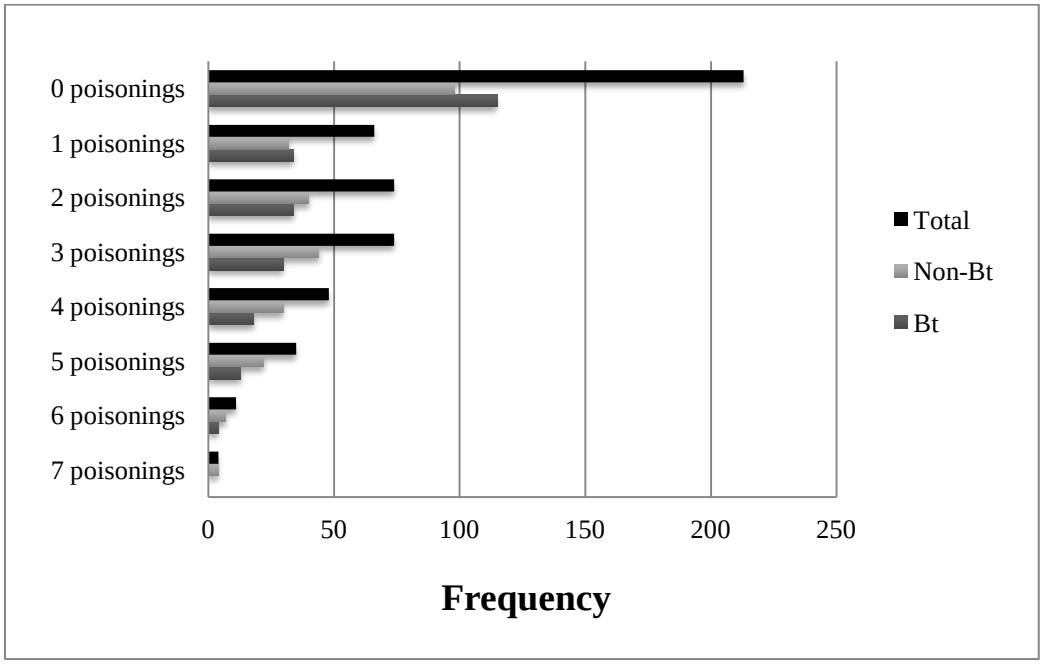

Fig. 3 Frequency of the incidence of acute pesticide poisonings among Bt and non-Bt farmers

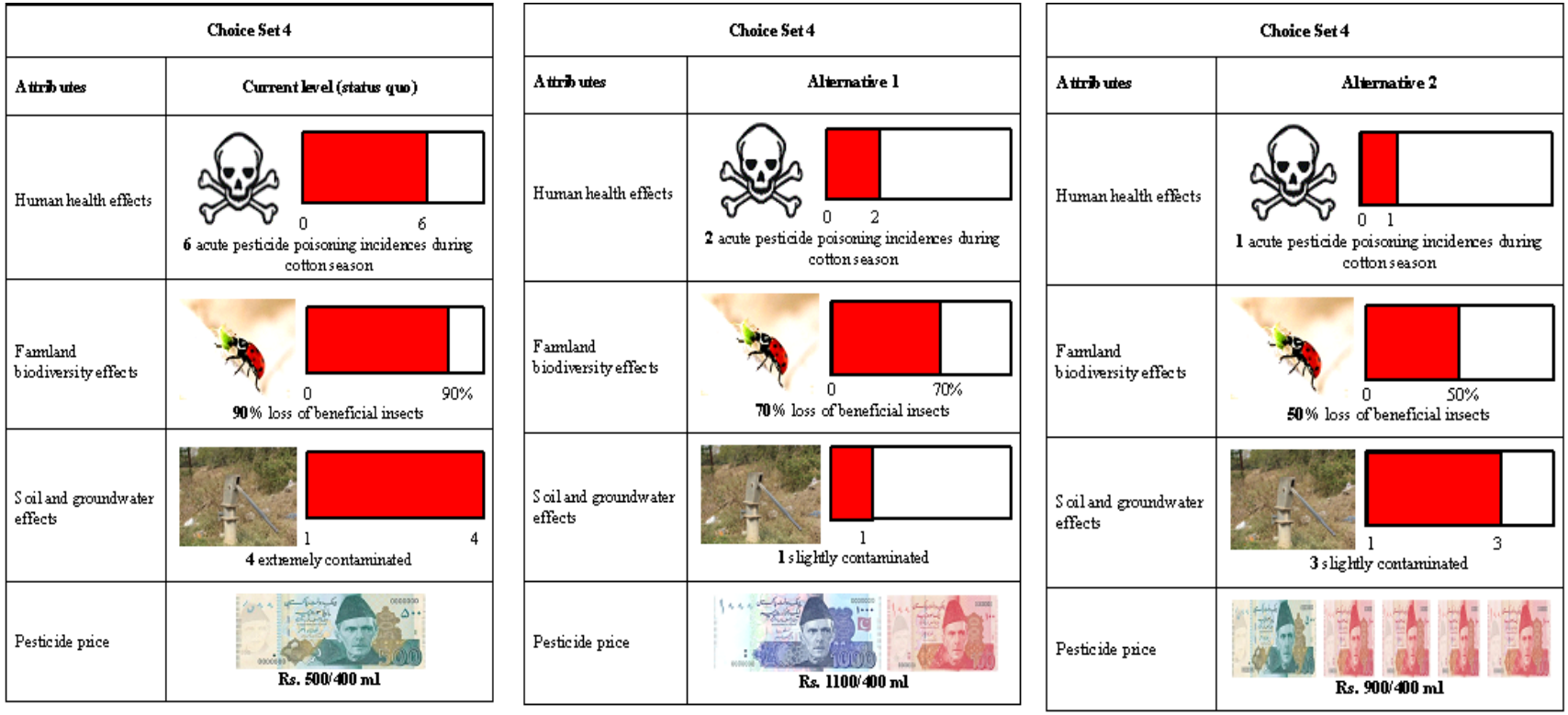

Fig. 4 Example of choice set

Note: For the experiment, the choice cards had different colors to facilitate visual differentiation.