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Valuing the Changes in Herbicide Risks Resulting from Adoption of Roundup Ready Soybeans by U.S. Farmers: A Revealed-Preference Approach

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A revealed-preference–based approach is proposed for valuation of the environmental and human impacts of pesticides. It is assumed that farmers reveal their willingness to pay for improved pesticide safety by selecting a specific product out of the set of available alternatives based on their costs, effectiveness, and safety. The approach is applied to estimate the welfare impact of changed patterns of herbicide use on Roundup Ready soybeans. The results indicate that farmers associate positive values with safety improvements. The aggregate welfare impact of the reduced risk for the U.S. soybean farmers was estimated to be $90.3 million in 2001.

Key Words: pesticide human and environmental risks, revealed preferences, Roundup Ready soybeans

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Pesticides are an integral part of modern agriculture. They provide a highly efficient, cost-effective, and flexible method of controlling pests and contribute to high yields and consistency of crop production. However, the widespread use of pesticides over the past several decades has led to concerns over their potential human health and environmental impacts. Pesticides are often detected in surface and groundwater, and their use affects the quality and quantity of nontarget species (Florax, Travisi, and Nijkamp). A link has also been established between pesticide exposure and human health (see Kafle).

As a response to the concerns over pesticide safety, regulatory agencies at different levels are prompted to implement various pesticide risk management policies, which include command and control approaches, market-based instruments, and moral suasion (Travisi, Nijkamp, and Vindigni). During the assessment of any new pesticide policy, in addition to evaluation of its direct economic impact, it is essential to evaluate the changes in social welfare resulting from the changes in pesticide human and environmental risks associated with this policy. Without such input, the policy assessment could suffer from serious biases and result in erroneous conclusions.

Pesticide risk evaluation procedures are complex because of the multidimensional nature of pesticide impacts. A number of

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studies have attempted to develop a methodological base for such an evaluation. The proposed methods include the cost of illness approach (Wilson), averting/defensive expenditure method (Antle and Pingali), the contingent valuation technique (Cuyno, Norton, and Rola; Higley and Wintersteen), and hedonic analysis (Beach and Carlson; Fernandez-Cornejo and Jans). Florax, Travisi, and Nijkamp, as well as Travisi, Nijkamp, and Vindigni, conduct a detailed review of the empirical valuation literature on pesticide risk exposure and conclude that knowledge is rather fragmentary and there is a high degree of variability in risk value estimates related to both employed valuation techniques and available data. Typically, stated preference approaches are used, and considerably fewer studies rely on revealed-preference techniques, which are often hampered by lack of data on the choice set considered by the actor and the actor's perception of risk. They also argue that the majority of studies are driven by interest in human health, and only few address the environmental impacts of pesticides.

The objective of this study is to propose an improved method to estimate an economically consistent value of the marginal changes in pesticide safety that could be useful for future pesticide management policy assessments. The estimation of this value is based on farmers' revealed preferences. Because the degree of pesticide risk depends not only on its safety but also the intensity and duration of exposure (Antle and Pingali; Sivayoganathan et al.), the potential risks to pesticide applicators, farmers, or farm workers who are occupationally exposed to pesticides are likely to be more significant than the risks to someone in the general population exposed only to traces of pesticides in food and water, *ceteris paribus*. Farmers are also dealing with pesticides on an everyday basis. Therefore, it is reasonable to assume that they have more accurate knowledge of pesticide human and environmental risks compared to the general population. In addition, farmers are not only producers who use pesticides as productive inputs, but also consumers who are exposed to negative pesticide externalities. At the same time, we acknowledge that our value estimates are likely to underestimate the true social value of reduced risk from alternative pesticide reducing management scenarios, which would also include the benefits to the general population.

