

ABSTRACT

SYDOROVYCH, Olha. Valuation of the Environmental Impact of Roundup Ready Soybeans Based on a New Herbicide Risk Index. (Under the direction of Michele C. Marra.)

Genetically engineered crop varieties are designed to simplify and provide additional options for pest management. However, the empirical evidence concerning the impacts of GE crops adoption on pesticide use and resulting environmental quality is mixed. A methodology was developed for the analysis of the environmental impacts of pesticides that can be applied in the areas of comparative evaluation of alternative pest management strategies and individual pesticides. First, an index system was developed for individual herbicides combining the information on their acute and chronic health risks with their toxicity to non-target species and the environment. A key challenge was to choose the weights that will determine the relative effects of the individual components of the index. An improvement on the previous attempts to create pesticide environmental indexes was made by applying revealed preference information, resulting in more reliable weight estimates based on a cardinal scale of the importance of different risks. Second, the stated preference valuation technique was used to estimate the monetary value of a change in herbicide safety resulting from adoption of Roundup Ready soybean varieties.

The data were generated by a computer-aided telephone survey of U.S. soybean farmers. The information on actual herbicide choices made by the farmers, combined with the information about different production-related and safety attributes of the

herbicides, was used to establish which herbicide attributes mattered most to the farmers in their herbicide choices. In particular, information on the farmers' preferences for herbicide environmental and human safety attributes was used to calculate the relative weights of the herbicide risk index incorporating all the relevant herbicide safety information. The results show that, in addition to production related characteristics, farmers consider herbicide safety attributes in their choice decisions.

The risk indices of individual herbicides developed here were used to calculate the average toxicity of herbicides used on conventional and Roundup Ready soybeans, and the corresponding difference in herbicide toxicity indicating that, on average, the farmers experienced a reduction in herbicide toxicity when switching to Roundup Ready soybeans compared to conventional soybeans. To the average farmer the value of improved herbicide safety on Roundup Ready soybeans was estimated to be between \$0.04 and \$1.13 per acre per year.

Valuation of the Environmental Impact of Roundup Ready Soybeans Based on a New Herbicide Risk Index

By

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To my mother, Daniela Sydorovych,
whose love and support made this possible

BIOGRAPHY

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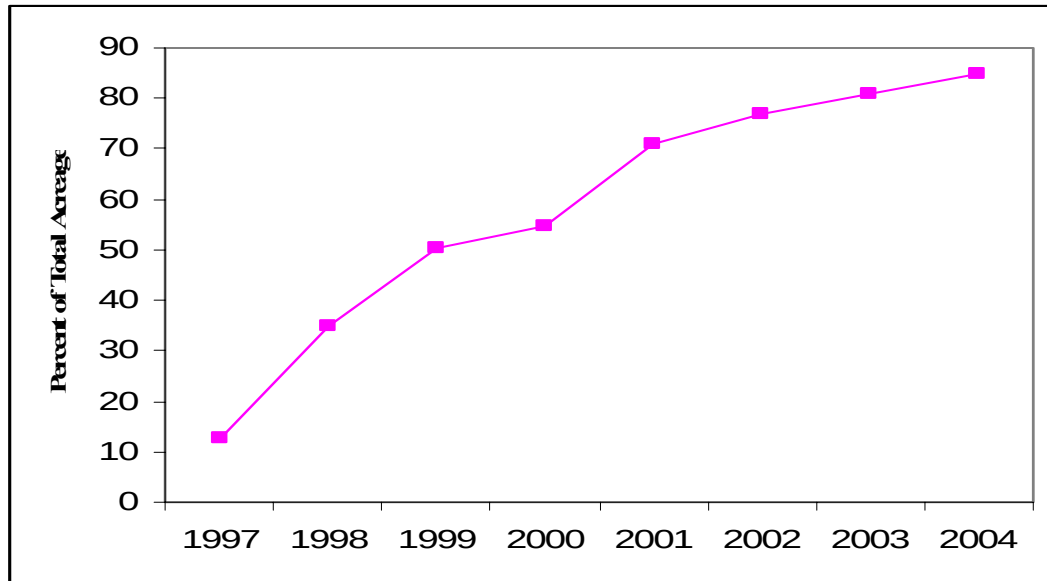
LIST OF ABBREVIATIONS

EIQ	Environmental Impact Quotient
EPA	Environmental Protection Agency
FFDCA	Federal Food, Drug, and Cosmetic Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FQPA	Food Quality Protection Act
GE	Genetically Engineered
GUS	Groundwater Ubiquity Score
IPM	Integrated Pest Management
MSDS	Material Safety Data Sheet
NASS	National Agricultural Statistics Service
RR	Roundup Ready
RUM	Random Utility Model
SMV	Stated Marginal Value
USDA	The United States Department of Agriculture
WTA	Willingness to Accept
WTP	Willingness to Pay

1. Introduction

Herbicides are an integral part of modern agriculture. They provide a highly efficient, cost-effective, flexible and convenient method of controlling weeds. By eliminating weeds, herbicides contribute to substantial increases in yields and consistency of crop production. However, the widespread use of herbicides over the past several decades has led to social concerns about their potential impacts on human health and the environment.

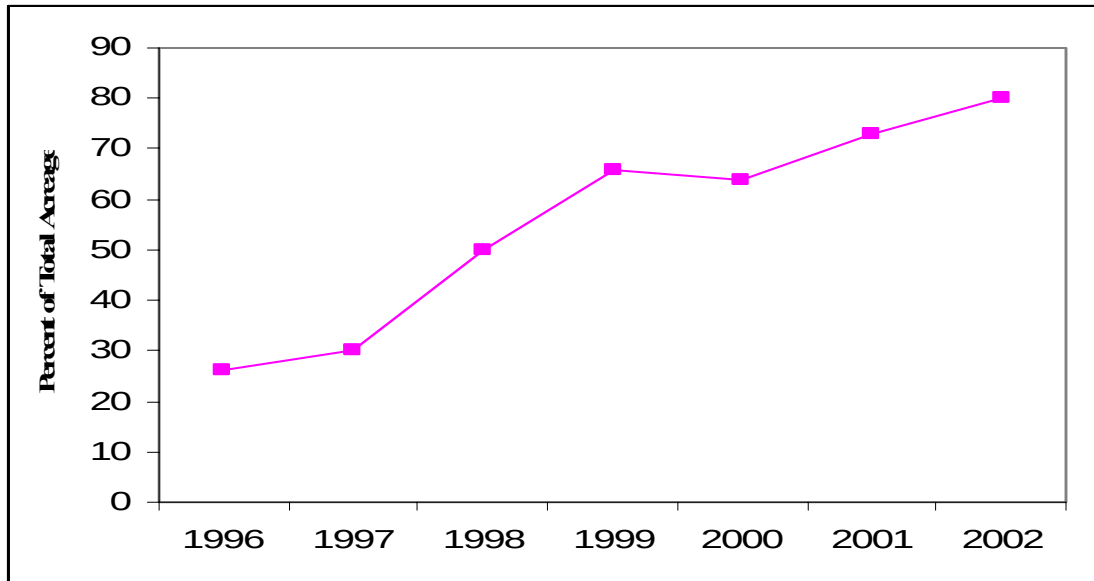
Roundup Ready (RR) soybeans contain the gene that imparts crop resistance to *glyphosate*, a non-selective herbicide, which normally cannot be applied over conventional crop varieties without their severe injury and is highly effective in controlling weeds commonly found in soybeans (Gianessi et al., 2002). The percent of U.S. soybean acres planted to RR soybeans has been growing consistently since their commercial introduction in 1996 (Figure 1.1). While total soybean acreage increased from 70 million acres in 1997 to 75 million acres in 2004, the share of genetically engineered (GE) soybean varieties increased from 13 to 85 percent in the same period (NASS, 2004). This result was driven not only by the availability of the highly effective, broad-spectrum herbicide for weed control on RR soybeans, but also by greater simplicity, flexibility and convenience of the new production system (Marra, Piggott, and Sydorovych, no date).



Source: NASS, USDA, 2004

Figure 1.1. Proportion of GE Varieties in Soybean Acreage Planted in the U.S.

As a result of wide adoption of RR soybeans, post-emergent applications of *glyphosate* on soybeans have largely replaced the use of other common soybean herbicides. According to Figure 1.2, the use of *glyphosate* increased from 26 percent of the acreage treated in 1996 to 80 percent in 2002 (NASS, no date). Such a replacement has resulted in the substitution of a single broad-spectrum herbicide characterized by outstanding environmental properties (Malik, Barry, and Kishore, 1989) for a variety of more selective herbicides with varying levels of environmental effects. Therefore, it has been reported in recent literature that adoption of RR soybeans may be associated with certain environmental and human health benefits (Carpenter et al., 2002).



Source: NASS, USDA, no date.

Figure 1.2. Proportion of Total Soybean Acreage Treated with *Glyphosate*

Several studies attempted to establish whether the adoption of GE crops for pest management reduces the use of pesticides. The existing evidence is contradictory. Heimlich et al. (2000), Carpenter (2001), Carpenter and Gianessi (2001), and Gianessi et al. (2002) found an overall downward trend in pesticide application rates on GE crops. White, Veeman, and Adamowicz (2004) and Hubbell, Marra, and Carlson (2000) argue that adoption of GE crops resulted in reduced numbers of insecticide applications. On the contrary, Benbrook (2003), and Fernandez-Cornejo and McBride (2002) found an increase in the total volume of pesticides applied on GE crop varieties. Frisvold and Marra (2004) attribute such polar results to different measurement methods. Furthermore, analyses based on the volume of the pesticides applied or the number of pesticide applications are inadequate since they ignore crucial information on pesticide toxicity (Frisvold and Marra, 2004; Levitan, 2000; OECD, 2001; Nelson and Miranowski, 1996). The reason pesticide use

is measured in the first place is to get a sense of the extent of negative environmental externalities created by pesticides. If all pesticides were totally benign to all animal and plant species, except the target pests, then no one except the manufacturers and pesticide users would care about the degree of pesticide use.

The first objective of this study was to develop a measure of herbicide use that incorporates the information on various aspects of herbicide environmental and human toxicities. Such a measure applied to the herbicides used on RR and conventional soybeans would be more meaningful as an objective measure of the environmental and human health impacts of RR soybeans adoption compared to the measures relying on the volume or number of applications of herbicides.

An ounce of one pesticide may be lethal to aquatic species and benign to humans, while an ounce of another may be highly corrosive to human skin but deteriorate rapidly in the environment. How can we aggregate applications of these two pesticides to create a coherent measure that can be used by policymakers to protect human and ecosystem health efficiently? One possibility is to develop an index that reflects multiple dimensions of pesticide toxicity, and is weighted by consumers' concerns about each dimension of toxicity.

To achieve the first objective of this research I developed an index system for individual herbicides that combines the information on their acute and chronic human health risks with the information on their environmental toxicity. Such an index system will allow the estimation of the average, per acre toxicity of the herbicides used on conventional and RR soybeans. In addition, one should be able to test whether adoption of RR soybeans indeed results in reduced use of herbicides by a measure that has meaning for policymakers.

A key challenge in the development of the index system combining the information on different pesticide environmental and human health risks is to choose the weights that will determine the relative effects of the individual components of the index. The determination of the relative weights is necessary because there is no reason to believe that, for example, the reduction of chronic human health risk of pesticides may be as important to society as the reduction of pesticide risk to birds. In the development of the relative weights I rely on the information of the farmers participating in a survey that revealed their preferences by the actual herbicide choices they made during the soybean growing season.

The second objective of this study was to develop an economically consistent method to evaluate marginal changes in herbicide safety resulting from adoption of RR soybeans. The changes in herbicide safety that may be associated with adoption of RR soybeans will bring about the changes in social welfare. Without such an evaluation the economic analysis of the impacts of RR soybeans could suffer from serious biases and result in erroneous conclusions.

The dollar value that a particular pesticide adds to crop returns can be measured by calculating the value of comparative yield losses incurred when this pesticide is not used, coupled with its additional cost. Monetizing the environmental and health improvements that result from changes in exposure to pesticides is more difficult, partially due to the numerous potential environmental effects, such as ground and surface water effects, human health effects, and wildlife effects.

Current economic literature presents a number of evaluation techniques for the changes in the quality of non-market goods, such as improved safety of pesticides. The main assumption used by these techniques is that individuals trade their health and environmental

quality as if they were usual market goods. It is also assumed that individual preferences provide a valid basis for the valuation. Commonly used techniques can be grouped into two broad categories of revealed and stated preference methods.

I apply a stated preference valuation technique to estimate the value to farmers of the changes in environmental and human safety of herbicides used on RR soybeans compared to those used on conventional soybeans. The stated preference valuation methods rely on a strong theoretical foundation. They use survey questions to elicit respondents' preferences for non-market goods by finding out the value respondents would place on a specific improvement in their "quality" (Carson, 1991).

This study is developed as follows. Chapter 2 contains a review of the literature relevant to the problem in hand. It presents studies attempting to evaluate different welfare impact resulting from the adoption of GE crops including the changes in pesticide use, and attempts to develop some rating system for pesticide based on their environmental and human health risks. In addition, the chapter reviews the techniques available in economics to evaluate the impact of the changes in non-market goods, such as environmental quality and human health.

Chapter 3 presents the household production model adapted to the problem of herbicide choice by the farmers. The model is also appropriate to reflect farmers valuation of the changes in herbicide safety associated with adoption of RR soybeans. The model is used as the theoretic basis for the analysis in this study.

Chapter 4 is dedicated to the development of the herbicide risk index. It starts with the review of the current U.S. legislature determining the priorities in pesticide safety. The chapter also establishes the levels of different pesticide environmental and health risks, and

presents the potential sources of risk information on individual pesticides. Finally, Chapter 4 compares the index developed in this study with the similar indices developed previously in the literature. Chapter 5 introduces the data used in the analysis, data sources and relevant summary statistics.

Chapter 6 describes the empirical implementation. It presents the issues relevant to the estimation of the herbicide choice model and estimation results. Based on these results, the relative weights of the individual herbicide risk index categories are calculated. The herbicide risk index values of individual herbicides are used to calculate the average per acre toxicities of the herbicides used on conventional and RR soybeans, and the change in herbicide toxicity resulting from the adoption of RR soybeans. Along with the results on the change in the herbicide use measured by the herbicide risk indices, this chapter presents the measures of the change in herbicide use based on the volume of herbicides applied and on the volume of herbicide active ingredients applied. Chapter 6 concludes with the discussion of the differences in the results driven by the herbicide use measurement method used.

Chapter 7 is dedicated to the issues relevant to the estimation of the model of farmers' valuation of the improved herbicide safety. First, the empirical model is presented. Second, issues relevant to the estimation are discussed. Finally, results of the estimation are reported. The summary of the results and conclusions of the study are presented in Chapter 8, followed by the suggestions for further work.

2. Review of the Literature on the Welfare Effects of Adoption of GE Crops

The introduction of genetically engineered crop varieties resulted in considerable resonance in economic literature. There were numerous attempts made to establish the determinants of the adoption decisions, and to evaluate productivity-related, distributional and environmental effects of the introduction of these crops both *ex ante* and *ex post*. The review of the relevant literature presented in this chapter includes studies attempting to estimate direct and indirect environmental welfare effects of adoption of GE crop varieties for the society in general and/or particular social groups.

2.1. Estimation of the Direct Welfare Effects of GE Crop Adoption

According to Nelson and Bullock (2003) a farmer's decision to plant a certain crop is motivated primarily by his expectation of private benefits and costs. In particular, cost saving associated with reduced pesticide use on GE varieties and improved convenience should be large enough to compensate for higher seed costs and technology fees. In addition, this decision may depend on private and external environmental effects associated with GE crops. Positive effects include environmental benefits resulting from the use of less toxic pesticides such as *glyphosate*, accompanied by a reduced number of pesticide applications. Negative effects are also possible, and include the development of weed resistance, damage to non-target plants due to pesticide drift, and effects on non-target species.

The attempts to estimate the welfare effects resulting from the adoption of GE crops are numerous and diverse. A few of the relevant studies are mentioned in this section and summarized in Figure 2.1. Some of the studies, such as Qaim (2001), Bohorova and Scrimgeour (1999), Alston et al. (2002), Giannakas and Yiannaka (2004) conducted *ex ante* analysis of the welfare effects, while others like Lin, Price, and Fernandez-Cornejo (2001), Pray et al. (2001), Marra, Pardey, and Alston (2002), McBride and El-Osta (2002), Ismael et al. (2002) explored ex post effects. A number of studies used the concept of economic surplus in a partial-equilibrium model for consumers, farmers and, in some cases, seed producers (Qaim, 2001; Falck-Zepeda, Traxler, and Nelson, 2000). Others employed some alternative welfare measure, such as analysis of production budgets (Lin, Price, and Fernandez-Cornejo, 2001; Klotz-Ingram et al., 1999; Ismael et al., 2002; White, Veeman, and Adamowicz, 2004).

It is a very complex task to capture all diverse welfare aspects of the adoption of GE crops. Therefore, most of the studies concentrated on a limited welfare issue. For example, some studies explored the effects of the adoption of GE crops at the farm level by answering three main questions.

- (a) Does the adoption of GE crops result in yield gains or losses?
- (b) Is there a reduction in the use of pesticides and pesticide application costs?
- (c) How will adoption affect the welfare of farmers and/or consumers?

Crop	Area	Period	Reference	Study Objective	Methodology	Summary of Findings	Environmental Impact
Cotton Corn Soybeans	U.S.	1996-1998	Gianessi et al. (2002)	Analysis of adoption, diffusion path, and farm-level impacts.	Farm-level analysis.	Farm-level impacts of GE crops vary by crop and technology. Adoption of herbicide-tolerant corn and Bt cotton improved net farm returns. Herbicide-tolerant soybeans and Bt corn did not have a significant impact on net farm returns.	An overall reduction in pesticide use was estimated to be 19.1 mil acre-treatments, or 6.2 percent of total treatments. Total active ingredients also decline by about 2.5 mil pounds.
Cotton	U.S.	1996-1998	Klotz-Ingram et al. (1999)	Analysis of the effect of GE cotton on yields, profits, and pesticide applications.	Farm-level analysis.	Adoption of GE cotton varieties may increase yields and may positively affect the profits. Pesticide use is affected only in some cases. Benefits depend highly on region and year.	Impact of GE crop adoption on pesticide use varies throughout different regions.
Soybeans	U.S.	1997	Lin, Price, and Fernandez-Cornejo (2001)	Economic impact of herbicide-tolerant soybeans.	Farm-level analysis.	Yields were estimated to be 3 percent higher. Weed control costs were estimated to be 11 percent lower, with a cost savings of US\$ 3.50 per acre. The impact on herbicide use measured in pounds of active ingredients is mixed among production regions. The benefits to U.S. farmers were estimated to have been about US\$ 60 million, or about 20 percent of all benefits from the adoption.	Adoption of herbicide-tolerant soybeans may lead to positive environmental and health benefits.
Canola	Canada	1998	Fulton and Keyowski (1999)	Distribution of benefits among different types of producers.	A conceptual model of differentiated producers.	The model shows that some producers benefit from the new technology leading to adoption, while others do not.	
Corn Soybeans	U.S.	1998	McBride and El-Osta (2002)	The economic impact of GE crops on financial performance of farms.	Adoption model.	GE technologies impact farm finances mainly through changes in variable costs and returns. Factors other than economics may be driving adoption.	