The specific application of this method is to estimate the impact of Roundup Ready (RR) soybeans on the welfare of the U.S. farmers. Currently, these soybean varieties account for the largest share of total U.S. soybean acreage (91% in 2007) (U.S. Department of Agriculture). Because the adoption of RR soybeans results in the substitution of a single broad-spectrum herbicide characterized by favorable environmental properties (Malik, Barry, and Kishore) for a variety of more selective herbicides with varying levels of environmental effects, they may benefit human health and the environment (Carpenter et al.; Marra). If one considers herbicide relative toxicity information in addition to the information on the application volume and the number of applications, RR soybeans show an improvement in the environmental "footprint" brought about by their adoption (Nelson and Bullock; Qaim and Traxler; Sydorovych and Marra). This improvement should have an impact on the welfare of farmers. We evaluate this impact for a sample of U.S. soybean farmers.

Theoretical Framework

There exists an extensive literature that develops evaluation techniques for nonmarket goods, such as herbicide safety. Commonly used methods can be grouped under two broad categories of revealed and stated preference-based methods. For both, the main assumptions are that individuals trade health and environmental quality as if they were usual market goods and that individual preferences provide a valid basis for valuation. As mentioned previously, the majority of previous studies looking at pesticide risk valuation rely on stated preference information (Brethour and Weersink; Cuyno, Norton, and Rola; Foster and Mourato; Higley and Wintersteen; Press and Soderqvist). Such methods are often criticized for the hypothetical nature of the survey questions, answers to which may not be very informative about the actual preferences and behavior of the respondents (Kling). Alternatively, we argue that it is possible to use revealed-preference information to estimate the value of the change in herbicide safety in order to avoid the biases often associated stated preference-based methods.

In revealed-preference methods, the researcher observes respondents' behavior in well-developed markets for ordinary goods and services and extrapolates the results to the goods that are not traded explicitly in the market. Hedonic price analysis was used by Beach and Carlson and Soderqvist to investigate whether farmers value groundwater pollution risk and user toxicity of pesticides. Fernandez-Cornejo and Jans also use the hedonic analysis to adjust aggregate pesticide price indices for changes in pesticide toxicity. However, the hedonic method may not be appropriate for explaining marginal values of pesticide safety for market segments with small shares, and the random utility approach could alternatively be used (Hubbell and Carlson). We follow this approach by assuming that the farmers reveal their values of herbicide safety by selecting a specific pesticide product out of the set of available product alternatives based on their observed attributes, including not only pesticide costs and effectiveness, but also safety. Our method also provides a flexible framework, allowing us to consider multiple pesticide human and environmental risks while attempting to capture the complex nature of pesticide impacts.

A Behavioral Model of Herbicide Choice

Herbicides are productive inputs affecting farm profits. Beach and Carlson also suggest considering the impact of some nonproductive herbicide attributes, such as water quality and user safety, on farmers' utilities. Farmers may be concerned about herbicide impacts on their own health and the health of family members and workers, as well as on the quality of on-farm environmental resources, such as soil and water. They may also derive utility from fishing, hunting, swimming, or some other recreational activities that are affected by herbicides, or they may have some altruistic concerns for environmental preservation.

Therefore, the choice of a herbicide out of the set of available alternatives by a farmer can be represented as a utility maximization problem. Each herbicide product in the farmer's choice set is represented as a set of attributes h consisting of h^y, a vector of attributes affecting yields; h^c, herbicide product and application costs; and h^s, a vector of environmental and human safety attributes. The reduced-form, indirect utility function, U, of farmer i (i:$i = 1, \ldots, I$) associated with the attributes of the herbicide alternative j (j:$j = 1, \ldots, J$) is represented as:

$$(1) \qquad U_{ij} = \beta'_i h_{ij} + \varepsilon_{ij},$$

where h_{ij} are observed attributes of the herbicide alternative j for farmer i, including the herbicide application costs, effectiveness, and safety, and β_i is a vector of coefficients for farmer i. Finally, ε_{ij} is the stochastic portion of the utility function of farmer i associated with herbicide alternative j.

The farmer observes all elements of the model and chooses herbicide alternative j that maximizes his utility: $U_{ij} = Max(U_{i1}, U_{i2}, \ldots U_{iJ})$. If we also assume that the coefficients vary across farmers with density $f(\beta)$, and ε_{ij} is an extreme value iid random term, we can model the probability of choosing herbicide alternative j among J alternatives by farmer i as the integral of the conditional choice probability for the herbicide alternative j by farmer i over all possible values of β_i:

$$(2) \qquad P_{ij} = \int \frac{\exp(\beta' h_{ij})}{\sum_{j=1}^{J} \exp(\beta' h_{ij})} f(\beta) d\beta,$$

leading to the mixed logit model (Train). Estimated coefficients represent marginal utilities of different herbicide attributes to the farmer, and the farmer's willingness to pay (WTP) for the improvements in herbicide safety attribute k (k:$k = 1, \ldots, K$) can be calculated as the marginal rate of substitution between this herbicide safety attribute and

Table 1. Survey Participation Summary Statistics ($N = 610$)

	Mean	SD
Number of years as principal farm operator	33.32	11.87
Age (years)	54.58	10.83
Formal education (years)	13.43	2.12
Annual household income ($1,000)	341.14	277.21
Time spent in farming (%)	90.13	20.98
Time spent in crop production (%)	78.53	26.26
Operational farm acres in 2001	915.78	1,020.88
Soybean acres in 2001	466.76	406.61
Roundup Ready acres in 2001	281.34	371.13
Roundup Ready acres treated with herbicides in 2001	274.15	372.09

herbicide application costs:

$$(3) \qquad WTP_{ik} = \frac{\partial U_{ij} \big/ \partial h^s_{ijk}}{\partial U_{ij} \big/ \partial h^c_{ij}} = \frac{\beta^s_{ik}}{\beta^c_i},$$

where β^s_{ik} is the estimated coefficient on herbicide safety attribute k and β^c_i is the coefficient on herbicide application costs. This value is the base for our estimation of the value farmers place on the changes in herbicide safety when RR soybeans are adopted.

Estimation of the Herbicide Choice Model

The data on herbicide use were obtained from a national, computer-aided telephone survey of soybean farmers in 2002 conducted by Doane's Market Research. Farmers selected to participate in the survey represent 19 major soybean growing states. The number of survey respondents in each state was selected based on the state's share in national soybean acreage in 2001. The majority of respondents operated large farms and 45% of respondents were growing only RR soybeans in 2001. Thirty-three percent of respondents were partial adopters of RR technology, and 22% of respondents were growing conventional soybeans only. Table 1 contains some summary statistics for survey participants.

The survey explored issues relevant to the comparative economic analysis of conventional and RR soybeans. In particular, it concentrated on differences in herbicide use. There were 1,769 individual herbicide choices made by 610 farmers participating in the survey. These choices were used as a basis for the estimation of the values farmers place on herbicide safety. Appendix A contains an example of survey questions designed to extract information on herbicide use by the farmers. Similar questions were used for conventional and RR soybean herbicides applied at different stages of production.

Attributes of the Herbicide Choices

A number of herbicide attributes may affect the farmer's choice of herbicide product. Since herbicides are designed to control weeds, their effectiveness in dealing with weeds should be one of the most important attributes to the farmers. Herbicide effectiveness is measured separately for broadleaf and grass weeds as an average percent of weed control calculated for all weeds in each weed class for which information on percent control was available.[1] The costs associated with herbicide application, including the stage-specific herbicide application cost and materials cost per acre, determine profit and, therefore, should also affect the choice.

[1] The survey did not contain information on the specific weeds the farmers were trying to control. The true herbicide effectiveness measure depends on weed populations particular to the location. Therefore, our average effectiveness measures are only proxies for the true measure.

Herbicide human and environmental safety may also be important to the farmers. For example, Beach and Carson include herbicide user safety and water quality in a farmer utility function and find statistically significant impacts of these variables. In this study, we investigate the impact of an extended set of herbicide risk attributes for which information is available to the farmers from the product label and the Material Safety Data Sheet (MSDS).