Figure 2.1. Welfare and Environmental Impacts of GE Crops by Crop, Area, Period, and Study

Crop	Area	Period	Reference	Study Objective	Methodology	Summary of Findings	Environmental Impact
Corn Soybeans	U.S.	1999	Bullock and Nitsi (2001)	Assessment of the economic gains from adoption and their distribution.	Farm-level analysis.	A savings from under US\$ 6.50 to over 20.00 per acre in production costs of GE soybeans, insufficient in most cases to cover the seed price premium. Bt corn yields are higher by 4.70 bushels per acre, which is greater than calculated break-even point.	Reduced use of insecticides resulted in additional benefits to farmers of US\$58 mil.
Cotton	South Africa	1998-1999	Ismael et al. (2002)	Qualification of the economic impact of adoption.	Adoption model, stochastic production frontiers.	Higher yield and reduction in chemical application costs outweigh the higher seed costs.	
Sweet potatoes	Kenya	<i>ex-ante</i>	Qaim (2001)	Analysis of economic implications.	Partial equilibrium model	The projected annual gross benefit is US\$ 5.4 mil for virus resistance and US\$ 9.9 mil for weevil resistance. Farmers will be main beneficiaries. Consumers will capture one-fourth of the aggregate benefits.	
Cotton	U.S.	1996	Falck-Zepeda, Traxler, and Nelson (2000)	Distribution of benefits from the introduction of Bt cotton.	Economic surplus method.	A total increase in world surplus of US\$ 240 mil., out of which 59 percent went to U.S. farmers, 21 percent to Monsanto, 9 percent to U.S. consumers, 5 percent to Delta and Pine Land.	
Corn	U.S.	<i>ex-ante</i>	Alston et al. (2002)	Estimation of the economic impact of corn rootworm resistant transgenic technology.	Partial budget analysis.	Estimated total benefits for 2000 would have been US\$460 mil: US\$171 mil to the technology developer, US\$231 mil to farmers from yield gains, and US\$58 mil to farmers as non-pecuniary benefits of reduced insecticide use.	

Figure 2.1. (Continued)

Crop	Area	Period	Reference	Study Objective	Methodology	Summary of Findings	Environmental Impact
Soybeans	U.S.		Moschini, Lapan, and Sobolevsky (1999)	Evaluation of welfare effects of RR soybean adoption.	A model with monopolistic developer of the technology who holds intellectual property rights and markets it to competitive farmers.	The U.S. gains substantially from the innovation, but U.S. farmers are adversely affected by the price decline due to adoption and spillover of the technology to foreign competitors. Consumers always gain by capturing a share of the overall efficiency gains.	
Kiwifruit	New Zealand	<i>ex-ante</i>	Bohorova and Scrimgeour (1999)	Evaluation of potential market performance and productivity gains of genetically altered kiwifruit.	Partial equilibrium model.	Kiwifruit diversification has the potential to generate significant market premiums associated with the quality of the fruit and the time of product placement.	
Cotton	China	1997-1999	Pray et al. (2001)	Evaluation of the economic, income distribution, environmental, and health impacts of Bt cotton in a developing country.	Farm-level analysis.	The use of Bt varieties resulted in reduced pesticide use without reducing the yield or quality of cotton. This resulted in substantial economic benefits for small farmers. Consumers did not benefit directly. Because of weak intellectual property rights, very little went back to the developers of these varieties.	Farmers using Bt cotton reported fewer pesticide poisonings.
Potatoes	Canada	1999	White, Veeman, and Adamowicz (2004)	Economic effect of the loss of ability to grow GE potatoes, based on the direct financial costs to farmers and health costs.	Partial budget analysis, Cost of illness.	CAN\$ 6-36 mil direct benefits to the farmers in Prince Edward Island from growing GE potatoes.	CAN\$ 4,732-44,824 mil (for farmers and their families).

Figure 2.1. (Continued)

Crop	Area	Period	Reference	Study Objective	Methodology	Summary of Findings	Environmental Impact
Corn Cotton Soybeans	U.S.		Marra, Pardey, and Alston (2002)	Collecting and characterizing the farm-level evidence of the impact of transgenic field crops.	Farm-level analysis, aggregate impact	Transgenic cotton is likely to result in reduced pesticide use. Bt corn will provide some yield increase resulting in increases in profit. Saving in pesticide costs will more than offset the lost revenue from lower yields in RR soybeans. In general, transgenic crops have proven to be profitable.	
Soybeans	U.S.	<i>ex-ante</i>	Giannakas and Yiannaka (2004)	Estimation of market potential of second-generation soybeans generated to increase the oleic acid content of the oil and lower the content of trans fatty acids.	A model of heterogeneous consumer preferences.	The value to the consumers, market acceptance, and welfare gains to the producers are determined by the prices of products using the new soybeans. If these prices are sufficiently high, GE soybeans may even drive conventional soybeans out of market.	
Corn Cotton Soybeans	Worldwide	1991-2001	Marra (2001)	Review of biotechnology impact based on available evidence.	Farm-level analysis, aggregate impact	Transgenic cotton is likely to result in reduced pesticide use. Bt corn will provide some yield increase resulting in increases in profit. Saving in pesticide costs will more than offset the lost revenue from lower yields in RR soybeans. In general, transgenic crops have proven to be profitable.	Pesticide-inherent varieties contain biological insecticides that are safer than their conventional counterparts and involve no spray drift. Herbicide-tolerant varieties allow for the substitution of safer herbicides. Therefore, there are reduced health and ecosystem concerns.
Corn Cotton Soybeans	U.S.	1996-1998	Heimlich et al. (2000)	Estimation of the changes in pesticide use due to GE crop adoption.	Same-year pesticide use differences, year-to-year differences, regression analysis.	Adopters used 7.6 mil fewer acre-treatments of pesticides in 1997 and 17 mil fewer in 1998. There was an overall downward trend in pesticide application rates from 1996 to 1998.	Adoption of RR varieties results in a substitution of glyphosate herbicide for previously used herbicides that are 3.4 to 16.8 times more toxic according to a chronic risk indicator and persist in the environment nearly twice as long.

Figure 2.1. (Continued)

Marra, Pardey, and Alston (2002) analyzed the farm-level economic evidence available in the public domain at the time to assess the impact of GE field crops. The preliminary conclusions based on a relatively small number of locations and years of observations indicate that adoption of GE cotton is likely to result in reduced pesticide use and an increase in profit. Bt corn provides a small yield gain resulting in profit increase. Even given some yield discrepancy for RR soybean varieties, savings related to the pesticide costs will offset the loss of revenue due to lower yields.

Gianessi et al. (2002) examined 40 case studies to estimate the potential impacts of GE crops on U.S. agriculture. The combined impacts per year from adoption of all 40 studied crops are estimated to be 14 billion pounds of increase in yields, and \$1.6 billion reduction in production costs. Based on increased yields and cost savings, the overall value to U.S. agriculture was estimated to be \$2.5 billion per year.

Klotz-Ingram et al. (1999) used the 1997 survey data from the U.S. Department of Agriculture to estimate the effects of adoption of GE cotton on pesticide use, yields and profits. The results of the farm-level impact model indicate that adoption of GE cotton may have positive effects on yields and profits, while its impacts on pesticide use measured by the number of different active ingredients applied per acre times the number of repeat applications varied across regions.

Lin, Price, and Fernandez-Cornejo (2001) estimated the farm-level effects of adoption of herbicide-tolerant soybeans in 1997. On average, adoption resulted in a three percent increase in yield and 11 percent decrease in weed control costs. Even though there was a slight increase in the herbicide use per acre measured in pounds of active ingredients, the authors mention the possibility of positive environmental effects resulting from improved

safety of herbicide products. According to their elasticity-based estimates, the benefits to the U.S. farmers in 1997 were estimated to be around \$60 million, or about 20 percent of the total benefits from adoption of the technology.

Fulton and Keyowski (1999) argue that farmer heterogeneity with respect to management skills, agronomic factors and technologies adopted affects the distribution of benefits from the adoption of herbicide resistant canola. They develop a model for the distribution of benefits among producers accounting for farmers' heterogeneity and availability of a conventional technology alternative. They show that some Canadian producers benefit from the adoption while others do not.

McBride and El-Osta (2002) evaluate the impacts of adoption of GE corn and soybeans on the financial performance of farms. Based on the 1998 USDA-ARMS survey data the authors find that adoption of GE crops does not require a capital-intensive investment and impacts the financial performance of the farm mainly through the changes in variable production costs and returns varying by crop, type of technology, farm characteristics, and geographical region. Therefore, some other factors such as flexibility and simplicity may be the primary adoption reasons.

Bullock and Nitsi (2001) analyze cost savings resulting from the adoption of RR soybeans and Bt corn. The extent of savings for soybean farmers depends on weed pressure. Farmers experienced reductions in herbicide and labor costs of \$6.50 per acre or less. They conclude that, unless the new technology reduces management costs sufficiently to cover the seed price premium, it will not pay for itself. The extent of cost savings from the adoption of Bt corn was highly dependent on the infestation level. At the same time, Bt corn resulted in yield gains significant enough to result in financial benefits to farmers.

Ismael et al. (2002) investigate the farm-level effects of Bt cotton adoption based on a survey of 100 smallholders from South Africa. The authors found that the adoption resulted in yield gains and reduced pesticide application costs significant enough to outweigh the higher seed costs.

A number of studies explored the welfare effects of adoption of GE crops on the entire society. Some of them break down the total social welfare measure into more specific effects for different social groups, such as farmers, consumers, and biotechnology industry.

Qaim (2001) analysed *ex ante* economic implications of the adoption of GE virus- and weevil-resistant sweet potatoes in Kenya. Model calculations based on the expected reduction in crop losses showed the projected annual gross benefit of \$5.4 million for virus resistance and \$ 9.9 million for weevil resistance. Producing households and consumers were the main beneficiaries.

Falck-Zepeda, Traxler, and Nelson (2000) concentrated on the distribution of benefits from adoption of Bt cotton in the U.S. in 1996. The authors adopt the modification of the economic surplus method to measure the welfare effects. The method is summarized in Alston, Norton, and Pardey (1995), and requires for the monopoly profit of the innovating seed company to be included in the measurement of the welfare effects. The estimates show an increase of \$240 million in the world's surplus in 1996, of which 59 percent went to the U.S. farmers, 26 percent to the companies responsible for the development of the Bt gene, 9 percent to the U.S. consumers, and 6 percent to the rest of the world.

Alston et al. (2002) conduct an *ex-ante* analysis of the benefits from the adoption of corn rootworm resistant technology for the U.S. in 2000. Based on data describing the infestation problems across the country, performance of corn rootworm resistant technology

at different infestation levels, and a survey of corn farmers, the authors evaluate the farm-level economic impacts resulting from the adoption of the technology. These estimates are later converted into the valuation of the economy-wide effects. The results suggest that the new technology adopted on all U.S. corn acres treated for rootworm in 2000 would have resulted in \$460 million of total benefits, of which \$171 million would go to the developer of the technology and \$289 million to farmers in the form of increased yields and reduced insecticide use.

Bohorova and Scrimgeour (1999) evaluate potential productivity gains associated with introduction of genetically diversified kiwifruit in New Zealand. The results indicate that kiwifruit diversification has the potential to generate significant market premiums associated with the quality of the fruit and the time of product placement on the market. The authors point out that there might be some additional environmental benefits of these varieties associated with reduced pesticide use.

Moschini, Lapan, and Sobolevsky (1999) developed a model suitable to evaluate the welfare effects of RR soybean adoption in the U.S. as an adopting country with the possibility of spillovers of new technology to foreign competitors. The U.S. gains from the superior innovation, but U.S. farmers can be adversely affected by the price decline resulting from the spillover. This happens because the spillover of new technology to foreign competitors erodes the competitive position of the domestic producers.

Based on a survey data, Pray et al. (2001) found substantial economic benefits to small farmers resulting from the adoption of Bt cotton in China. On average, Bt varieties resulted in reduced yields, but also reduced the use of inputs and labor costs. In general, Bt varieties were more profitable. Farmers obtained the major share of benefits. Because of

weak protection of intellectual property rights, very little went back to the government research institutes or foreign firms that developed the crops. In addition, authors mentioned reduced use of pesticide resulting in some preliminary evidence of a positive impact on farmers' health.

White, Veeman, and Adamowicz (2004) investigate the economic effects of the loss of ability to grow GE potatoes in Prince Edward Island in Canada associated with the decision of a major food processing company to stop processing GE potatoes. The authors concentrate on the direct financial costs to farmers and specific health costs that may be associated with the change. Based on a partial budget methodology, the results of the analysis show that the financial benefits to farmers in the area from the use of fewer inputs with the modified potatoes are significant (about \$36 million for NewLeaf Pro potatoes), while the health benefits associated with reduced exposure to pesticides are estimated to be relatively small and range from \$4,732 to \$44,824.

Giannakas and Yiannaka (2004) develop a model of heterogeneous consumer preferences for ex ante analysis of the market potential of a second-generation GE soybeans, modified to increase the oleic acid content of the oil and lower the content of trans fatty acids. The analysis is oriented towards the impact on domestic producers. The authors find that the value to the consumers, market acceptance, and welfare gains to the producers are determined by the prices of products using the new soybeans. If these prices are sufficiently high, GE soybeans may even drive conventional soybeans out of the market.

2.2. Evaluation of the Environmental Effects Associated with Adoption of GE Crops

Evaluation of the welfare impacts of GE crops requires accounting for all possible effects these crops might have on society, including environmental and health effects. Most of the studies described in the previous section ignored this issue, and only a few mention it, without engaging in further analysis. This section concentrates on economic methods that can be used to measure such environmental effects, and reviews studies attempting to apply these methods to value environmental impacts associated with GE crops and pesticides.

As mentioned previously, adoption of GE crops may result in reduced pesticide use, and, therefore, potential environmental benefits. These benefits may include improvements in:

- (a) health of farmers, farm workers, and consumers;
- (b) condition of farm resources, such as land, ground and surface water;
- (c) ecosystem in general, including aquatic, terrestrial and avian wildlife.

Economic evaluation of these benefits requires, first, to measure the change in environmental and health impact of pesticides, and, second, to express this change in monetary terms.

The first step requires a comparison of safety attributes of pesticides applied on GE and conventional crops. This process may involve the development of some safety rating system or index for individual pesticides based on different environmental and health risk characteristics. Further discussion of this issue and a review of relevant literature are presented in Chapter 4.

As for the second step, there is an extensive literature that develops evaluation techniques for non-market goods, such as improved safety of pesticides. Commonly used

methods can be grouped into the two broad categories of revealed and stated preference methods. For both, the main assumption used is that individuals trade their health and environmental quality as if they were usual market goods. In addition, it is assumed that individual preferences provide a valid basis for valuation.

The optimization process for an individual common to both stated and revealed preference methods relies on maximization of his utility of consumption and environmental quality subject to a budget constraint. As shown in Braden, Kolstad, and Miltz (1991):

$$(2.2.1) \quad \begin{aligned} \max \quad & U(c, v, q; \mathbf{z}) \\ \text{s.t.} \quad & c + bv = \pi, \end{aligned}$$

where

- c = individual's normalized consumption,
- v = quantity of environmental attribute,
- q = quality of environmental attribute,
- $\mathbf{z}$ = a vector of other attributes of the utility function,
- b = price associated with v ,
- π = individual's income.

Given a certain level of income π and environmental quality q , an individual solves the optimization problem (2.2.1) for consumption c^* and quantity of environmental attribute $v(c^*, v^*)$ as functions of b , π , and q . To investigate a change in q , holding optimal utility level constant, we can totally differentiate the utility function and budget constraint:

$$(2.2.2) \quad dU = \frac{\partial U}{\partial q} dq + \frac{\partial U}{\partial v} dv + \frac{\partial U}{\partial c} dc,$$

$$(2.2.3) \quad d\pi = b dv + v db + dc.$$

Since we investigate how changes in q and v can be compensated by changes in π , it is assumed that $dU = 0$. Rearranging the previous two equations, we obtain:

$$(2.2.4) \quad -dc = \frac{\partial U / \partial q}{\partial U / \partial c} dq + \frac{\partial U / \partial v}{\partial U / \partial c} dv,$$

$$(2.2.5) \quad -dc = v db + b dv - d\pi.$$

Setting the right hand sides of the two equations equal to each other and rearranging, we obtain:

$$(2.2.6) \quad \frac{\partial U / \partial q}{\partial U / \partial c} dq + \frac{\partial U / \partial v}{\partial U / \partial c} dv - v db - b dv = -d\pi.$$

Equation (2.2.6) is a common step in the derivation of the environmental quality values in the revealed and stated preference methods, and will be referred to in the following sections.

2.2.1. Stated Preference Methods

Contingent valuation, a commonly used stated preference method, uses survey questions to elicit preferences for non-market goods by finding out what respondents would be willing to pay for a specific improvement in non-market goods or what level of compensation they would be willing to accept for certain deterioration. That there is no market for the good under question, and the respondents are presented with a hypothetical market where they make decisions (Mitchell and Carson, 1989).

More specifically, the contingent valuation is looking for a change in respondent's income given a certain change in environmental quality such that at the new level of income and environmental quality the respondent would be as well off as with the original income and environmental quality. Going back to the equation (2.2.6), and assuming fixed prices ($db=0$) and equality of the marginal rates of substitution between two products to the ratio of product prices at the optimum $\left(\frac{\partial U / \partial v}{\partial U / \partial c} = b \right)$, we obtain:

$$(2.2.7) \quad \frac{\partial U / \partial q}{\partial U / \partial c} = - \frac{d\pi}{dq}.$$

In other words, change in income plays the role of a “price” reflecting consumer's maximum willingness to pay for a change in environmental quality.

The contingent valuation method relies on strong theoretical foundations. The resulting Hicksian welfare measure can be expressed as willingness to pay (WTP) or willingness to accept (WTA) depending on the initial assignment of property rights. This preferred welfare measure can be obtained directly, which is an advantage relative to other methods measuring welfare benefits and relying on Marshallian consumer surplus (Carson, 1991).

In the case of improved environmental quality (WTP measure), survey respondents are asked to give their valuation of the improvement. Then, Equation 2.2.7 can be expressed as a difference between two expenditure functions:

$$(2.2.8) \quad Q = \pi - e(q_1, V^*(\pi, q_0; \mathbf{z}); \mathbf{z}),$$

where

- Q = respondent's valuation of the improved environmental quality,
- π = respondent's current income level,
- $e(\cdot)$ = expenditure function, the level of income that solves for the reference level of the utility given a new level of environmental quality while other factors remain unchanged,
- q_1 = improved level of environmental quality,
- $V^*(\cdot)$ = an indirect utility function representing the reference level of utility,
- q_0 = reference level of environmental quality,
- $\mathbf{z}$ = a vector of other arguments in the utility function.

There were numerous attempts in economic literature to apply this framework to different aspects of non-market valuation. A partial listing of earlier studies can be found in Carson (1991). More recently, the methodology was applied in the area of the valuation of the environmental costs of pesticides. Higley and Wintersteen (1992) evaluate the environmental costs of the single application of field crop insecticides. The authors survey farmers to rank the importance of different environmental risks of insecticides, and to estimate the environmental costs of these risks. The study takes into account an extensive list of risks including surface and ground water, human acute and chronic health, and non-target wildlife risks. First, the farmers had to rank the importance of avoiding risk in eleven risk categories. Second, they were asked to give the value of avoiding high, moderate, and low levels of risk from a single application of pesticide on a per-acre basis in terms of yield

losses. The WTP to avoid high risk was estimated to be \$12.54; moderate \$8.76; and low \$5.79. The environmental costs were calculated for the most common field crop insecticides by multiplying the relative importance of the specific risk category by the corresponding risk cost.

2.2.2. Revealed Preference Methods

In revealed preference methods the researcher observes 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. Two common types of revealed preference methods are the household production function and hedonic price analysis.

The household production function method investigates the consumption of ordinary commodities that are substitutes or complements of the environmental good. For example, the costs associated with traveling to a particular recreation site characterized by certain attributes are used to calculate the willingness to pay for the site itself and individual attributes that characterize it. Similarly, the expenditures on some averting inputs, such as air filters, can be used to measure willingness to pay for improved air quality. In the area of pesticide safety the expenditures on better safety equipment used in handling pesticides, such as protective eyewear or waterproof gloves, may help to measure willingness to pay for reduced health risks from the exposure to pesticides.

In the formal representation, we can solve equation (2.2.5) for $d\pi$:

$$(2.2.9) \quad -d\pi = -dc - vdb + bdv,$$

and substitute into equation (2.2.6). As before, assuming that $\frac{\partial U/\partial v}{\partial U/\partial c} = b$ we obtain:

$$(2.2.10) \quad \frac{\partial U/\partial q}{\partial U/\partial c} = b \frac{dv}{dq} + \frac{dc}{dq}.$$

Where the value of the change in environmental quality is equal the sum of changes in the consumption portfolio weighted by a price (price of c is normalized to one).

Since some environmental goods can be viewed as attributes of market commodities, hedonic price analysis attempts to separate the part of the variation in the prices of market commodities that is caused by the variation in environmental goods. For example, environmental characteristics of the neighborhood such as air quality may have some effect on the prices of houses in the neighborhood. In a similar fashion, pesticide environmental characteristics may affect their prices along with their production related characteristics. To implement this method it is necessary to estimate the demand for the attributes of the commodity, and observe the price variation based on attribute levels.

Unlike the household production method dealing with quantities, the hedonic method works with prices. It is assumed that the price of the environmental attribute q depends on its level $\left(\frac{\partial b}{\partial q} \neq 0\right)$, and all compensation takes place through prices. With no income change

($d\pi = 0$), and $\frac{\partial U/\partial v}{\partial U/\partial c} = b$, equation (2.2.6) becomes:

$$(2.2.11) \quad \frac{\partial U/\partial q}{\partial U/\partial c} = \frac{db}{dq} v.$$

The marginal rate of the substitution between q and income is equal to the marginal value of q times the number of units of the commodity containing q .

By applying revealed preference techniques to the valuation of pesticide risks, Beach and Carlson (1993) propose a farm household model incorporating different herbicide attributes in order to understand the market for herbicides. The authors argue that farmers value water quality and user safety of herbicides as they select among different products. Using the hedonic analysis the authors show that leaching potential and user toxicity are statistically significant with smaller elasticities comparing to weed control efficacy.

Fernandez-Cornejo and Jans (1995) estimate the hedonic price function for pesticides in order to calculate the quality-adjusted price indices. Pesticide characteristics taken into account are pesticide potency, hazardous characteristics, and persistence in the environment. Separate functions were estimated for pesticides by crop and pesticide class. Their estimated coefficients on the toxicity variable were significant and negative. Calculated prices of the quality characteristics show that the farmers paid on average \$0.17 to reduce pesticide toxicity by one unit in a period from 1968 to 1985, and \$0.34 in a period from 1985 to 1992.

Wilson (2002) used the cost of illness approach to estimate the private costs to Sri Lankan farmers of the health problems resulting from exposure to pesticides during handling and spraying. The cost of illness approach is based on the assumptions that people are producers, and illness results in medical expenditures and foregone earnings. Any action taken to improve health is treated as an investment in preventing the loss of income. The analysis shows that the private, direct and indirect costs arising from pesticide exposure are considerable and exceed the average farmers' income because most of the farmers violate the recommended precautions for the use of pesticides to avoid immediate costs associated with minimizing or avoiding exposure to pesticides.

3. A Behavioral Model of Herbicide Choice and Valuation of the Changes in Relative Safety of Herbicides

A farmer has to make a number of important decisions during the crop growing season. These decisions are driven by his previous experience, knowledge and information set, as well as other characteristics. Among these decisions, is the choice of herbicide products applied at different production stages. First of all, herbicides are production inputs affecting farmer's profit. They may also enter farmer's utility by affecting environmental quality and health. As a producer the farmer is concerned about the effects of herbicides on his health, the health of farm workers, and on-farm environmental resources used in production, such as water and soil. The farmer is also a consumer who may be concerned about the negative environmental externality caused by herbicides including adverse health effects, effects on non-target species, and off-farm environmental resources.

As shown by Beach and Carlson (1993), an agricultural household model is appropriate to use in situations when agricultural inputs affect directly both profit and utility. In this adaptation of the agricultural household model, the farmer's objective is to choose an herbicide product out of a set of available alternatives based on its production-related and safety attributes. Each herbicide product in the farmer's choice set is characterized by a stacked vector of attributes $\mathbf{H}$ consisting of $\mathbf{h}^\pi$, a vector of attributes affecting production, and $\mathbf{h}^e$, a vector of attributes affecting health and environmental safety. Therefore, $\mathbf{H} = (\mathbf{h}^\pi, \mathbf{h}^e)$ represents the full set of herbicide attributes. A representative farmer is maximizing the utility of consumption and herbicide safety subject to the budget constraint:

$$(3.1) \quad \begin{aligned} \max_{c, \mathbf{h}} U &= U(c, \mathbf{h}^e; \mathbf{g}) \\ \text{s.t. } c &= (p \cdot y(\mathbf{h}^\pi; \mathbf{f}) - r) \times A, \end{aligned}$$

where $c(\cdot)$ = farmer's consumption; U is increasing in c ,

$\mathbf{h}^e$ = the vector of herbicide environmental and human safety attributes; U is increasing when herbicide safety improves,

$\mathbf{g}$ = a vector of other utility arguments,

p = the price the farmer expects to receive for his crop,

$y(\cdot)$ = expected yield per acre,

$\mathbf{h}^\pi$ = the vector of herbicide attributes affecting production expressed in terms of the herbicide efficiency; y is increasing in $\mathbf{h}^\pi$,

$\mathbf{f}$ = a vector of farm characteristics,

r = per acre cost associated with application of herbicide,

A = the number of crop acres.

The optimization problem can be presented as the Langrangean,

$$\max_{c, \mathbf{h}} L = U(c, \mathbf{h}^e; \mathbf{g}) + \lambda \left((p \cdot y(\mathbf{h}^\pi; \mathbf{f}) - r) \times A - c \right), \text{ where } \lambda \text{ is the Langrange multiplier.}$$

Based on the set of the first order conditions, the optimization requirements are imposed on the equality of the marginal utility of an additional unit of consumption and the marginal

utility of an additional dollar of profit $\left(\frac{\partial U}{\partial c} = \lambda \right)$, on the equality of the marginal utility of

additional herbicide safety and the marginal utility of additional profit from a herbicide

choice $\left(\frac{\partial U}{\partial \mathbf{h}^e} = \lambda A p \frac{\partial y}{\partial \mathbf{h}^\pi} \right)$, and on the equality of consumption and profit (budget

constraint).

The solution of this problem contains the optimal level of farmer's consumption, the marginal utility of an additional dollar of profit, λ , and the herbicide choice with the optimal bundle of safety and production attributes. The comparison of different bundles of herbicide attributes can be related to the comparison of the corresponding utility functions. Therefore, actual choices of the herbicides by farmers can reveal their preferences for different productive and safety herbicide attributes. This information is used later to establish the relative importance, and, therefore, relative weights, of the individual herbicide safety characteristics that will be combined in the herbicide risk index used to calculate the difference in the toxicity of herbicides applied on conventional and RR soybeans.

Conventional and RR soybeans require application of different herbicide products during a soybean growing season. As mentioned previously, it is believed that herbicides applied on RR soybeans are on average safer than herbicides applied on conventional soybeans. Therefore, there might be some additional value to the farmers of improved environmental and human safety of herbicides applied on RR soybeans compared to herbicides applied on conventional soybeans. This value should be dependent on actual differences in the toxicities of the herbicides applied on both varieties experienced by the farmers. The following is the theoretical valuation model of the changes in environmental and human safety of herbicides used on RR soybeans compared to herbicides used on conventional soybeans.

The farmer has certain amount of acres to be allocated between conventional and RR soybeans. The amount of available acres is assumed to be fixed in the short-run. Similar to Equation 3.1, the farmer's utility function is defined over consumption and herbicide safety, which is represented by the environmental and human safety attributes of the herbicides applied on conventional and RR soybeans. The level of herbicide safety is determined by the amount of acres allocated to each soybean variety. As a result, the farmer's choice problem can be represented as:

$$\begin{aligned}
 (3.2) \quad & \max_{c, A_{RR}} U \left(c, \mathbf{h}_{CO}^e(A_{CO}), \mathbf{h}_{RR}^e(A_{RR}); \mathbf{g} \right) \\
 & s.t. \quad c = p \cdot y \left(\mathbf{h}_{CO}^\pi(A_{CO}), \mathbf{h}_{RR}^\pi(A_{RR}); \mathbf{f} \right) - r_{CO} A_{CO} - r_{RR} A_{RR} \\
 & \quad A_{CO} + A_{RR} = A,
 \end{aligned}$$

where

- c = farmer's consumption c ,
- $\mathbf{h}_{CO}^e$ = the vector of safety attributes of herbicides applied on conventional soybeans,
- A_{CO} = the number of acres allocated to conventional soybeans;
- $\mathbf{h}_{RR}^e$ = the vector of safety attributes of herbicides applied on RR soybeans,
- A_{RR} = the number of acres allocated to RR soybeans,
- $\mathbf{g}$ = a vector of other utility arguments,
- p = the price the farmer expects to receive for his crop,
- y = average expected yield per acre of conventional and RR soybeans,

$\mathbf{h}_{CO}^{\pi}$ = the vector of production-related attributes of herbicides applied on conventional soybeans,

$\mathbf{h}_{RR}^{\pi}$ = the vector of production-related attributes of herbicides applied on RR soybeans,

$\mathbf{f}$ = a vector of farm characteristics,

r_{CO} = herbicide application costs per acre of conventional soybeans,

r_{RR} = herbicide application costs per acre of RR soybeans,

A = the total number of soybean acres.

The change in herbicide safety experienced by the farmer after adoption of RR soybeans is determined by herbicide safety attributes on both varieties, which are functions of the acreage allocated to the corresponding variety. Then, the marginal utility derived from an additional acre allocated to RR soybeans is the product of the marginal utility of additional herbicide safety and the change in herbicide safety from a change in the acres allocated to RR soybeans $\left(\frac{\partial U}{\partial A_{RR}} = \frac{\partial U}{\partial h^e} \frac{\partial h^e}{\partial A_{RR}} \right)$. The solution to the problem brings the optimal number of acres allocated to RR soybeans (A_{RR}), and a corresponding estimate of the change in herbicide safety, as well as optimal consumption and resulting income.

Farmers participating in the survey were asked to place the values on additional environmental and health benefits associated with the changes in herbicide use on RR soybeans compared to conventional soybeans. This value is determined by the actual change in herbicide safety experienced by the farmers and is similar, but not analogous to the

willingness to pay amounts estimated in contingent valuation studies (Equation 2.2.8). The difference is due to the fact that income is considered exogenous in contingent valuation studies. In this case, income as well as the extent of additional herbicide safety is dependent on the choice of acreage allocated to RR soybeans. Following Marra and Piggott (2005) the value of additional herbicide safety is termed a stated marginal value (SMV).

The farmer's valuation of the change in the relative safety of herbicides applied on RR soybeans is represented by the price, expressed in terms of income reduction, that the farmer would be willing to pay for improved herbicide safety that would make him equally well off as under the conditions imposed by growing conventional soybeans only. The difference between this value and WTP would be the reference level of income. While WTP would consider the income received from growing conventional soybeans only as the *status quo* and would assume that this income remains constant with the change in environmental safety associated with growing RR soybeans, SMV would work with the new income resulting from reallocation of certain proportion of acreage to RR soybeans. Therefore, the farmer's SMV can be represented as:

$$(3.3) \quad Q = \pi - e\left(\mathbf{h}_{RR}^e, V^*\left(\pi_{CO}, \mathbf{h}_{CO}^e; \mathbf{g}\right); \mathbf{g}\right),$$

where Q = the value to the farmer of improved herbicide safety,
 π = farmer's income associated with growing the current mix of
conventional and RR soybeans,
 $e(\cdot)$ = expenditure function: the level of income that solves for the reference
level of the utility (conventional variety) given a new level of

herbicide safety, ceteris paribus,

$\mathbf{h}_{RR}^e$ = a vector of herbicide safety attributes associated with RR soybeans,

$V^*(\cdot)$ = an indirect utility function representing the maximized utility level
associated with conventional soybeans,

π_{CO} = farmer's profit associated with conventional soybeans,

$\mathbf{h}_{CO}^e$ = a vector of herbicide safety attributes associated with conventional
soybeans,

$\mathbf{g}$ = a vector of other arguments in the utility function.

Finally, equation (3.3) can be expressed in the equivalent form (Willig, 1976):

$$(3.4) \quad Q = Q(\mathbf{h}_{CO}^e, \mathbf{h}_{RR}^e, \pi; \mathbf{g}).$$

The functional forms chosen for this function and the expenditure function impose restrictions on each other. The function represented by Equation 3.3 is then a base for estimating a valuation function that represents a monetary value of the change in economic welfare that occurs for a given change in environmental quality.

4. Developing The Herbicide Risk Index

The potential benefits to the environment and human health resulting from the adoption of RR soybeans can be expressed as a difference between herbicide risk indices calculated for RR and conventional soybeans. These indices should combine all the diverse information about herbicide environmental and health effects. Issues relevant to the development of such indices are presented in this chapter.

4.1. Legislation Regulating Pesticides in the United States

Pesticides are strictly regulated in the United States through a complex system that leads to product registration and use. There are two federal laws regulating health and environmental risks of pesticides: the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Miller Amendment of the Federal Food, Drug, and Cosmetic Act (FFDCA). FIFRA gives the U.S. Environmental Protection Agency (EPA) authority to register pesticides, require appropriate supporting chemical, toxicological, environmental, and residue studies, and develop labeling requirements. Pesticides that come into contact with food or animal feed are regulated under the FFDCA, which gives the EPA the authority to establish the legal limits for pesticide residue in or on food and feed (Whitford, 2002).

The current pesticide registration process involves balancing potential risks from the use of a given pesticide to humans and the environment and its economic, social, and environmental benefits. Pesticide regulation has shifted its focus from the efficacy and

labeling to pesticide manufacturing, use, and disposal as society has become more aware of pesticide risks. The recognition that total pesticide risk is a function of all routes of exposure has led to a greater attention towards cumulative exposure. As a result, the Food Quality Protection Act (FQPA), which focuses on pesticide residues in dietary and non-dietary sources, introduced the idea of a risk cup representing the amount of pesticide that a person could receive every day for 70 years without significant health risk. Previously, the cup was related to the residue of a single pesticide used on a specific crop. Presently, it is related to the residue of many pesticides with a common mechanism of toxicity. The result is that the common risk cup makes less room for each individual pesticide.

In the case of herbicides, the spectrum of weed control is determined by chemical and biological properties of the product. Because the main purpose of herbicides is to eradicate undesirable vegetation, it is not surprising that herbicides are usually characterized by high plant toxicity and low mammalian toxicity. But some herbicides are toxic to all forms of life. For example, *triazine* herbicides inhibit the Hill reaction of photosynthesis (transfer of electrons from water to electron acceptors in the presence of light), and usually exhibit minimal mammalian toxicity. On the contrary, *arsenic* compounds are poisons toxic to all forms of life (Stevens and Summer, 1991). The current trend in herbicide development and regulation is toward use of more selective agents with low mammalian toxicity and high selective phytotoxicity.

During the process of pesticide registration the EPA evaluates the data provided by the firm that developed the pesticide, and approves a label and Material Safety Data Sheet (MSDS) for the product. 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, non-target insect toxicity, environmental fate, residual chemistry, and spray drift. Since the labels and MSDSs follow established uniform standards for describing pesticide risks characteristics, they can be used as informational sources for the development of the pesticide risk index.

4.2. Pesticide Rating with Respect to Environmental and Health Risks

Human health risk is a function of both pesticide toxicity and level of exposure. A highly toxic pesticide may not pose significant risk if exposure is minimal. On the other hand, a slightly toxic pesticide may pose a high risk at high doses or prolonged exposure. Scientific investigation of pesticide health effects is complex and requires studying how an organism reacts to the pesticide, and what internal changes the pesticide triggers. The recognized potential routes of human exposure to pesticides are through ingestion of the residues in food and water, as well as dermal and inhalation exposure.

An ecological risk assessment of pesticides is used to determine the potential for pesticides to have adverse effects on wildlife and other components of the environment. This process is a way to organize the information about the likelihood and magnitude of risk. Pesticides may affect the wildlife on an acute basis (short-term, high concentrations), a chronic basis (long-term, low concentration), by secondary exposure (accumulation and movement through the wildlife food chain), or through indirect effects on food sources and

habitat. The degree of impact is determined based on sensitivity of the species to a pesticide and by the degree of exposure.

Pesticides may also cause pollution of surface and groundwater. Flowing surface water is transporting pollutants from eroded soil and from the bottom of the water channel. Storage water allows sediments to settle at the bottom and remain there. Runoff and erosion usually have the potential to move more pesticides off-site than leaching since, on average, it takes much less time for a pesticide to reach surface water via runoff than to reach the ground water via leaching (Whitford, 2002). Besides the runoff and erosion, pesticides can reach the surface water through spray drifts, subflow of soil-applied pesticides from drainage tiles or ditches, and direct application of pesticides to water to control aquatic plants.

Leaching is a process of downward movement of water containing pesticides through the soil. The factors that determine a pesticide's leaching potential are persistence, mobility, and the property to release rapidly back into soil solution once it is bound, as well as soil type, topography, rainfall, application rates, and frequency and types of applications.

4.2.1. Acute Human Risk Criteria

Three levels of risk were established for oral, dermal and inhalation toxicities, and eye effect (Table 4.1). An LD 50 is a statistical estimate of material dosage that would result in the death of 50 percent of a population of test species under stated conditions, for example, a single oral dose of an aqueous solution given to male rats (Hayes, 1991). It is the universally accepted, primary way of expressing 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. A similar value, LC 50, is developed for inhalation toxicity (C stands for concentration). It is stated in micrograms of compound per liter of air. The eye effects are expressed in terms of corneal opacity and duration of irritation.

In addition, all information on acute human toxicity of a pesticide is summarized in a “signal word” which is the crucial part of the safety information on the pesticide label. The signal words used are “Danger” (high risk), “Warning” (moderate risk), and “Caution” (slight risk), with the later further subdivided into low risk and relatively non-toxic categories. The data for the choice of the signal word are obtained from the animal studies on exposure through ingestion, inhalation, and dermal (skin and eye) absorption. The route of exposure (oral, dermal or respiratory) that indicates the highest human toxicity potential determines the signal word for the pesticide label.

4.2.2. Chronic Human Risk Criteria

Criteria for assigning a chronic risk level are based on the results of the tests evaluating carcinogenicity and reproductive, birth, and developmental effects for each herbicide. Following Mullen, Norton, and Reaves (1997), a certain herbicide is considered to present a high risk to chronic human health if there is positive scientific evidence of the presence of two or more of the above effects, and moderate risk if there is evidence of the presence of any one of the above effects. The pesticide is considered to present a low risk level if there is no positive evidence of the presence of any of the above effects, but a signal word assigned to the pesticide is “Warning” or “Danger”.