Pesticides are strictly regulated in the United States through a complex system that leads to product registration and use. During the registration process, the EPA evaluates the information available for the pesticide and approves a product label and MSDS. The label and MSDS are intended to provide the farmers and the public with general, technical, risk, and safety information about pesticides, as well as serve as the legal notice of approved uses and rates. They contain information on product chemistry, physical and chemical characteristics, aquatic and wildlife toxicology, plant protection, reentry protection, nontarget insect toxicity, environmental fate, residual chemistry, and spray drift (Whitford). The labels and MSDSs follow established uniform standards for describing pesticide risks attributes and are used as informational sources for various pesticide risks in our study.

LD_{50} is the material dosage that would result in the death of 50% of a population of test species under stated conditions. It is the primary way of expressing the acute effects of solids and liquids that are swallowed or contaminate the skin and is usually expressed in terms of milligrams of material per kilogram of body weight (Rozman, Doull, and Hayes). We apply a measure proposed by Nelson and Bullock, the number of LD_{50} doses in the herbicide recommended application rate, to represent a level of acute human risk from herbicide exposure.

The EPA's criteria for assessing chronic human health risks are based on the results of tests evaluating carcinogenity and reproduction, birth, and developmental effects of pesticides that are also reported on product label and MSDS. We assume that a certain herbicide is considered to be a high risk to chronic human health if there is positive evidence of the presence of any of the above effects.

Herbicide residues may also contaminate surface and groundwater. Generally, all methods used to assess the impact of herbicides on the quality of water resources concentrate on leaching and runoff potential determined by the herbicides' persistence, water solubility, and mobility. We consider a herbicide a high risk if its label contains a special surface or groundwater advisory, for example, "This product has properties and characteristics associated with chemicals detected in groundwater" or "Under some conditions, this product may have a high potential for runoff into surface water."

In addition, we consider the impact on birds and aquatic organisms. Similar to the human acute effect, herbicide risk to birds is expressed in terms of LD_{50} doses. A herbicide is considered a high risk to aquatic organisms when its reported LC_{50} value (lethal concentration of the material in water that would result in the death of 50% of a population of test species under stated conditions) is below 1 ppm (Whitford). Since a given herbicide does not affect all species at the same rate, the final risk level is assigned as the highest risk among all species for which information is reported. Some of the previous risk evaluation studies also considered pesticide risk to beneficial arthropods and nontarget insects. Since the risk to insects from all herbicides included in our choice set was very low, this risk category was not considered in our analysis.

Finally, the herbicide application rate may affect the farmer's perception of herbicide safety. Between two equally toxic herbicides, one that requires a higher application rate would be considered a higher risk. In addition, it might be possible that the rate of application affects the farmer's perception of product effectiveness. We account for these possible impacts in the choice model by including the herbicide recommended label rate of application measured as the volume of herbicide active ingredients (AI) applied per acre,

Table 2. Summary Statistics of the Attributes of Herbicides Choices and Expected Impact of the Attributes on the Probability of Herbicide Choice by a Farmer (N = 1,769)

Herbicide Attribute	Expected Impact[a]	Mean	SD
Grass weed efficiency (%)	+	67.16	28.52
Broadleaf weed efficiency (%)	+	61.46	25.78
Herbicide application costs ($/acre)	−	15.13	5.17
Application rate (lbs of AI/acre)	+/−	0.72	0.55
Acute health risk by ingestion (LD_{50} dozes)	−	244.78	392.46
Chronic health risk (dummy, 1 if high risk)	−	0.10	0.30
Surface water risk (dummy, 1 if high risk)	−	0.12	0.32
Groundwater risk (dummy, 1 if high risk)	−	0.33	0.47
Bird toxicity (LD_{50} dozes)	−	202.97	317.17
Aquatic toxicity (dummy, 1 if high risk)	−	0.43	0.50

[a] "+" ("−") indicate that the higher value of the herbicide attribute would increase (decrease) the probability that the herbicide is chosen.

converted into pounds per acre. Table 2 presents the summary statistics of the attributes of herbicide choices made by the farmers and expected impacts of the attributes on the choice probability.

Estimation Results

The herbicide choice model was estimated using the Multinomial Discrete Choice (MDC) procedure available in the SAS software package. Estimation results (Table 3) show that, in addition to the production-related attributes, farmers considered herbicide human and environmental safety when making their product choices. The coefficient means on herbicide acute and chronic health risks and surface water contamination potential are statistically significantly different from zero at standard levels of significance. The coefficient standard deviations also indicate that the farmers exhibit some random preference variations over the impact of herbicide application costs and grass weed effectiveness on herbicide choices. Our data did not allow controlling for possible variations in some farmer and farm characteristics that may affect herbicide product choice. Therefore, we assume that the coefficients of the random components in the mixed logit estimation results capture some of the effects of these unobservable characteristics.

Valuation of the Changes in Herbicide Safety after RR Soybean Adoption

As mentioned previously, a ratio of the coefficient mean for each of the herbicide safety attributes to the coefficient mean on herbicide application costs represents farmers' WTP for a one-unit improvement in this safety attribute on per acre basis (Train). Estimated coefficients are also used to generate the standard errors of WTP estimates by the bootstrapping technique (Krinsky and Robb), in which the estimated parameter vector, $\hat{\beta}$, and the variance-covariance matrix, $\hat{\Sigma}$, are used to generate 1,000 random draws from a multivariate normal distribution with mean $\hat{\beta}$ and variance-covariance matrix $\hat{\Sigma}$. The resulting value estimates are presented in Table 4. The results indicate that the farmers were willing to pay $9.99 per acre per year to avoid high risk to chronic human health, $3.35 per acre per year to avoid a high risk of surface water pollution, and $0.004 per acre per year for a one-LD_{50} dose risk reduction to human health by acute exposure. Risk value estimates are calculated based on 1,000 drawings from a multivariate normal distribution with mean $\hat{\beta}$ and variance-covariance $\hat{\Sigma}$.

To estimate the impact of changed patterns of herbicide use on RR soybeans on farmers' welfare, we need to explore how adoption of RR soybeans affects herbicide safety. The results of this analysis are also presented in

Table 3. Mixed Logit Estimation Results of the Herbicide Choice Model (N = 1,769)

Herbicide Attribute	Coefficient Mean[a]	Coefficient SD[a]
Grass weed efficiency (%)	0.026*** *(0.003)*	0.038*** *(0.004)*
Broadleaf weed efficiency (%)	0.012*** *(0.002)*	0.009 *(0.013)*
Herbicide application costs ($/acre)	−0.129*** *(0.010)*	0.138*** *(0.019)*
Application rate (lbs of AI/acre)	0.815*** *(0.072)*	0.079 *(0.651)*
Acute health risk by ingestion (LD_{50} dozes)	−0.001*** *(0.000)*	0.000 *(0.000)*
Chronic health risk (dummy, 1 if high risk)	−1.270*** *(0.112)*	0.067 *(0.644)*
Surface water risk (dummy, 1 if high risk)	−0.426*** *(0.103)*	0.058 *(0.734)*
Groundwater risk (dummy, 1 if high risk)	−0.022 *(0.088)*	0.011 *(0.586)*
Bird toxicity (LD_{50} dozes)	−0.001 *(0.000)*	0.000 *(0.000)*
Aquatic toxicity (dummy, 1 if high risk)	0.069 *(0.104)*	0.732 *(0.703)*
Log-likelihood value	−5,931	

[a] Asterisks (***) indicate coefficients significantly different from zero at $\alpha = 0.01$. The first number is the coefficient and the number in parentheses, its standard error.

Table 4. To control for some possible spatial, temporal, and managerial variations in herbicide use patterns, we selected a subsample of survey responses consisting of 199 observations representing all participating farmers who were partial adopters of RR technology and planted both RR and conventional soybeans in 2001. Based on the results of the *t*-tests, this subsample is representative of the complete sample with respect to farmers' mean age, number of years as principal farm operator, education, yearly household income, farm acreage, and the percent of time spent in crop production. All original soybean growing states are represented, and the share of responses in each state is similar to their share in the complete sample. We use this subsample's observations as the basis for estimating on-farm differences in herbicide use.