Table 4.1. Acute Human Risk Levels of Pesticides

Signal Word	Risk Level	Oral LD ₅₀ ^a	Dermal LD ₅₀ ^a	Inhalation LC ₅₀ ^b	Eye Effect
Danger	High	0 – 50	0 – 200	0 – 0.2	Corrosive: corneal not reversible
Warning	Moderate	50 - 500	200 – 2,000	0.2 – 2	Corneal opacity: reversible within 7 days; irritation present for 7 additional days
Caution	Low	500 – 5,000	2,000 – 20,000	2 – 20	No corneal opacity: no irritation; or reversible within 7 days
Caution	Relatively Non-toxic	> 5,000	>20,000	> 20	None

^a LD₅₀ values are stated in mg of pesticide per kg of body weight. 1mg/kg=1 part per million (ppm).

^b LC₅₀ values are stated in micrograms of compound per liter of air.

Source: Whitford, 2002.

4.2.3. Environmental Risk Criteria

The environmental hazard statements on the pesticide labels indicate the nature of potential hazards, as well as necessary precautions to avoid personal injury and damage to non-target organisms and the environment. Wildlife groups included are mammals, fish, birds, aquatic organisms, and pollinating insects. More detailed information on the risks to the specific species is available from the MSDS of the herbicide. Since a given pesticide does not affect all species at the same rate, the final risk level for the wildlife group is assigned as the highest risk reported within the group. Table 4.2 presents the rules of assigning the risk levels to birds and fish. The assignment of the toxicity level for mammals is consistent with the pesticide's signal word based on the highest risk level (oral, dermal, inhalation, eye effect) for humans, which is derived from the animal studies.

Table 4.2. Wildlife Toxicity Levels

Risk Level	Fish LC₅₀	Avian Acute Oral LD₅₀
High	0 – 1 ppm	0 – 50 ppm
Moderate	1 – 10 ppm	51 – 500 ppm
Low	11 – 100 ppm	501 – 2,000 ppm
Relatively Non-toxic	> 100 ppm	> 2,000 ppm

Source: Whitford, 2002.

Some pesticides' labels and MSDSs were missing the relevant information for certain wildlife groups. In such cases, the Extension Toxicology Network (ExToxNet) on-line information database supported by Oregon State University and accessible through the World Wide Web at <http://ace.orst.edu> was used to fill the gaps.

4.2.4. Water Pollution Risk Criteria

The impact of pesticides on water resources depends on their chemical properties such as biodegradation, mobility in the environment, and solubility in water, as well as rate and method of application, and environmental conditions, such as soil properties, climate, and weather. Figure 4.1 summarizes the process for determining the site-specific potential for water contamination by pesticides.

There exist a number of methods to estimate the impact of pesticides on the quality of water resources. They range from simple calculations such as trigger values and chemical property comparisons to complex techniques such as computer modeling and laboratory and field experiments. In general, these methods concentrate on leaching and runoff potential, which are determined pesticides' persistence, water solubility, and mobility.

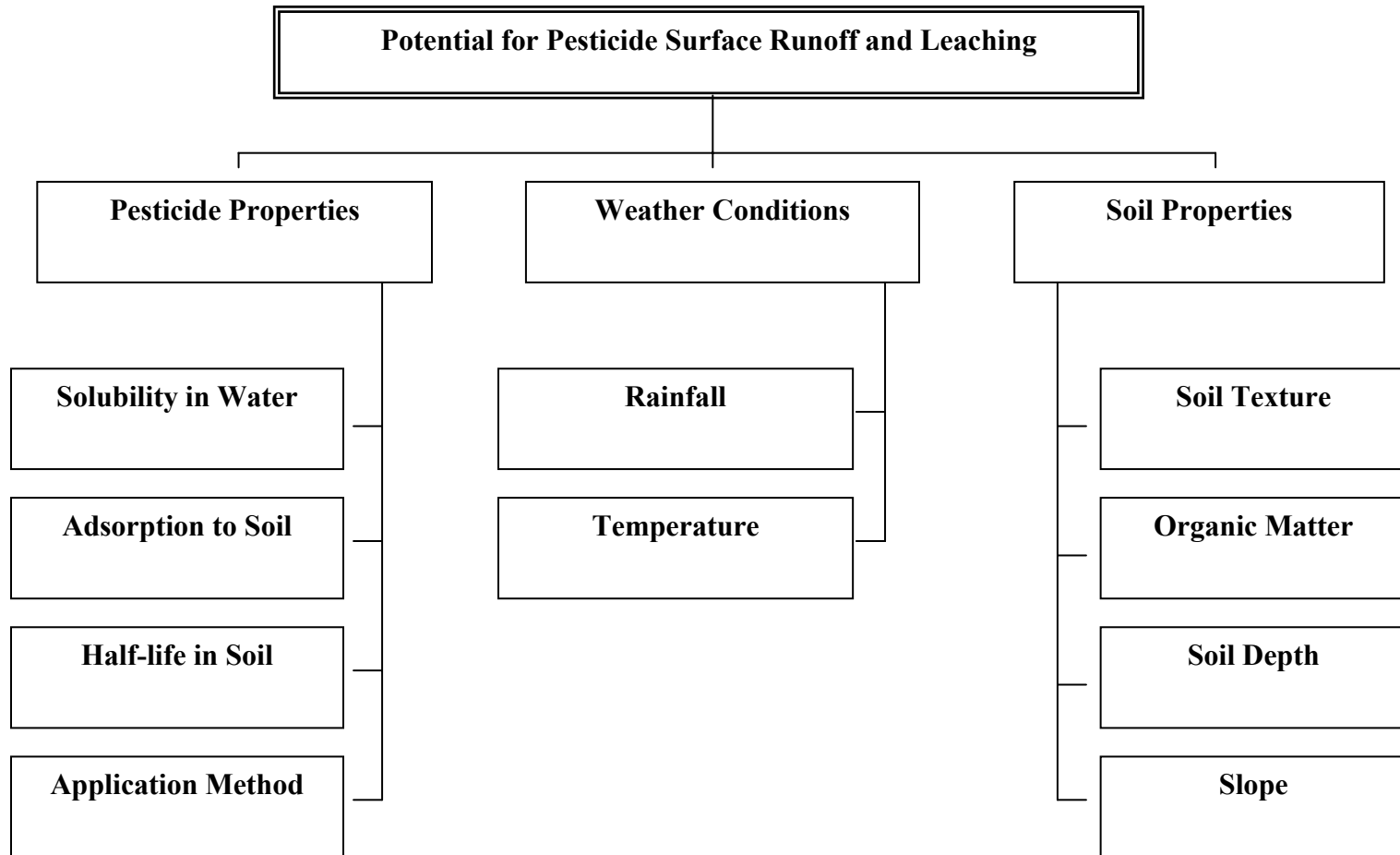


Figure 4.1. Site-Specific Potential for Pesticide Surface Runoff and Leaching

K_{oc} is a measure of soil adsorption, the tendency of pesticides to attach to soil particle surfaces. Higher values indicate a pesticide that is very strongly attached to soil and is less likely to move. The water solubility at room temperature affects how easily pesticide residue washes off and leaches through soil. Half-life in soil, expressed in days, is the time necessary for the pesticide to be transformed or degraded to one-half its previous concentration. It varies depending on soil moisture, temperature, oxygen status, microbial population, soil pH, and other factors (Becker, et al., 1989). Table 4.3 summarizes the information on pesticide mobility, water solubility, and persistence classifications.

Table 4.3. Criteria for Pesticide Surface and Groundwater Contamination Potential

Risk Level	Mobility (sorptive K_{os})	Water Solubility (mg/L)	Persistence (1/2 days in soil)
High	< 500	> 30	> 60
Moderate	500 – 1,000	1 – 30	21 – 60
Low	> 1,000	< 1 (insoluble)	< 21

Source: Becker et al., 1989.

The ground water risk levels (high, moderate, low) for selected herbicides were taken from Becker et al. (1989). If leaching ratings were not available, Gustafson's Groundwater Ubiquity Scores (GUS) were used instead (Gustafson, 1989). The GUS is defined in terms of herbicide's soil half-life ($t_{1/2}$), and K_{oc} , for which the appropriate measures were taken from the herbicide's MSDS and Wauchope et al., 1992:

$$(4.2.1) \quad GUS = \log_{10}(t_{1/2}) \times [4 - \log_{10}(K_{oc})].$$

A herbicide is assigned a high level of leaching potential if its GUS is greater than 2.8, moderate if its GUS is between 1.8 and 2.8, and low if the GUS is less than 1.8 (Gustafson, 1989).

Similarly, surface water risk levels (high, moderate, low) of the selected herbicides or their active ingredients were obtained from Becker et al. 1989. When the surface water ratings were not available, three herbicide characteristics were evaluated: mobility, water solubility, and persistence (Table 4.3). Following Mullen, Norton, and Reaves (1997), if two or more characteristics reach high risk values, the herbicide is considered a high risk to surface water, if one characteristic reaches the high risk value, the herbicide is considered a moderate risk, and if no characteristic reaches the high risk value, the herbicide is considered a low risk.

4.3. The Herbicide Risk Index

As mentioned previously, pesticides used in agriculture to enhance production often adversely affect the environment. Potential effects of pesticides on the environment are so diverse that their analysis may require developing some classification system of pesticide risks. In addition, it may be necessary to combine the information on all diverse effects of pesticides into one index value when the total environmental impact of pesticides is evaluated. This section looks at the studies that develop the systems to classify pesticide risks and indexing techniques to combine the information on different pesticide risks into a

single value and describes the idea behind the herbicide risk index developed in this study and compares this index with similar previous indices.

4.3.1. Pesticide Risk Classification and Rating Literature

There have been a number of attempts to classify environmental risks of pesticides. OECD (2001) developed the following areas of risk: human health, non-target organisms, and land quality. Quantification of human health risks from the exposure to pesticides is very complex. First of all, there are uncertainties concerning the extrapolation to humans of the results of laboratory tests on animals. In addition, it is difficult to separate the effects of pesticides from many other health influences, such as composition of the diet, alcohol and tobacco consumption, age, gender, etc. The effects of pesticides on flora and fauna are very complex as well. Even when pesticides are not impacting directly certain organism, they can accumulate in the elements of food chain reducing or deteriorating its food sources. Pesticides also contribute to the degradation of land resources. The mobility of a pesticide in the environment is mainly determined by its type, rate of use, topography, soil type, and weather conditions, and its persistence may range from few days to several years.

Some authors attempted to develop some rating systems of pesticide risks. Most of them concentrate on a particular area of risk associated with pesticides. Possible examples include pesticide leaching potential (Mulkey, Carsel, and Smith, 1989), impact on arthropod natural enemies (Theiling and Croft, 1988), bee toxicity (Morse, 1989).

Few studies attempted to combine the information on a variety of environmental effects of pesticides. A pesticide rating approach, called the Environmental Yardstick for

Pesticides, was developed in Europe by the Centre for Agriculture and Environment (Reus and Pak, 1993). This method does not attempt to combine all the relevant environmental information about pesticides in a single index value. Instead, the environmental yardstick assigns “pollution points” to each pesticide separately with respect to its leaching into groundwater, acute effects on water organisms, and effect on soil organisms. The pollution points are calculated using computer models describing the emission of the pesticide into groundwater, soil and surface water, and its biodegradation. The effects on water and soil organisms are estimated by comparing the exposure concentration with the toxicity data.

Studies presented below go even further in their attempts to rank pesticides with respect to their potential environmental risks. They analyze expanded lists of possible environmental effects of pesticides, and attempt to develop certain methods to combine this information in a single environmental risk index which makes it possible to compare and rank different pesticides with respect to their environmental risk potentials.

Fernandez-Cornejo and Jans (1995) developed a pesticide toxicity index that encompasses acute and chronic toxicity by modifying the Combined Risk Index proposed by the RAND Corporation. Their index is calculated as follows:

$$(4.3.1) \quad TI = \frac{LAI + LCI + LTI}{3},$$

where TI = the pesticide toxicity index;

LAI = the acute element of the index, which is equal 4 if the active ingredient belongs to the toxicity category I (Danger) of the EPA classification, 3 for

category II (Warning), 2 for category III (Caution), and 1 for category IV (Caution, relatively non-toxic);

LCI = the carcinogenic potential of the pesticide, which is equal 4 if the pesticide is a carcinogen (produces malignant tumors in animal studies), 2, if the pesticide is neoplastigen or oncogenic (produces benign or malignant tumors), 0.5, if the pesticide is mutagenic (produces genetic changes in living cell or other chronic effects);

LTI = the teratogenic potential of the pesticide, which is equal 4 if pesticide is likely to produce malformations, monstrosities, or serious deviations from the normal type, and 0 otherwise.

Kovach et al. (1992) developed a method to calculate the environmental impact of most common fruit and vegetable pesticides. The authors use the environmental impact quotient (EIQ) of pesticides reducing all environmental impact information to a single value. The EIQ equation is based on three principal components of the agricultural production system: farm worker, consumer, and ecological. All principal components have equal weights, but within each component relevant individual factors are weighted differently. An individual factor's weight is based on the magnitude of its influence on the principal component. A consistent rule throughout the model is that the impact potential of specific pesticide on the individual environmental factor is equal to its toxicity multiplied by exposure. The farm worker effect is a sum of applicator exposure and picker exposure multiplied by long-term health effect or chronic toxicity. The consumer component is the sum of the consumer exposure potential and ground water effect. The ecological component

combines aquatic and terrestrial effects and is a sum of the effects on fish, birds, bees, and beneficial arthropods. EIQ values are established for active ingredients of pesticides. An EIQ for a specific pesticide is obtained by multiplying EIQ for each active ingredient by the percent of active ingredient in the formulation adjusted for the application rate.

Higley and Wintersteen's (1992) approach was developed to assess the environmental risks associated with the single application of a pesticide. The purpose of the study was to improve the economic injury levels for field crop insecticides that previously focused solely on the direct economic costs associated with pesticide use. The model considers pesticide risks to various environmental categories and assigns a cost to these risks. The environmental categories include water quality and effects on non-target organisms and human health. They are subdivided into eight specific categories: surface water, groundwater, aquatic organisms, birds, mammals, beneficial insects, and human acute and chronic toxicity. The level of risk in each specific category (high, moderate, low, and none) is determined by the objective criteria based on the results of laboratory tests on pesticides. The relative importance of risk in each category (stated importance of an individual category on a scale from 1 to 10 divided by the total importance for all categories) and the monetary values of avoiding different levels of risks (high, moderate, and low) are estimated using a contingent valuation survey of farmers in four North-Central states. The survey uses the open-ended valuation questions to obtain the WTP to avoid a certain level of risk (high, moderate, low) resulting from a single pesticide application. The environmental cost of a single pesticide application in each category is calculated by multiplying the relative importance of the category by a cost corresponding to this category's risk level. Then, the

total environmental cost of one pesticide application is obtained by adding up the costs for individual risk categories.

Another attempt to develop a pesticide environmental index was made by Mullen, Norton, and Reaves (1997) to conduct the economic analysis of environmental benefits of the Integrated Pest Management (IPM) Program in Virginia for peanut production. IPM strategies combine biological, cultural, physical, and chemical tactics to minimize economic, environmental, and health risks of pesticides. First, this paper estimates the effects of IPM on the risks posed by pesticides to the environment and human health. Second, it determines society's willingness to pay to reduce these risks.

In the Mullen, Norton, and Reaves (1997) study the environment is subdivided into eight broad categories: groundwater, surface water, acute human health, chronic human health, aquatic species, birds, mammals, and arthropods. Further, three levels of pesticide risk are identified: high, moderate, and low. The environmental categories are the same as those used by Higley and Wintersteen, and similar to those used by Kovach et al. but the method of analysis is different. Active ingredients are assigned one risk level ($j = 1$ to 3) for each environmental category ($i = 1$ to 8), resulting in 24 risk/environmental classes for pesticides. Rather than measuring the change in total pounds of all active ingredients, the change in pounds of active ingredients in each ij pesticide class attributable to IPM adoption is measured. So, separate criteria are used for each environmental category to classify the risk posed by each active ingredient.

The authors estimated the change in pesticide use induced by adoption of IPM on the study crop. Because there are few market proxies for the willingness to pay to avoid risk from pesticides, a contingent valuation survey was administered to obtain the value of

reduced risk. Respondents were asked their WTP to avoid each level of risk via an increase in their monthly grocery bill. After answering the WTP question, the respondents were asked to rate (on a scale from 0 to 6) how important it is to avoid each level of risk to each of eight environmental and human health categories.

4.3.2. The Herbicide Risk Index and Its Comparison with Previous Risk Indices

Each herbicide is characterized by a unique set of production related characteristics such as mode of action, application type, persistence, solubility, etc. These characteristics determine how effective the herbicide is in dealing with weeds. The effectiveness of the herbicide combined with its cost affects the profit the farmer will receive at the end of the season. In addition, herbicides differ with respect to their risk potential to the environment and human health. Therefore, the farmer's herbicide choices associated with a certain crop affect not only the profit and resulting utility of consumption, but also the utility the farmer obtains from clean environment and good health.

It was assumed in this research that the farmer has to account for these effects of herbicides while choosing one herbicide product out of a set of available alternatives. The choice of herbicide is, therefore, presented as a function of the herbicide production-related and environmental and health risk characteristics. Therefore, modeling the herbicide choice relationship with different herbicide attributes enables us to determine which particular herbicide attributes matter for the choice. Going even further, I may be able to establish the relative importance of different attributes for the choice. This is important because it enables

us to calculate the relative weights of different herbicide safety attributes to combine all the relevant herbicide safety information into the herbicide risk index.

Figure 4.2 compares three studies that attempted to develop risk index for pesticides: Higley and Wintersteen (1992), Mullen, Norton, and Reaves (1997), and our study. The process of summarizing the information on different pesticide risks into a single value is usually done in two steps (Kovach et al., 1992; Higley and Wintersteen, 1992; Mullen, Norton, and Reaves, 1997). First, risk criteria are established for different pesticide environmental and health risk categories. Individual pesticides are assigned risk levels in each category of risk based on these criteria. Second, this information is summarized into a single index number making it possible to compare and rank different pesticides with respect to their overall risk.

The first step is straightforward. The information used is objective and is obtained from the standard tests on pesticides. It is available from the pesticide label, MSDS and other sources. I approach this task in a way similar to the previous studies (Higley and Wintersteen, 1992; Mullen, Norton, and Reaves, 1997) with respect to the categories of risk considered, rules assigning risk levels within each category, and information sources.

To accomplish the second step it is necessary to establish the relative weights of the individual risk categories that will be included in the index. Previous studies used stated preference information to develop these weights. In both cases (Higley and Wintersteen, 1992; and Mullen, Norton, Reaves, 1997), survey respondents were asked to rate the importance of avoiding different pesticide risks on a certain scale. The authors used the means of these ratings to calculate the relative weights of the categories. However, the respondents were not asked to rate different risks relative to each other. Therefore, the

ratings were not based on a cardinal scale, i.e. the ratings of the importance of different risks are not comparable with each other, and cannot be used to weight different risks while combining them into a single risk index.

In addition, analytical methods that rely on stated preference information are often criticized in the literature 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, 1997). I achieve improved reliability of the relative weights of herbicide risk categories by relying on the revealed preference information assuming that the farmers reveal their preferences for herbicide attributes, including different aspects of safety, by choosing the specific herbicide product out of the set of available alternatives.