Acute human health risk and bird toxicity from herbicides used in RR and conventional soybean production systems are calculated as the sum of LD_{50} doses of all herbicides used by a farmer on each soybean variety adjusted for the proportion of acreage treated by this herbicide and the number of applications, where higher values indicate higher risk. Chronic health risk, surface and groundwater risks, and aquatic toxicity are measured as a proportion of herbicides that are considered as high risk in each category that were applied by the farmer on each variety, also adjusted for the proportion of acreage treated by this herbicide and the number of herbicide applications. The results (Table 4) indicate that adoption of RR soybeans, on average, resulted in an on-farm herbicide risk reduction in all risk categories considered for our sample of farmers. The extent of risk reduction varies from 22–91% for different risk categories.[2]

Finally, we can calculate the impact of changed patterns of herbicide use on RR soybeans compared to conventional soybeans on the welfare of the farmers in the sample. The product of the average on-farm change in risk estimated for our sample of farmers and expressed in risk units per acre (LD_{50} doses or proportion of high risk herbicides) and farmers' valuation of the one-unit reduction in this risk is the value per acre per year farmers place on herbicide risk reduction associated with RR soybeans (Table 4). Presented values are calculated based on 1,000 drawings from a multivariate normal distribution with mean $\hat{\beta}$ and variance-covariance $\hat{\Sigma}$ of the herbicide choice model. The farmers are willing to pay $0.50 per acre per year for the

[2] Some weed resistance to *glyphosate*, which is the main component of Roundup, was found in a few small areas in the United States, indicating that there could have been an increase in future risk on RR soybeans since 2001 from possible additional applications of Roundup. However, our data do not allow us to consider it in the analysis, and the empirical risk reduction results using our data may be somewhat overstated compared to what they might be today.

Table 4. Herbicide Risk by Category on Conventional and RR Soybeans and On-Farm Risk Change on RR Soybeans, and Farmers' WTP for Herbicide Risk Reduction on RR Soybeans in 2001

	Acute Health Risk	Chronic Health Risk	Surface Water Risk	Groundwater Risk	Bird Toxicity	Aquatic Toxicity
Herbicide risk estimates[a]						
RR Soybeans (risk units/acre)	367.65 *(684.66)*	0.01 *(0.07)*	0.06 *(0.18)*	0.09 *(0.21)*	318.03 *(547.01)*	0.13 *(0.25)*
Conventional soybeans (risk units/acre)	496.14 *(827.82)*	0.11 *(0.23)*	0.16 *(0.37)*	0.40 *(0.46)*	406.49 *(689.45)*	0.53 *(0.77)*
On-farm change in risk (risk units/acre)[b]	−128.49** *(801.35)*	−0.09*** *(1.23)*	−0.10*** *(0.38)*	−0.31*** *(0.47)*	−88.46* *(666.12)*	−0.40*** *(0.77)*
On-farm reduction in risk (%)	25.90	90.91	62.50	77.50	21.76	75.47
Value of herbicide risk ($/risk unit)[c]	0.004*** *(0.001)*	9.99*** *(1.20)*	3.35*** *(0.87)*	NS	NS	NS
Value of risk change on RR soybeans ($/acre)	0.50*** *(3.14)*	0.93*** *(2.31)*	0.33*** *(1.30)*	–	–	–

[a] Average risk estimates are calculated for 199 farms where both conventional and RR soybeans were grown in 2001. The first number is the mean and the number in parentheses, its standard deviation.

[b] Asterisks (***, **, and *) indicate a number significantly different from zero at $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.1$, correspondingly.

acute human risk reduction of herbicides due to RR soybean adoption, \$0.93 per acre for chronic human risk reduction, and \$0.33 per acre for surface water risk reduction. Even though the farmers also experienced reductions in other risks (groundwater risk, herbicide bird and aquatic toxicity), the results of the herbicide choice model indicate that reduction in these risks would not have a significant impact on the welfare of this sample of farmers.

The farmers who participated in the survey planted, on average, 467 acres of soybeans in 2001, out of which 59.5% of acres were planted to RR varieties. Given this, our previous value estimates would translate into a welfare gain of about \$489 per farm per year due to reduced risk from the herbicides associated with RR soybeans (\$139 in reduced acute health risk, \$258 in reduced chronic health risk, and \$92 in reduced surface water risk). The value of nationwide benefits to the farmers from reduced risk of herbicides used on RR soybeans, which were planted on 51.3 million acres in 2001 (U.S. Department of Agriculture), is estimated to have been about \$90.3 million, out of which \$25.6 million is due to improved acute human safety, \$47.7 million due to improved chronic health, and \$16.9 million due to reduced risk to surface water. Finally, it is necessary to emphasize that these estimates represent welfare impact due to reduced herbicide risk on RR soybeans. For comprehensive assessment, they should be considered in combination with the estimates of more direct economic impact of RR soybeans on social welfare as, for example, in Falck-Zepeda, Traxler, and Nelson and Price et al.

Conclusions

This paper develops a methodology for the assessment of the welfare gains to farmers associated with alternative pesticide management policies. Improvement on the previous methods applying nonmarket valuation methods for pesticide risk changes was achieved by relying on revealed-preference information resulting in improved reliability of value estimates relative to estimates obtained from previous methods, which were often based on stated preferences. We assume that the farmers reveal the values they place on different aspects of pesticide safety by selecting a specific pesticide product out of the set of available product alternatives based on their attributes, which include not only pesticide costs and effectiveness, but also human and environmental safety.

The specific application of this method is to evaluate the impact of changed patterns of herbicide use on RR soybeans on the environment and human health and, ultimately, on the welfare of the U.S. soybean farmers. Our results indicate that the farmer associated positive values with reduced risk from herbicides to acute and chronic human health, as well as with reduced risk of surface water pollution. Because RR soybean adoption, on average, results in on-farm reduction in these risks, we expect some positive impact on the welfare of the farmers. The aggregate impact on the welfare of U.S. soybean farmers was estimated to have been a little over \$90 million in 2001 alone. This estimate reflects welfare impact of RR soybeans resulting from reduced human and environmental herbicide risks and should be considered in combination with the estimates of more direct economic welfare impact for comprehensive assessments of the RR soybean technology.

The proposed methodology presents a flexible framework allowing consideration of various human health and environmental risks of pesticides in the analysis capturing the complex multidimensional nature of pesticide impacts. It can be applied for the assessment of the impact of any new policy introducing alternative pesticide management procedures that may affect environmental quality and human health. When such policies are introduced, it is essential to evaluate changes in social welfare resulting from changes in pesticide human and environmental risks associated with these policies, in addition to evaluation of their direct economic impact. Without such input, the policy assessment could suffer from serious biases and result in erroneous conclusions.

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Appendix A. An Example of Survey Questions Designed to Extract Herbicide Use Information

Now I want to ask you about your soybean weed control practices for non–Roundup Ready and Roundup Ready soybeans you planted in 2001.

13a. For the Roundup Ready soybeans you planted in 2001, how many of those acres did you treat at least once with a herbicide?

_________ acres treated at least once

13b. Thinking about your Roundup Ready varieties you planted in 2001, what specific herbicide or herbicides did you use preplant or at planting (report only the residual-type products and not the burndown products)?

[For each brand mentioned in Q.13b ask:]

14a. How many of your Roundup Ready soybean acres in 2001 were treated with [brand]? [If "Don't Know" >>> Your best estimate would be fine.]

14b. What was your average application rate per acre for [brand] in 2001 on your Roundup Ready soybeans?

14c. How many applications of [brand] did you make in 2001 on your Roundup Ready varieties?