Comparison Category	Higley and Wintersteen (1992)	Mullen et al. (1997)	This Study
Motivation	Assessment of the environmental risks associated with a single pesticide application to improve the economic injury levels of pesticides previously focusing only on economic costs.	Economics analysis of environmental benefits of IPM.	Development of a generalizable measure of the changes in pesticide use.
Application	Selected insecticides.	Pesticides used in peanuts production in Virginia.	Selected soybean herbicides.
Survey Respondents	Field crop farmers in four North-Central states.	Random sample of U.S. residents.	Random sample of U.S. soybean farmers.
Risk Categories	Surface water, groundwater, aquatic organisms, birds, mammals, beneficial insects, acute human ingestion, inhalation, and dermal toxicity, eye effect, and chronic human health.	Surface water, groundwater, aquatic organisms, birds, mammals, beneficial insects, acute human ingestion, inhalation, and dermal toxicity, eye effect, and chronic human health.	Surface water, groundwater, fish, birds, mammals, acute human ingestion, inhalation, and dermal risks, human eye effect, and human chronic health.
Sources of Information	Becker et al. (1989), ExToxNet, Croft (1990).	Becker et al. (1989), ExToxNet.	Pesticide labels and MSDSs, Becker et al. (1989), ExToxNet, Morse (1988), Wauchope et al. (1992).
The Relative Weights of Risk Categories	Determined by survey respondents who stated the importance of avoiding risk to different categories based on 1-10 scale of increasing importance.	Determined by survey respondents who rated on 1-6 scale the importance to avoid risk from pesticides at each risk level (high, moderate, low).	Estimated based on revealed preference information by applying the conditional logit procedure to herbicide choices made by the farmers.
Valuation Question	Willingness to pay to avoid high (moderate, low) risk from a single pesticide use. The format of the valuation question is open-ended.	Willingness to pay to avoid high (moderate, low) risk from pesticide use via an increase in the monthly grocery bill. The format of the valuation question is open-ended.	Added value per acre, if any, of additional human and environmental safety from the herbicides used on RR soybean varieties. The format of the valuation question is open-ended.

Figure 4.2. Comparison of Pesticide Risk Index Studies

Comparison Category	Higley and Wintersteen (1992)	Mullen et al. (1997)	This Study
Valuation Algorithm	The mean relative weight of each category was multiplied by the mean WTP to avoid the corresponding level of risk. Resulting values for different categories were then added to obtain the environmental impact value for a single application of each insecticide.	The effect of IPM adoption on pesticide use is assessed based on the volume of active ingredients separate for each risk level and environmental category. This information is then combined with the corresponding WTP and ratings of the categories.	The average herbicide toxicity was calculated for conventional and RR soybeans based on the herbicide risk indices. The change in herbicide toxicity was calculated individually for each farmer. Then, the relationship was modeled between farmers' stated values of health and environmental benefits due to reduced herbicide use on RR soybeans and actual changes in herbicide toxicity.

Figure 4.2. (Continued)

5. The Data

The data were generated by a computer-aided telephone survey of soybean farmers conducted by Doane's Market Research in cooperation with North Carolina State University in 2002. The survey explored the issues relevant to the comparative economic analysis of conventional and RR soybeans. In particular, it concentrated on differences in herbicide use. In addition to the direct agronomic and economic differences, the survey also attempted to extract farmers' valuation of various indirect aspects of the herbicide use differences such as changes in environmental quality and health. The framers were asked to give their values per acre per year of the changes in environmental quality and their health resulting from the changes in herbicide use on RR soybeans as compared to conventional soybeans.

There were 610 surveys completed. Farmers were selected to participate in the survey from the nineteen soybean growing states. Table 5.1 shows the numbers of completed surveys in each state. The last column of Table 5.1 shows the percent of the total U.S. soybean acreage planted by state in 2001. All major soybean producing states were represented in the survey except for North Dakota which was responsible for only 3 percent of the total soybean acreage planted in the U.S. in 2001.

The majority of survey respondents operated large farms: 599 observations (98 percent) were collected for the farms with the total farm acreage exceeding 200 acres in 2002. Most participating farmers were growing only RR soybeans in 2001 with 274 responses (45 percent). In the category of partial adopters there were 199 responses (33 percent). Finally, 137 farmers (22 percent) were growing conventional soybeans only.

Table 5.1. Surveys Completed by State

State	Number of Respondents	Percent of Respondents	Percent of the Total U.S. Soybean Acreage in 2001^a
Iowa	94	15.4	14.8
Illinois	93	15.2	14.4
Minnesota	62	10.2	9.8
Indiana	50	8.2	7.5
Nebraska	45	7.4	6.7
Missouri	42	6.9	6.7
Ohio	41	6.7	6.2
South Dakota	39	6.4	6.1
Kansas	27	4.4	3.8
Arkansas	26	4.3	3.9
Michigan	19	3.1	2.9
Wisconsin	13	2.1	2.1
Kentucky	12	2.0	1.7
Mississippi	12	2.0	1.6
North Carolina	12	2.0	1.9
Tennessee	10	1.6	1.4
Louisiana	7	1.1	0.8
South Carolina	4	0.7	0.6
Alabama	2	0.3	0.2
All States	610	100.0	93.1

^a Source: NASS, USDA, January 2002.

Table 5.2 presents some acreage statistics for the survey sample. The mean farm acreage in 2002 for the sample was 1,154 acres with an average of 46 percent of farm land

owned and 54 percent leased. The average crop acreage was 955 acres in 2001 and 994 acres in 2002, and the average soybean acreage was 467 acres in 2001 and 476 acres in 2002. The farmers planted on average about 59 percent of RR soybeans in 2001 and 72 percent in 2002.

Table 5.2. Acreage Statistics for the Survey Sample

Characteristics	Mean (N=610)	Standard Deviation
Farm Acres in 2002	1,153.6	987.4
<i>Owned</i>	534.0	628.6
<i>Leased</i>	619.5	706.9
Total Acres Used for Crop Production in 2001	954.6	787.1
Soybean Acres in 2001	466.8	406.6
<i>Percent of RR Soybeans</i>	59.5	42.9
Total Acres Used for Crop Production in 2002	993.7	841.0
Soybean Acres in 2002	476.1	404.9
<i>Percent of RR Soybeans</i>	72.0	39.8

Table 5.3 presents selected demographic characteristics of the survey sample. The average farmer in the sample was 57 years old, spent 33 years in farming activities, and completed 13 years of formal education. The average farmer in the sample spent 90 percent of his work time in all farm activities, out of which 78 percent was spent in crop production. The yearly household income was calculated as a midpoint of the selected income intervals represented in Table 5.4. The average household income for the sample was \$341,000 per year.

Table 5.3. Demographic Characteristics of the Survey Sample

Characteristics	Mean (N=610)	Standard Deviation
Farmer Age	56.6	10.8
Years Spent in Farming	33.3	11.9
Years of Education	13.4	2.1
Percent of Time Spent on Farm Operation	90.1	21.0
<i>In Crop Production</i>	<i>78.5</i>	<i>26.1</i>
Income (\$ 1,000 per year)	341.1	277.2

Table 5.4. Household Income Intervals and Selected Interval Midpoints

Income Interval (\$ 1,000 per year)	Interval Midpoint (\$ 1,000 per year)
Under 2.5	2.5
2.5 – 9.9	6.25
10.0 – 19.9	15.0
20.0 – 39.9	30.0
40.0 – 99.9	70.0
100.0 – 249.9	175.0
250.0 – 499.9	375.0
500.0 – 999.9	750.0
Above 1,000.0	1,000.0

Survey respondents were asked to base their responses about RR soybean varieties on the 2001 growing season. Since they had to compare numerous details of growing conventional and RR soybeans, and some of them did not plant any conventional soybeans in

2001, they were asked to base their responses about conventional varieties on the last year (reference year) when they planted at least 10 percent of their soybeans to conventional varieties.

Table 5.5 summarizes the number of responses for each reference year when at least 10 percent of conventional soybeans were planted. Years mentioned range from 1985 to 2001. The majority of respondents concentrated on 2001 with 350 observations representing 57 percent of all responses. In this reference year, 14 respondents were full adopters of RR soybeans and did not grow any conventional soybeans previously. On the other hand, 137 respondents were growing conventional soybeans only. The remaining 199 respondents planted RR and conventional soybeans, and therefore, provided details on growing both varieties in 2001. For the remaining reference years, responses about RR soybeans were based on the 2001 growing season and responses about conventional soybeans on the reference year.

Table 5.5. Number of Responses by the Reference Year When Respondent Planted at Least 10 Percent of Conventional Varieties

Reference Year	Number of Respondents	Percent of Respondents
2001	350	57
<i>Full Adopters</i>	14	2
<i>Partial Adopters</i>	199	33
<i>Non-Adopters</i>	137	22
2000	45	7
1999	45	7
1998	66	11
1997	42	7
1996	23	4
1995	15	2
<i>RR Commercialized</i>		
1994	2	0.3
1993	8	1
1992	1	0.3
1991	1	0.3
1990	5	0.8
1988	3	1
1987	1	0.3
1985	3	1
All Years	610	100

Since this analysis focuses on safety characteristics of the herbicides applied on RR and conventional soybeans, the following section presents herbicide use information for both soybean varieties. Table 5.6 contains the information on the 2001 soybean acreage treated at

least once with herbicides. A total of 43,541 acres of all soybeans were planted to RR varieties, of which 97 percent were treated at least once with herbicides. Conventional varieties were planted on 113,106 acres, of which 78 percent were treated with herbicides.

Table 5.6. Soybean Acreage Treated with Herbicides in 2001

Soybean Variety	Acres
Roundup Ready Soybeans	43,541
<i>Percent Treated with Herbicides</i>	<i>97</i>
Conventional Soybeans	113,106
<i>Percent Treated with Herbicides</i>	<i>78</i>

The difference in the average proportion of the acreage treated with herbicides between RR and conventional soybeans can be explained by the fact that *glyphosate* herbicides applied on RR varieties are universally effective in dealing with most of the weeds while herbicides applied on conventional soybeans are on average effective against only selected weeds. Therefore, given the same weed composition and pressure on the field, it may be necessary, when tank mixing is not feasible, to apply multiple herbicides on conventional soybeans as compared to a single herbicide on RR soybeans. When a farmer is considering the cost and benefits of herbicide application, he will be less likely to apply herbicides on conventional soybeans, or will apply them only in the specific areas of the field where the weed pressure is strongest.

More specific information about the herbicides applied by survey respondents is presented in the Appendices. Appendix 1 lists all herbicides mentioned by the farmers

participating in a survey. In some instances, the farmers did not use the correct brand name of herbicide product. For example, Ultra Blazer (*acifluoren*) was referred to as “Blazer.” Therefore, the second column on the table contains herbicide brand names corresponding to the names mentioned by the farmers. In addition, Appendix 1 also contains the generic names of the herbicides.

In some instances, complete information on certain herbicide mentioned by the farmers, such as product price per acre, was not available. If there existed a herbicide that could be considered its close substitute, the characteristics of the substitute herbicide were used instead. In addition, some of the herbicides mentioned by farmers could be considered perfect substitutes. For example, farmers mentioned several herbicide brands with the formulation identical to Glyphosate, for example, Mirage, Glyphomax, Glystar Plus. Since characteristics of these herbicides were very similar, they were considered as the same herbicide in the analysis.

Appendix 2 contains the information about herbicide applications on RR and conventional soybeans at different stages of production. It shows the total number of farmers who applied each herbicide pre and post-emergence on both varieties. Observations on a farmer who applied the same herbicide at different stages or on both varieties are assumed to be independent. According to the information presented in Appendix 2, the four most commonly used herbicides are Glyphosate, Trifluralin, Prowl, and Pursuit.

Table 5.7 summarizes the information about the number of herbicide applications. There were 1,769 herbicide applications made by the farmers, including 778 pre-plant and pre-emergent applications and 991 post-emergent applications. A total of 633 applications were made on RR soybeans, and 1136 on conventional soybeans. Information about actual

herbicide choices made by farmers in our sample was used to establish farmer's preferences for herbicide attributes. In particular, as explained earlier I calculated the relative weights of the categories included in herbicide risk index. The results are presented in the following chapter.

Table 5.7. Number of Herbicide Applications by Technology Type

Stage	Roundup Ready Varieties	Conventional Varieties	Roundup Ready and Conventional Varieties
Pre-Plant and Pre-Emergent	185	593	778
Post-Emergent	448	543	991
All Stages	633	1,136	1,769

6. Estimation of the Herbicide Choice Model and Calculation of the Herbicide Risk Indices

Estimation of the model is carried out in several stages. Figure 6.1 presents a flow chart describing the empirical implementation of the model. First of all, actual herbicide choices made by the farmers in the sample are used to estimate farmers' preferences for different herbicide production-related and safety attributes. This information allows me to calculate the relative weights of individual herbicide environmental and human safety characteristics included in the herbicide risk index. The index values of individual herbicides are used later to calculate herbicide toxicity per acre of RR and conventional soybeans, and the change in these two values, if any, for each farmer. Finally, the information about the change in herbicide toxicity experienced by each farmer combined with farmers' stated values of this change is used to estimate farmers' valuation of herbicide human and environmental safety.

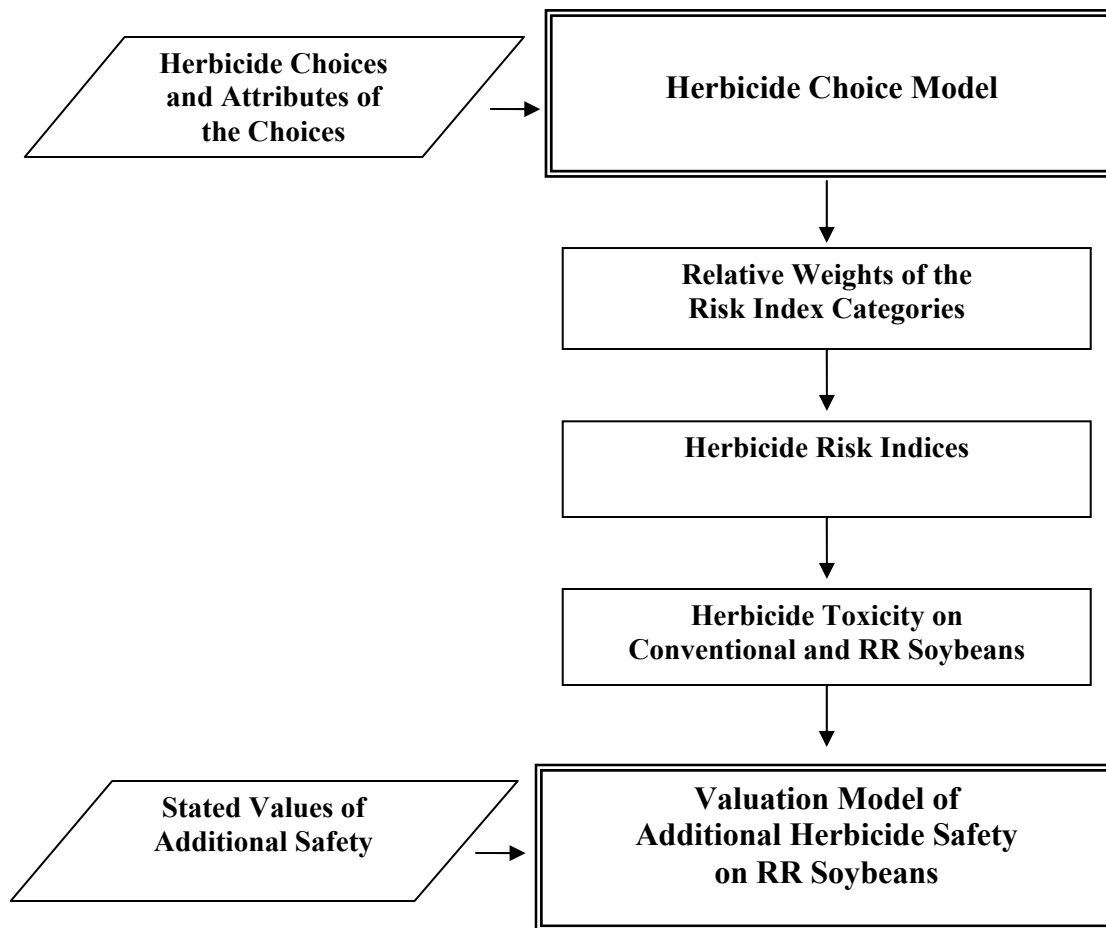


Figure 6.1. Flow Chart of the Empirical Implementation of the Model

6.1. Empirical Model of Herbicide Choice

As mentioned earlier, farmers consider a set of different production-related and safety herbicide attributes while making their herbicide choices. The comparison of different bundles of herbicide attributes can, therefore, be related to the comparison of the corresponding utility functions, and actual choices of the herbicides by farmers can be used to reveal their preferences for different attributes of herbicides.

I apply the conditional logit procedure (McFadden, 1974) to reveal farmers preferences for different herbicide attributes. The conditional logit model is derived from the Random Utility Model (RUM), and allows considering the effects of choice attributes on the determinants of choice probabilities (Maddala, 1983). The attributes are choice specific and are typically the same for all subjects, but the model can be modified to allow individual-specific effects. The conditional logit model is based on the restrictive assumption of homogeneous error variances, which leads to the undesirable independence of irrelevant alternatives (McFadden, 1973). Some alternative methods, such as the random coefficient model, are more general since they relax the assumption of homogeneous error variances. However, these methods incur very high computational costs, which might obstruct the estimation of confidence intervals of marginal effects or elasticities. Therefore, the conditional logit model remains the standard discrete choice approach (Haan, 2004).

Estimated coefficients on different herbicide attributes obtained by estimating the conditional logit model of herbicide choices by the farmers can be used to establish which attributes matter for the choice and their relative importance. I used these coefficients to calculate the relative weights farmers place on different attributes of herbicide safety combined in the herbicide risk index.

In formal presentation, the utility function of the farmer i for herbicide choice j is given by:

$$(6.1.1) \quad U_{ij} = V_{ij} + \varepsilon_{ij},$$

where V_{ij} = non-stochastic portion of the utility function,

ε_{ij} = a random component.

Assuming that non-stochastic portion of the utility function is a linear function of the parameters, and the error disturbances ε_{ij} have independent Type I extreme value distribution with a cumulative distribution function $\exp(-\exp(\varepsilon_{ij}))$, the probability of choosing herbicide alternative j among J alternatives by farmer i is written as:

$$(6.1.2) \quad P_i(j) = \frac{\exp(V_{ij})}{\sum_{k=1}^J \exp(V_{ik})}$$

6.1.1. The Attributes of the Herbicide Choice Model

A number of herbicide characteristics may influence a farmer's choice of herbicide product. Since herbicides are used to control weeds, it is reasonable to assume that herbicide effectiveness in dealing with weeds is one of the most important characteristics influencing the choice. Herbicide effectiveness can vary for different weed classes or even different weed species within each class. Unfortunately, the data set did not contain any information regarding the specific weeds the farmers were trying to control. Therefore, it was impossible to create an accurate measure of herbicide effectiveness. Instead, two alternative measures were considered.

The first measure was based on the list of top ten most common weeds for the state in which each farm was located¹. The average herbicide weed response was calculated separately for each state based on this list. The first measure was not very successful since it did not result in a statistically significant coefficient in the herbicide choice model.

In the end, it was useful to separate broadleaf and grass weed herbicide effectiveness measures in the estimation which resulted in statistically significant coefficients in the herbicide choice model. This result can be explained by the fact that some herbicides are designed to control only one type of weeds (grasses or broadleaves) and are ineffective in dealing with the other type. For example, Prowl has very high grass weed effectiveness with the average grass weed response of 76 percent, but is also quite ineffective against broadleaf weeds (23 percent). This herbicide is likely to be used by the farmers if they need to control grasses. Therefore, the effectiveness measure combining broadleaf and grass weed response data would not be informative about the actual performance of the herbicide.

In the second attempt to measure herbicide effectiveness an average percent of broadleaf and grass weed response was calculated as a simple average for all weeds reported within broadleaf and grass weed categories. For example, percent of weed response was reported for ten different grass weeds for herbicide X. A simple average percent of grass

¹ A number of information sources were used to create the lists of top ten most common weeds for each state participating in the survey. The information on the Southern states (Alabama, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, and Tennessee) was obtained from the Southern Weed Science Society 2001 Proceedings. The information for the North-Central states (Iowa, Illinois, Indiana, Michigan, Minnesota, and Wisconsin) was obtained from Iowa State University Cooperative Extension Service on-line resources. The information for Arkansas was obtained from Arkansas State Plant Board on-line resources. The information on most common soybean weeds in Kansas was obtained from Kansas State University Cooperative Extension Service on-line resources. The information on weeds of South Dakota was obtained from South Dakota State University Cooperative Extension Service on-line resources. Finally, the information about weeds in Nebraska was obtained from the University of Nebraska – Lincoln Cooperative Extension Service on-line resources.

weed response was then calculated based on these ten values and assigned to herbicide X. Similarly, percent of weed response was reported for 18 broadleaf weeds for the same herbicide. A simple average percent of broadleaf weed response was calculated based on these 18 values and assigned to herbicide X. The number of weeds for which response values were reported varied for different herbicides.

The costs associated with herbicide application are the determinants of the final profit and should also matter for the choice. Herbicide application costs may vary for different stages of production: pre-plant incorporated costs differ from the costs of post-emergent over-the-top herbicide sprays. Within each stage, herbicide application costs remain the same for different herbicides. Therefore, it was assumed that the costs associated with each herbicide choice consist of the stage-specific herbicide application costs and the cost of herbicide product.

In addition to the production related herbicide characteristics, farmers may also be concerned about herbicide safety. They will choose safer herbicides because they are concerned about their own health and health of their workers and family, as well as the quality of affected environmental resources. There are three distinct ways for herbicide safety to enter farmer's utility. First of all, herbicide safety may indirectly affect production through deteriorated health of farm workers, or quality of on-farm environmental resources such as soil and water. Second, farmers may extract utility from fishing, hunting, swimming or other recreational activities that are affected by herbicides. Finally, farmers may have some altruistic concerns for environmental preservation. Therefore, it is expected that safety characteristics of herbicides enter the herbicide choice function because farmers will try to choose less toxic herbicide products *ceteris paribus*.

In addition, two more herbicide characteristics were considered in the herbicide choice model. Herbicide persistence represents the time in days necessary for the herbicide to be transformed or degraded to one-half its original concentration. Persistence can be linked to herbicide efficiency: herbicides with higher persistence will remain effective for a longer period of time. At the same time, persistent herbicides are riskier: higher persistence expands the time window when the potential exposure to the negative effects of herbicides is possible. The first effect of herbicide persistence is expected to have a positive effect on choice, while the second – negative. The direction of the combined effect of herbicide persistence on herbicide choice will depend on which of the two effects is stronger.

Herbicide application rate can be linked to farmers' perceptions of herbicide risks. It is reasonable to assume that if the farmer is concerned about herbicide environmental externalities, his perception of their magnitude is dependent not only on herbicide risk ranking but also its application rate. This can be explained better with the help of an analogy. We would consider some extra safety characteristics of a new car as more important if we intend to drive this car a lot and as less important if we use the car only occasionally. Similarly, the farmer would care more about high risk attributes of herbicide applied at a relatively high rate than about high risk attributes of herbicide applied at a relatively low rate. To account for this effect, herbicide recommended application rate (the "label" rate) expressed in pounds of herbicide product per acre was included in the herbicide choice model.

As a result, herbicide attributes included in the herbicide choice model are mean broadleaf and grass weed responses to herbicides, per acre herbicide application costs, persistence, application rate per acre, acute human toxicity to eyes and skin and by ingestion

and inhalation, chronic human toxicity, fish, bird, mammalian toxicity, and potential to contaminate ground and surface water resources.

As mentioned in Table 5.7, a total of 1,769 independent herbicide choices were made by the farmers on both RR and conventional soybeans at different stages of production in the survey. Appendix 1 contains the list of herbicides mentioned in the survey. The appendix also contains the generic and brand names associated with the names mentioned in the survey. Herbicide brand name is used in the analysis that follows. Appendix 2 contains detailed information about the applications of individual herbicides. If a farmer applied the same herbicide on both soybean varieties and/or at different stages of production, these applications were considered as independent herbicide choices. The most commonly used herbicide was Glyphosate with 505 independent choices made, followed by Trifluralin (188 choices), Prowl 3.3 EC (115 choices), and Pursuit (104 choices).

Appendix 3 represents human health related characteristics of the herbicides. This information was obtained from the herbicide MSDSs and on-line from the ExToxNet. The appendix contains the risk ratings of the individual herbicides with respect to their ingestion, inhalation, dermal toxicities, eye effect, as well chronic risk rating. In addition, Appendix 3 contains the EPA rating word for each herbicide. The rating words used are “Danger” (high risk), “Warning” (moderate risk), and “Caution” (slight risk). In each human health category, herbicide risk levels are determined as high, moderate, low or non-toxic based on the rules described in Sections 4.2.1 and 4.2.2.

Appendix 4 summarizes the information on the environmental effects of individual herbicides mentioned in the survey. The effects considered are herbicide toxicity to birds, fish, mammals, and the potential to contaminate surface and groundwater. Similar to the

human health risks, all individual herbicides are assigned a certain risk level (high, moderate, low, non-toxic) based on the rules described in Sections 4.2.3 and 4.2.4. Risk information was obtained from the herbicide MSDSs and the ExToxNet.

Appendix 5 presents production related characteristics of herbicides: mean percent of broadleaf and grass weed response to the herbicide, application costs per acre at the recommended rate, herbicide persistence in the environment, percent of active ingredients in the formulation, and the recommended rate of application converted into pounds of herbicide material per acre.

The information about herbicide production related characteristics was obtained from a variety of sources. Recommended rates of application, percent of active ingredients in the formulation, persistence and percent of weed response were obtained from herbicide labels, the North Carolina Agricultural Chemical Manual and Iowa State University Extension on-line resources. The weed response value was calculated as an average percent of weed response within broadleaf and grass weed classes for all reported weeds. Information on the product cost was obtained from the National Agricultural Statistics Service (NASS) of the USDA, the University of Florida Cooperative Extension Service, the University of Wisconsin Cooperative Extension Service, and Iowa State University Extension on-line resources.

Unfortunately, there was no single complete information source about herbicide attributes available for the analysis. Gathering data from several sources may result in potential bias since it is possible that the values reported by different sources were measured in different ways and may not be comparable with each other.

As mentioned previously, the coefficients on herbicide risk characteristics obtained by estimating the herbicide choice model are used to calculate the relative weights of the risk index categories. Since different herbicide risk attributes are not measured in the same units (see Tables 4.1, 4.2, 4.3), the magnitude of the coefficients on the herbicide risk attributes would not be directly indicative of the relative importance of different risks. At the same time, it is possible to rescale these measures of different risks to make them comparable. If an herbicide presents a high risk in certain risk category, it is assigned a value of 3 in this category, if it presents a moderate risk, it is assigned a value of 2, if it presents a low risk, it is assigned a value of 1, and if it presents no risk, it is assigned a zero value.

Table 6.1 presents summary statistics of the attributes of the herbicide choices made by the farmers. The mean percent of grass weed response to herbicides was 67 percent and of broadleaf weed response, 61 percent. The average herbicide application cost per acre was \$15.13 with the average pre-plant incorporated cost per acre of \$19.99 and pre-emergent and post-emergent broadcast cost per acre of \$13.30. On average, the herbicides were persistent in the environment for 42 days. Herbicide environmental and health risk attributes, which can vary within the range from 0 to 3, are presented in the table as well. In addition, Figure 6.2 presents histograms and cumulative density functions of the herbicide attributes included in the herbicide choice model.

Table 6.1. Summary Statistics of the Attributes of Herbicides Choices

Herbicide Characteristics	Mean (N=1,769)	Standard Deviation
Grass Weed Response (Percent)	67.16	28.52
Broadleaf Weed Response (Percent)	61.46	25.78
Herbicide Application Costs (\$ per Acre)	15.13	5.17
Recommended Application Rate (Lbs per Acre)	1.85	1.39
Persistence (Days)	42.30	18.70
Eye Toxicity (0-3)	1.72	0.72
Dermal Toxicity (0-3)	0.83	0.68
Ingestion Toxicity (0-3)	0.69	0.49
Inhalation Toxicity (0-3)	0.99	0.50
Chronic Toxicity (0-3)	1.16	0.96
Fish Toxicity (0-3)	1.76	1.04
Bird Toxicity (0-3)	0.35	0.62
Mammal Toxicity (0-3)	1.59	0.68
Groundwater Risk (0-3)	1.51	0.83
Surface Water Risk (0-3)	2.11	0.89

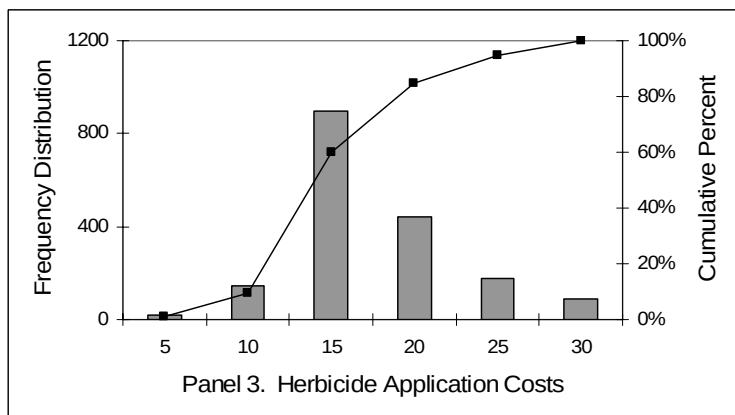
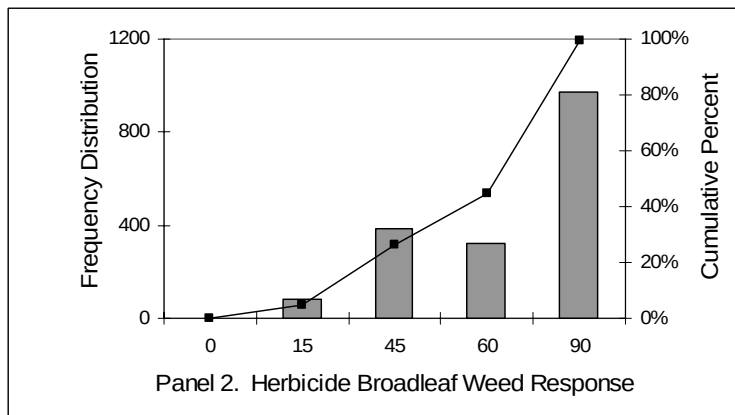
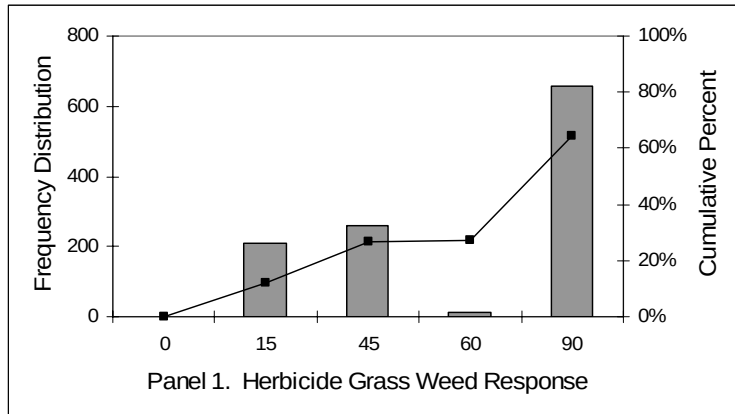


Figure 6.2. Histograms and Cumulative Density Functions of Herbicide Attributes

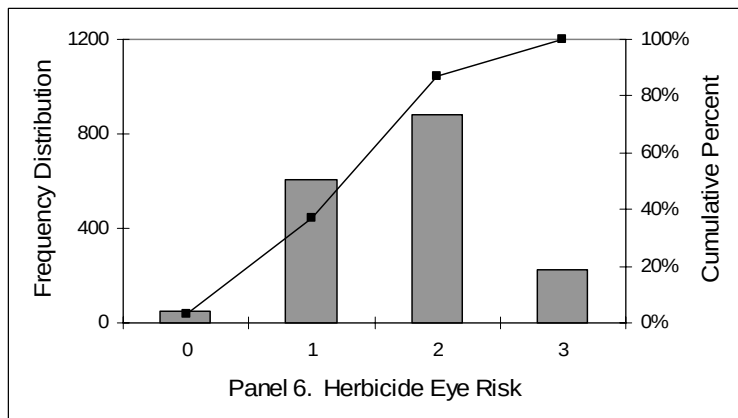
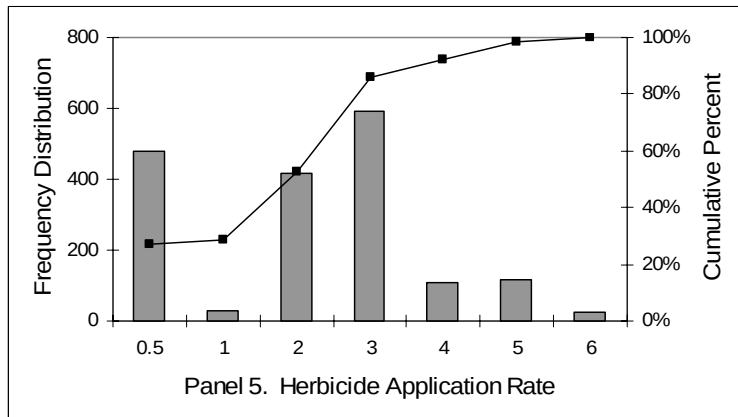
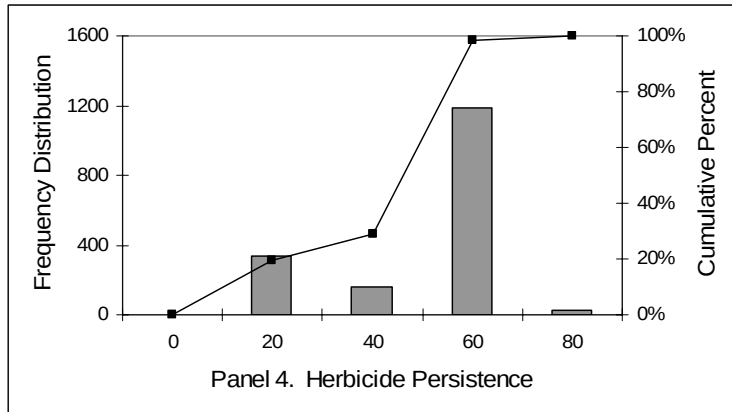


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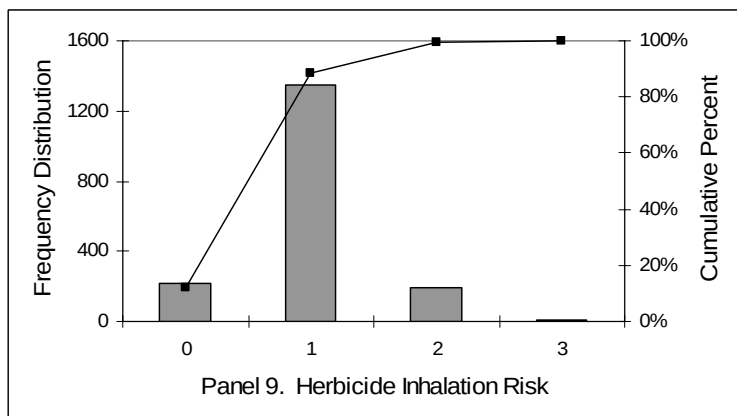
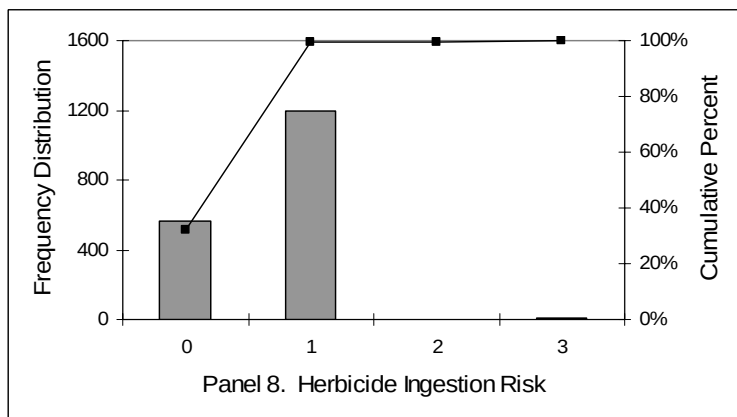
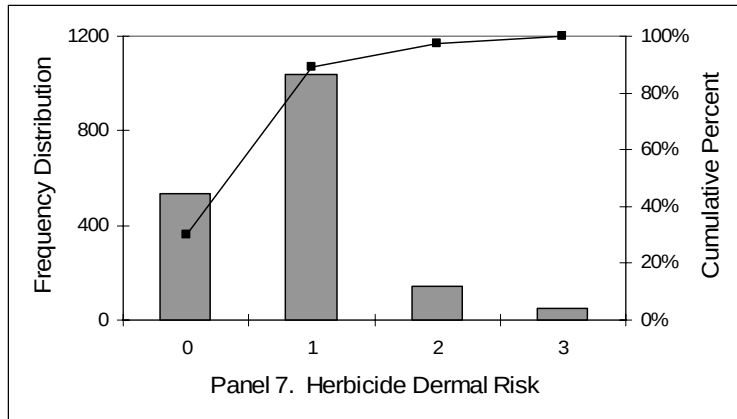


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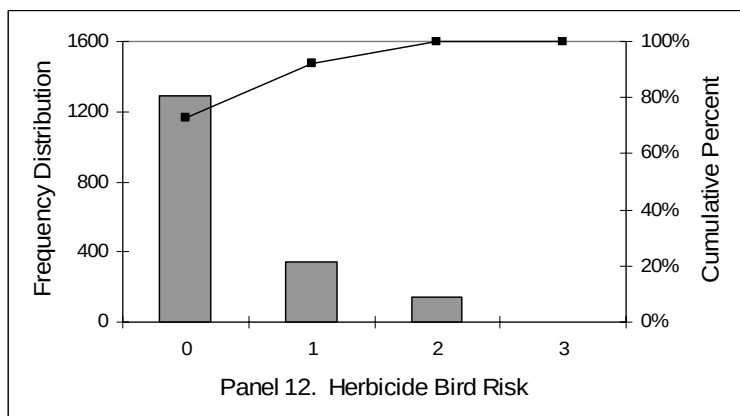
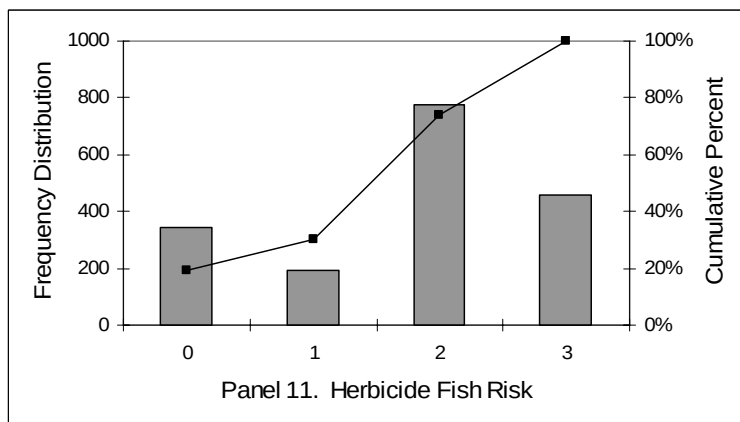
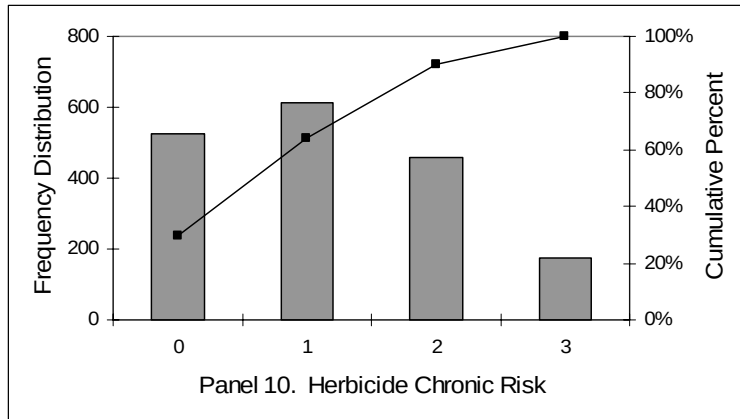


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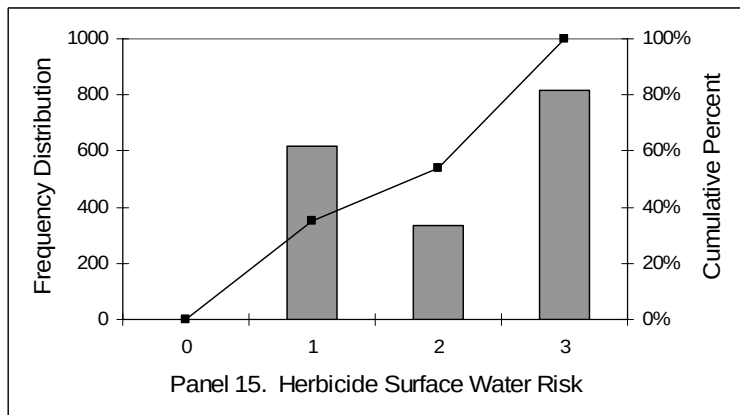
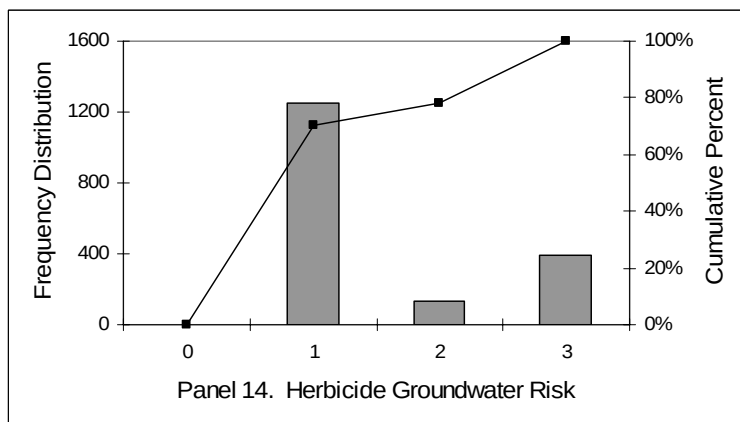
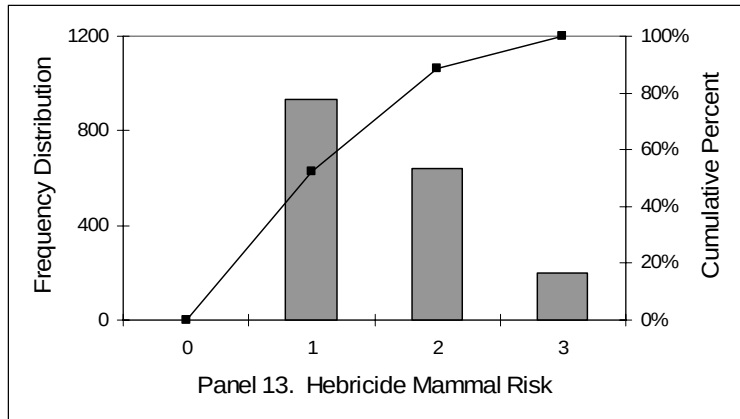


Figure 6.2. (Continued)

6.1.2. Pre-Estimation Diagnostics

Estimation of the herbicide choice model allows determining the relative importance of different herbicide characteristics for the choice. Unfortunately, some of the characteristics were highly correlated. For example, a herbicide characterized by high dermal toxicity is also likely to have high ingestion toxicity. In addition, broadleaf and grass weed responses, calculated as an average response of a variety of weeds within broadleaf and grass weed categories, are only proxies for the true measures of herbicide effectiveness. Herbicide effectiveness often varies for different weed species. In the absence of the information on problem weed species present on a particular farm, the true effectiveness measure is not available. As a result, the estimates of the choice model may also suffer from an omitted variable bias. In particular, unobservable herbicide characteristics that are correlated with observable characteristics used in the estimation may bias the coefficient estimates on the observable characteristics. For example, a highly toxic herbicide is quite likely to be highly effective. If a true effectiveness measure is not available, the coefficients of some risk variables may capture some of the effectiveness impact.

Multicollinearity may result in unstable parameter estimates, high standard errors, and implausible magnitudes or signs of the estimated parameters (Greene, 2002). Two possible ways to deal with correlated explanatory variables in discrete choice modeling are summation of the correlated variables, or elimination of one of them from the model, which may result in specification bias but is necessary for full identification of the model.

A number of econometric tools were used to reveal the collinear variables: analysis of the correlation coefficients (Table 6.2), tolerance factors of the linear regressions of the

herbicide choices on herbicide characteristics, and R^2 statistics from regressing each of the explanatory variables on the other explanatory variables.

The herbicide mammalian risk level is consistent with the EPA signal word (the mammalian risk level is high if herbicide is rated as “Danger”, moderate if herbicide is rated as “Warning”, and low if herbicide is rated as “Caution”). The signal word is in turn determined by herbicide’s highest acute risk level out of ingestion, inhalation, dermal, and eye risks. Therefore, the mammalian risk variable may be correlated with acute toxicity variables. Indeed, the tolerance factor on the mammalian risk variable was 0.03 indicating a very high degree of correlation with other variables in the model. As a result, the mammalian risk variable was eliminated from the model.

There was evidence of correlation between herbicide ingestion and inhalation toxicities. The coefficient of correlation between these two variables is 0.51. In addition, the R^2 statistics of the linear regression model of herbicide ingestion toxicity on other characteristics decreased substantially once the inhalation toxicity variable was removed from the model (R^2 statistics decreased from 0.45 to 0.24). Consequently, herbicide inhalation and ingestion toxicity variables were summed in the estimation of the model.

Table 6.2. Correlation Coefficients of the Explanatory Variables in the Herbicide Choice Model

	Grass Weed Response	Broadleaf Weed Response	Application Costs	Persistence	Application Rate	Eye Effect	Dermal Toxicity	Ingestion Toxicity	Inhalation Toxicity	Chronic Risk	Fish Toxicity	Bird Toxicity	Mammalian Toxicity	Groundwater Risk	Surface Water Risk
Grass Weed Response		-0.44	0.28	0.24	0.39	0.02	-0.09	-0.10	0.03	-0.15	0.40	-0.16	-0.06	-0.36	0.15
Broadleaf Weed Response	-0.44		-0.05	-0.03	-0.23	0.07	-0.25	0.05	0.09	0.04	-0.47	-0.05	0.30	0.09	-0.11
Application Costs	0.28	-0.05		0.07	0.23	NS	-0.14	-0.14	-0.14	-0.02	0.01	0.15	-0.01	0.11	0.13
Persistence	0.24	-0.03	0.07		0.19	-0.03	-0.53	0.02	0.02	-0.24	0.04	-0.06	-0.10	0.04	0.24
Application Rate	0.39	-0.23	0.23	0.19		0.30	0.08	-0.20	-0.30	0.02	0.31	-0.02	0.18	-0.03	0.06
Eye Effect	0.02	0.07	NS	-0.03	0.30		0.33	0.11	0.01	0.48	0.27	0.21	0.84	0.15	-0.31
Dermal Toxicity	-0.09	-0.25	-0.14	-0.53	0.08	0.33		0.20	-0.02	0.35	0.23	0.09	0.30	-0.03	-0.24
Ingestion Toxicity	-0.10	0.05	-0.14	0.02	-0.20	0.11	0.20		0.51	NS	-0.10	0.07	0.08	0.10	0.20
Inhalation Toxicity	-0.10	0.09	-0.14	0.02	-0.30	0.01	-0.02	0.51		0.15	NS	0.09	0.03	0.20	0.20
Chronic Risk	-0.15	0.04	-0.02	-0.24	0.02	0.48	0.35	NS	0.15		0.23	0.09	0.42	-0.01	-0.09
Fish Toxicity	0.40	-0.47	0.01	0.04	0.31	0.27	0.23	-0.10	NS	0.23		0.05	0.03	-0.38	-0.17
Bird Toxicity	-0.16	-0.05	0.15	-0.06	-0.02	0.21	0.09	0.07	0.09	0.09	0.05		0.02	0.38	-0.06
Mammalian Toxicity	-0.06	0.30	-0.01	-0.10	0.18	0.84	0.30	0.08	0.03	0.42	0.03	0.02		0.02	-0.45
Groundwater Risk	-0.36	0.09	0.11	0.04	-0.03	0.15	-0.03	0.10	0.20	-0.01	-0.38	0.38	0.02		0.11
Surface Water Risk	0.15	-0.11	0.13	0.24	0.06	-0.31	-0.24	0.20	0.20	-0.09	-0.17	-0.06	-0.45	0.11	

NS is indicating a correlation coefficient not significant at the 90 percent level.

In addition, estimated coefficients on herbicide fish and bird toxicities were positive (a high risk increases herbicide's chance of being chosen). This result can be explained by the bias created by unobservable herbicide efficiency correlated with herbicide toxicity characteristics. To deal with the correlation problems these two risk characteristics were eliminated from the model. As a result, the number of explanatory variables in the model was reduced to herbicide average broadleaf and grass weed responses, application costs per acre, recommended application rate, persistence, surface water and groundwater contamination potential, a sum of human ingestion and inhalation toxicities, dermal and eye effects, and chronic health risk.

6.1.3. Goodness of Fit Measure

Standard goodness of fit measures available for the linear regression models such as R^2 and an F-test of the hypothesis that all coefficients in the model are equal to zero are not applicable in the case of the conditional logit. The conditional logit model with excellent fit will produce an R^2 measure that would be substantially less than 1 (Maddala, 1983).

Following Hubbell (1995), alternative measures are used instead.

McFadden Pseudo- R^2 (McFadden, 1973) compares the estimated log-likelihood value of the complete model with the log-likelihood value of the restricted model including only choice specific intercept terms where the values of all other parameters are set equal to zero.

This statistics is calculated as follows:

$$(6.1.3) \quad McFadden's R^2 = 1 - \left(\frac{\text{Log}(L_U)}{\text{Log}(L_R)} \right),$$

where L_U = a value of the likelihood function for the complete model,

L_R = a value of the likelihood function for the restricted model.

However, choice specific constants cannot be estimated in this case because of a large number of herbicide alternatives available to farmers. Therefore, the value of the likelihood function for the restricted model is calculated assuming equal probabilities of selection for all herbicide alternatives. With n observations and M herbicide alternatives available, the restricted likelihood function is:

$$(6.1.4) \quad L_R = M^{-n}.$$

McFadden's pseudo R^2 calculated this way is not very informative about the absolute goodness of fit of a particular model, but can be used to compare the relative performance of different models.

Pearson's test compares the actual proportion of selected herbicides to the predicted proportion. As presented in Hubbell (1995), the Pearson goodness of fit measure is:

$$(6.1.5) \quad X^2 = \sum_{j=1}^M \frac{(n_j - n \bar{p}_j)^2}{n \bar{p}_j},$$

where n_j = the observed number of choices of herbicide j ,

n = a number of observations,

$\bar{p}_j$ = the average predicted probability of selecting herbicide j .

Pearson's χ^2 approximately follows a chi-square distribution with $(M-2)$ degrees of freedom. It tests the hypothesis of the equality of the observed and predicted sample proportions. As the predictive power of the model increases, this statistic will approach zero.

6.1.4. Estimation Results

The herbicide choice model was estimated using the conditional logit procedure available in the LIMDEP package. Estimation results are presented in Table 6.3. McFadden pseudo R^2 for this model was 0.13. Based on Pearson's χ^2 statistics with 44 degrees of freedom, the model did not explain farmers' choices of herbicides well.

Estimation results show that, in addition to the production related characteristics, farmers care about herbicide safety while making their herbicide choices. All characteristics considered except for the persistence and groundwater risk were significantly different from zero at the 1 percent level and had expected signs. Herbicide application costs negatively affect the choice: more expensive herbicides are less likely to be chosen. Farmers are more likely to choose herbicides characterized by higher effectiveness in eliminating broadleaf and grass weeds. Based on the absolute value of the corresponding coefficients grass weed response to the herbicide seems to matter more for the herbicide choices which can be explained by the fact that grass weeds are harder to control as than broadleaf weeds. Farmers are also more likely to choose herbicides with higher recommended application rates.

Table 6.3. Estimation Results of the Herbicide Choice Model

Herbicide Characteristics	Coefficient	Standard Deviation
Application Cost per Application	-0.11***	0.01
Broadleaf Weed Response	0.005***	0.001
Grass Weed Response	0.02***	0.001
Persistence	0.001	0.002
Application Rate	0.06***	0.02
Groundwater Risk	0.01	0.04
Surface Water Risk	-0.34***	0.03
Eye Toxicity	-0.17***	0.04
Dermal Toxicity	-0.55***	0.06
A Sum of Ingestion and Inhalation Toxicities	-0.13***	0.03
Chronic Health Risk	-0.11***	0.03
Value of Log-Likelihood Function at Convergence	-5932.30	
N	1,769	
McFadden's Pseudo R ²	0.13	
Pearson's X ²	1,755	

*** Indicating a coefficient significantly different from zero at the 99 percent confidence level.

6.1.5. Calculation of the Relative Weights of the Herbicide Risk Index

Coefficients on the herbicide risk characteristics reported in Table 6.3 were used to calculate the relative weights of the individual categories of the herbicide risk index. The relative index weights presented in Table 6.4 are calculated then as:

$$(6.1.6) \quad W_k = \frac{\hat{\beta}_k}{\sum_k \hat{\beta}_k},$$

where $\hat{\beta}_k$ = the estimated coefficient on the risk index category k .

Table 6.4. The Relative Weights of the Herbicide Risk Index

Herbicide Risk Characteristics	Relative Index Weight
Dermal Toxicity	0.38
Surface Water Contamination Potential	0.24
Eye Toxicity	0.12
Ingestion Toxicity	0.09
Inhalation Toxicity	0.09
Chronic Health Risk	0.08
Total	1.00

The relative weights of the herbicide risk characteristics presented in the Table 6.4 are used to calculate the risk indices for the individual herbicides. The indices are calculated as the sum of the herbicide risk ratings in each of the index categories adjusted by the relative weight of the category. Herbicide risk indices vary from 0 to 3 with the latter representing the highest risk possible. Appendix 6 contains the list of all herbicides and their risk indices. The mean index value is 1.56 with standard deviation of 0.36. Lasso (2.23), Cobra (2.16), Fusilade DX (2.11), and Fusion (2.11) have the highest risk indices. The safest herbicides are Glyphosate (0.65), Raptor (0.71) and Permit (0.91).

6.2. On-Farm Change in Herbicide Use Resulting from Adoption of RR Soybeans

As it was mentioned earlier in this study, there is no uniform opinion in the literature regarding the effects of the adoption of genetically engineered crops on pesticide use and resulting environmental quality. One of the objectives of this study was to develop a generalizable measure of pesticide use that can be used to evaluate these effects. Such a measure should not be based solely on the volume of pesticides applied or a number of pesticide applications as was done in few previous studies (Heimlich et al. 2000; Carpenter, 2001; Carpenter and Gianessi, 2001; Gianessi et al., 2002; Hubbell, Marra, and Carlson, 2000; Benbrook, 2003; Fernandez-Cornejo and McBride, 2002), but must also consider pesticide toxicity information (Frisvold and Marra, 2004; Heimlich et al., 2000; Levitan, 2000; OECD, 2001; Nelson and Miranowski, 1996).

Herbicide risk indices developed in this research (Appendix 6) carry the information on toxicity of individual pesticides. They can be used to calculate per acre toxicity of the herbicides applied on conventional and RR soybeans for each farmer in the data set. The difference of these two values is informative about the impact of RR soybean adoption on herbicide use and resulting environmental quality.

The number of herbicide choices made by at different stages of production and the number of applications of chosen herbicide vary across farmers. Therefore, to obtain an appropriate measure of the herbicide use per acre for each of the two soybean varieties it was necessary to add up the corresponding herbicide use values for individual herbicides farmers used at different stages of production. To make the herbicide use measure per acre accurate

it was also necessary to adjust it by the proportion of acreage of the corresponding soybean variety treated with each herbicide.

The participating farmers based their responses about herbicide use on different reference years (Table 5.5). The specifics of the survey design and resulting data set reduce the number of observations for the calculation of the on-farm change in herbicide use resulting from the adoption of RR soybeans. First of all, the process requires for the herbicide use to be reported for both RR and conventional varieties. This requirement automatically eliminates 14 observations representing full adopters and 137 observations representing non-adopters of RR soybeans in 2001 since these farmers reported their herbicide use on one variety only. In addition, for all observations for the reference years other than 2001 and 1996 the information on total RR and conventional soybean acreage was not reported in the survey. Therefore, the proportion of acreage treated with each herbicide was not available.

After these limitations were considered, I obtained two final samples that could be used to determine whether the adoption of RR soybeans resulted in reduced herbicide use.

- The first sample contained 199 observations on partial adopters in 2001 and 23 observations for 1996, a total of 222 observations for which complete required information was available.
- The second sample contained all farmers that reported their herbicide use on both varieties, a total of 459 observations: the number of all participating farmers (610 observations) less 14 observations on full adopters and 137 observations on non-adopters. For the second sample, information on the proportion of the total crop acreage treated with each herbicide was not available from the survey. Therefore, it

was assumed that herbicide treated proportion of acreage was equal to the average proportion of the first sample (0.95 for the herbicides applied - on RR soybeans, and 0.84 for the herbicides applied on conventional soybeans).

To make the analysis of the impact of RR soybean adoption on herbicide use complete, I present two alternative measures of herbicide use on RR and conventional soybeans. The first is measuring herbicide toxicity per acre based on the herbicide risk index. The second is measuring herbicide use based on the volume of herbicides applied. The results are presented in the following subsections.

6.2.1. Change in Herbicide Toxicity

The average on-farm herbicide use per acre calculated based on the risk indices of the individual herbicides was obtained separately for Roundup Ready (*RR*) and conventional (*CO*) soybeans. It was calculated by summing the risk index values, *index*, of the individual herbicides applied by a farmer multiplied by the number of applications of this herbicide, *N*, and adjusted for the proportion of the acreage treated, *a*:

$$(6.2.1) \quad T_{CO} = \sum_{i=1}^I index_{CO,i} \times N_{CO,i} \times a_{CO,i} ,$$

$$(6.2.2) \quad T_{RR} = \sum_{j=1}^J index_{RR,j} \times N_{RR,j} \times a_{RR,j} ,$$

where T_{CO} = the toxicity per acre of the herbicides used on conventional soybeans,

T_{RR} = the toxicity per acre of the herbicides used on RR soybeans,

$i : i = 1, \dots, I$ denotes a herbicide applied on conventional soybeans,

$j : j = 1, \dots, J$ denotes a herbicide applied on RR soybeans.

The change in the herbicide toxicity for each farmer is obtained by finding a difference of per acre toxicity of the herbicides used on conventional soybeans and those used on RR soybeans:

$$(6.2.3) \quad \Delta T = T_{RR} - T_{CO}.$$

Table 6.5 reports the average herbicide toxicity on RR and conventional soybeans calculated based on the individual herbicide risk indices where the first number is representing a mean and the second, the standard deviation. The table also reports the average on-farm change in the herbicide toxicity variable resulting from the adoption of RR soybeans.

Based on the results of the t-tests of the equality of the sample means, the average per acre toxicity of the herbicides used on RR soybeans and those applied on conventional soybeans and on-farm change in the average herbicide toxicity per acre did not differ for the two samples. For both samples, average toxicity of the herbicides applied on conventional soybeans was much higher than the average toxicity of the herbicides applied on RR soybeans. The average per acre difference in the herbicide toxicity was estimated to be -0.81 for the first sample, and -1.05 for the second sample. These differences are statistically different from zero at the 99 percent confidence level.

Table 6.5. Summary Statistics of the Average Herbicide Toxicity on RR and Conventional Soybeans

Average Herbicide Toxicity per Acre	Sample Representing 1996 and 2001 (N=222) ^a	Sample Representing All Years (N=459) ^a
Conventional Soybeans	2.27 (2.22)	2.45 (2.21)
RR Soybeans	1.47 (1.26)	1.40 (1.63)
On-Farm Change	-0.81*** (2.19)	-1.05*** (2.59)

*** Indicating a result statistically different from zero at the 99 percent confidence level.

^a The first number is the mean and the number in parentheses, its standard deviation.

6.2.2. Change in Herbicide Volume

One of the objectives of this work was to develop a new better measure of the changes in pesticide use. The resulting changes in the average herbicide use per acre associated with adoption of RR soybeans and calculated for the survey sample based on this new measure are presented in the previous section. But in addition to measuring the changes in herbicide use by the herbicide risk index the data set allows to estimate the changes in the average herbicide volume per acre, a method commonly used in the previous literature, and to compare the two results.

Similar to the previous case when herbicide use was measured by the herbicide risk index, the average on-farm volume of herbicides applied per acre was obtained separately for Roundup Ready (*RR*) and conventional (*CO*) soybeans. It was calculated by summing the

application volume in pounds of herbicide product, *volume*, of the individual herbicides applied by a farmer multiplied by the number of applications of this herbicide, *N*, and adjusted for the proportion of the acreage treated, *a*:

$$(6.2.4) \quad V_{CO} = \sum_{i=1}^I volume_{CO,i} \times N_{CO,i} \times a_{CO,i},$$

$$(6.2.5) \quad V_{RR} = \sum_{j=1}^J volume_{RR,j} \times N_{RR,j} \times a_{RR,j},$$

where V_{CO} = herbicide volume in pounds per acre applied on conventional soybeans,

V_{RR} = herbicide volume in pounds per acre applied on RR soybeans,

$i : i = 1, \dots, I$ denotes a herbicide applied on conventional soybeans,

$j : j = 1, \dots, J$ denotes a herbicide applied on RR soybeans.

The change in the herbicide volume applied for each farmer is obtained by finding a difference of per acre volume of the herbicides applied on conventional soybeans and those applied on RR soybeans:

$$(6.2.6) \quad \Delta V = V_{RR} - V_{CO}.$$

Table 6.6 reports the average herbicide volume applied on RR and conventional soybean varieties where the first number is representing a mean and the second, standard

deviation. The calculations were done for both total volume of herbicides applied and volume of herbicide active ingredients applied. The table also reports the average on-farm change in the herbicide volume variables.

Based on the results of the t-tests of the equality of the sample means, the average per acre volume of herbicides applied on RR soybeans did not differ for the two samples. At the same time, at the 10 percent significance level the average per acre volume of herbicide applied on conventional soybeans was lower for the sample representing 1996 and 2001 observations compared to the sample representing all years. As a result, at the 10 percent significance level on-farm difference in the average per acre volume of herbicide applied on conventional soybeans was higher for the sample representing 1996 and 2001 observations compared to the sample representing all years. The result holds for the total volume of herbicides applied and volume of herbicide active ingredients applied. For both samples and both volume measures, average volume of the herbicides applied on RR soybeans was higher than the average volume of the herbicides applied on conventional soybeans. The average differences were statistically different from zero at the 99 percent confidence level.

Table 6.6. Summary Statistics of the Average Herbicide Volume Applied on RR and Conventional Soybeans

Average Herbicide Volume (Pounds per Acre)	Sample Representing 1996 and 2001 (N=222)	Sample Representing All Years (N=459)
Total Volume:		
Conventional Soybeans	2.29 (3.60)	3.11 (8.17)
RR Soybeans	3.53 (2.80)	3.68 (7.33)
On-Farm Change	1.24*** (3.76)	0.57** (5.25)
Volume of Active Ingredients:		
Conventional Soybeans	0.86 (1.30)	1.17 (3.29)
RR Soybeans	1.44 (1.14)	1.50 (2.98)
On-Farm Change	0.59*** (2.25)	0.33*** (1.84)

*** Indicating a result statistically different from zero at the 99 percent confidence level.

** Indicating a result statistically different from zero at the 95 percent confidence level.

^a The first number is the mean and the number in parentheses, its standard deviation.

6.2.3. Discussion of the Results

The results of the analysis of the effects of RR soybean adoption on herbicide use are presented in the previous two sections. It obvious that the conclusion depends highly on the measurement units used in the analysis. Herbicide use was measured by the volume of herbicides applied, the volume of herbicide active ingredients applied, and by the toxicity

index of herbicides applied. I found an increase in the volume of herbicides applied on RR soybeans compared to conventional soybeans measured by both the total volume of herbicides and by the volume of herbicide active ingredients (Table 6.6). As measured by the total volume of herbicides applied, the farmers applied on average 1.24 pounds more herbicides on RR soybeans compared to conventional soybeans based on the sample representing 1996 and 2001 growing seasons, and 0.57 pounds more based on the sample representing all years. Also, the farmers applied on average 0.59 pounds more of herbicide active ingredients on RR soybeans compared to conventional soybeans based on the sample representing 1996 and 2001 growing season, and 0.33 pounds more based on the sample representing all years. These results are statistically significant at the 99 percent confidence level.

At the same time, when I consider the toxicity of the herbicides applied on both types of soybeans I arrive at a different conclusion. On average, the farmers experienced a reduction in herbicide toxicity resulting from adoption of RR soybeans. The average toxicity of herbicides applied on RR soybeans was 0.81 herbicide risk index units lower compared to the toxicity of herbicides applied on conventional soybeans based on the sample representing 1996 and 2001 growing season, and by 1.05 units based on the sample representing all years. These results represent about 35 (43) percent reduction in herbicide toxicity, and are statistically significant at the 99 percent level.

As mentioned previously, because of the data limitations the analysis was conducted separately for the sample containing observations only for 1996 and 2001 reference years for which the complete required information was available and the sample containing observation for all years. For the latter, some assumptions about the proportion of acreage

treated with herbicides were made. The results for the two samples show certain consistency with respect to the direction of the impact of RR soybean adoption on herbicide use. The farmers in both samples experienced an increase in the average volume of herbicides (herbicide active ingredients) applied per acre of RR soybeans and a reduction in the average toxicity of the herbicides per acre of RR soybeans measured by the herbicide risk index. At the same time, the estimates of the actual change in herbicide use vary slightly for the two samples. I believe that the results for the sample representing 1996 and 2001 reference years are superior since the calculations for this sample were based on actual values, not the approximations.

7. Farmers' Valuation of Additional Environmental and Human Safety Associated with Reduced Use of Herbicides on RR Soybeans

In the previous chapter I show that adoption of RR soybeans has resulted in reduced herbicide toxicity measured by the herbicide risk index. Therefore, certain environmental and human health benefits are expected. Farmers participating in the survey were asked whether they believe that the herbicides applied on RR soybeans are safer to humans and the environment. If they responded positively, they were asked to evaluate these environmental and health benefits of reduced herbicide use resulting from adoption of RR soybeans on per acre basis. These stated values combined with the actual measure of the change in herbicide toxicity were used to estimate farmers' valuation of improved herbicide safety.

7.1. Empirical Valuation Model

It was assumed that the representative farmer's true but unobservable valuation of the improvements in herbicide safety varies systematically with the vector of farmer attributes and the degree of the change in herbicide safety:

$$(7.1.1) \quad Q = \mathbf{z}'\boldsymbol{\alpha} + \beta \Delta T,$$

where Q = the stated value of additional human and environmental safety associated with reduced use of herbicides on RR soybeans,

$\mathbf{z}$ = a vector of attributes that affect the valuation,

ΔT = a change in herbicide safety resulting from adoption of RR soybeans
measured by the herbicide risk index.

Coefficient estimates provide the predicted values of health and environmental benefits to the farmers associated with improved safety of the herbicides used on RR soybeans.

7.2. The Determinants of the Valuation Function

The value of improved herbicide safety on RR soybeans reported by the farmer may be affected by his perception of herbicide toxicity, personal exposure level to herbicides, exposure of his family and workers, and the notion of altruism. Therefore, certain farm and/or farmer attributes associated with these factors may affect the valuation.

Intuitively, one would expect a positive relationship between income and values if the good being valued is “normal.” Carson, Flores, and Meade (2001) criticize the claim that most environmental goods are “luxury” goods which would imply that their income elasticity is greater than one. They claim that the usual empirical result for environmental commodities is a positive income elasticity of the values but substantially less than one. The problem is based on the fact that the terms “normal” and “luxury” are defined in terms of the income elasticity of demand, a measure based on varying quantity, but not in terms of the income elasticity of the valuation, a measure based upon holding the quantity fixed (how stated values for a fixed quantity of the good change as income changes). Flores and Carson (1997) show that a good which is a “luxury” good in a demand sense may have an income

elasticity of the valuation which is less than zero, between zero and one, or greater than one, and it is likely that the income elasticity of the valuation is less than the corresponding income elasticity of demand.

Respondent's experience, familiarity with the problem, and information set usually influence the marginal values. Cameron and Englin (1997) assess the influence of experience by explicitly modeling the relationship between respondent experience and both fitted individual resource values and the conditional variance of the estimated values. The authors find a discrete positive jump in response values as experience increases from zero, and, further, that more experienced respondents have smaller conditional variances. Paradiso and Trisorio (2001) investigate the effect of different settings of knowledge (direct and indirect) of the good on the respondents' valuation behavior. They find that direct knowledge of the good reduces the observed disparity between hypothetical and real values, and that different settings of knowledge generate different perceptions of the characteristics of the good. Based on the survey data used in this analysis, a farmer's years of being the principal operator of the farm is the most straightforward way to characterize his experience.

In the environmental economics literature it is often argued that the higher the level of education attained, the greater the stated values for non-market environmental goods. A possible interpretation of this is that the higher level of education enhances peoples' awareness of the potential risks (immediate and/or delayed) associated with the deterioration of the quality of environmental goods. Therefore, education defined as the last year of formal schooling is one of the characteristics that can affect farmers' valuations of health and environmental benefits. Nielsen et al. (2003) explored the effect of socio-demographic factors on the perceptions of risk, and found a positive relationship between education level

and valuation of reduced groundwater pollution which diminishes the future health risks related to drinking water. Jo (2001) found a somewhat different result. In this study, high school education increased the value of the proposed environmental program of preventing future oil spills in Alaska waters, whereas college education reduced it. The author's explanation of this phenomenon is that the college-educated tend to favor less government spending in almost all areas of public goods.

Kothen and Reiling (2000) state that 25 percent of the valuation responses related to wildlife and ecosystems are motivated by ethical beliefs. There is evidence that ethical beliefs about the environment are correlated with environmental attitudes (Spash, 1997). Therefore, analyzing the environmental attitudes may be useful for explaining the responses in the valuation studies on environmental quality. The literature supports the fact that respondents with stronger pro-environmental attitudes are likely to give higher values for environmental resources. The review of the relevant studies can be found in Kotchen and Reiling (2000), who also explore the relationship among environmental attitudes, nonuse values for endangered species, and underlying motivations for valuation responses. They find that pro-environmental attitudes result in higher value estimates.

It is difficult to find an appropriate measure of environmental attitudes. The most commonly used approach is to ask the respondents about their attitude toward a certain statement. For example, an individual who strongly agrees with the statement that "humans are severely abusing the environment" is expected to be more likely to support conservation efforts than an individual who strongly disagrees with the statement, assuming that other characteristics are identical (Kotchen and Reiling, 2000). I follow a different approach to measure farmers' pro-environmental attitudes. Conventional tillage systems cause soil

erosion resulting in reduced topsoil depth and water holding capacity of the soil.

Conservation tillage is one of the management practices that reduce soil erosion (Ditsch, Trimble, and Wade, 1988). At the same time, it requires comparatively higher management and herbicide costs (Carter, 1994). It was assumed here that a farmer practicing conservational tillage and considering it as beneficial to the environment will give a higher value of the environmental benefits.

Sensitivity to scope is another attribute that might affect the valuation of the environmental and health benefits. For a risk-averse decision maker the larger the initial risk, the larger should be the value of the marginal risk reduction. Diminishing marginal utility explains this, too. The implication of this relates to the reliability of the valuation studies to measure existence values. The empirical evidence is contradictory but Carson (1997) reviewed over 30 tests in which valuation estimates are sensitive to scope and concluded that stated valuation can produce reliable estimates in well constructed studies. The variation in the changes in herbicide safety measured by the risk index for different farmers allows us to investigate whether the stated values are sensitive to scope. It is expected that farmers who experienced greater reduction in herbicide safety on RR soybeans, *ceteris paribus*, would give the higher value to the benefits.

A number of studies explored the relationship between pesticide exposure and human health. A list of relevant studies can be found in Kafle (no date). Some studies argue that the degree of health risk varies considerably with the intensity and duration of exposure to pesticides (Antle and Pingali (1994); Lichtenberg (1989); Lichtenberg, Spear, and Zilberman (1988); Lichtenberg and Zilberman (1988); and the proceedings of a workshop on *The Effects of Pesticides on Human Health* (1990)). Therefore, the potential risks to a pesticide

applicator, farmer, or farm worker occupationally exposed to pesticides are likely to be greater than the risks to someone in the general population exposed only to traces of pesticides in food and water, *ceteris paribus*. Therefore, herbicide exposure channels and levels for the farmer, his family and workers may impact the values placed on health benefits. There were no data on farmer's exposure to herbicides available in the data set. It was suggested that the percent of time the farmer spent in crop production would serve as a proxy for the level of the exposure to herbicides. A farmer that spends more time in crop production is more likely to be involved in every day operations including herbicide handling and application, or at least more likely to be present when these operations take place. He is more likely to be concerned with the adverse health effects of herbicides and, therefore, will give a higher value.

7.3. Estimation Procedure

As mentioned earlier, the farmers were asked if they consider herbicides used on RR soybeans safer to them and their workers to handle than herbicides used on conventional soybeans. If they responded positively, they were asked to place a value per acre on this additional safety based on their herbicide usage in 2001. In the case of a negative response, additional human safety was assigned zero value. In a similar fashion, participating farmers were asked whether they consider herbicides used on RR soybeans safer to the environment than herbicides used on conventional soybeans. In the case of a positive response, they were asked to place a value per acre on this additional environmental safety. Otherwise, additional

environmental safety was assigned zero value. In addition, the farmers were asked to give their valuation of combined environmental and human safety benefits of RR soybeans.

The valuation studies based on stated preference information are often criticized for the hypothetical nature of the valuation questions where respondents are not dealing with an ordinary market commodity. Survey question scenarios similar to the one described in the previous paragraph often suffer from “part-whole bias” when the sum of the values of each of the parts of the good valued is greater than the value of the whole. In this study, the sum of stated additional environmental and human safety provided separately can be greater than the stated combined value. This phenomenon is attributed to the substitution possibilities between the parts and diminishing marginal utility. A complete discussion of these issues is presented in Marra and Piggott (2005). The authors argue that the category of survey respondents (i) for whom $0 < V_i < 1$, where V_i is the ratio of the stated whole to the sum of its parts, is dominant and the only one that conforms to the predictions of utility theory. For this category misrepresentations or other distortions are not expected to be present and, therefore, it should be viewed as the category that is most representative of the underlying value, to which all other categories are compared.

Table 7.1 presents the number of respondents in each V_i ratio category for the sample of responses representing 1996 and 2001 soybean growing seasons and for the sample representing all years. It was assumed that responses for which $0 < V_i < 1$ are most representative of the underlying value. Therefore, they are used separately in the estimation of the farmers’ valuation function of additional environmental and human safety of herbicides used on RR soybeans. There were 34 such responses for the sample representing 1996 and 2001 growing seasons, and 71 for the sample representing all years. Those farmers

who said they believe that there were no additional environmental and human safety benefits associated with reduced use of pesticides on RR soybeans and assigned zero value to the benefits were not included in these samples because these farmers may have given “protest zeros” which would result in a “strategic bias” in the final estimates.

Table 7.1. Number of Responses by the Ratio of the Total Value to the Sum of its Parts

Category of Respondents	Number of Observations	
	Sample Representing 1996 and 2001	Sample Representing All Years
$V_i = 0$	16	24
$0 < V_i < 1$	34	71
$V_i = 1$	8	21
$V_i > 1$	7	18
Missing Values Present	157	325
All Responses	222	459

Section 7.2 lists a number of possible farmer attributes that may affect the valuation of additional herbicide safety. The data set contained a significant number of missing values of the total household income. Since this characteristic was correlated with the total farm acreage in 2002 ($p=0.5$), farm acreage was used as a proxy for income to avoid the loss of degrees of freedom in estimation.

For a comparison, the valuation function was estimated separately for four samples:

- sample containing all responses for 1996 and 2001 growing seasons (sample I),
- sample containing responses for 1995 and 2001 growing seasons in $0 < V_i < 1$ category only (sample II),
- sample containing all responses for all years (sample III),
- sample containing responses for all years in $0 < V_i < 1$ category only (sample IV).

Table 7.2 presents the summary statistics of the explanatory variables with the first number representing the mean and the second, the standard deviation. The mean stated values of improved herbicide safety in Table 7.2 represent the combined values of additional environmental and human safety mentioned by farmers. These values are much higher for the samples including only responses in $0 < V_i < 1$ category (samples II and IV) because these samples did not include any responses assigning zero values to the benefits for the reasons explained earlier. The average stated value of improved herbicide safety was estimated to be \$4.89 for sample I, \$13.48 for sample II, \$5.61 for sample III, and \$13.47 for sample IV. Estimates of the average on-farm reduction in herbicide toxicity measured by the herbicide risk index ranged from 0.32 index units for sample II to 1.05 index units for sample III. The average farm had over 1,000 acres in 2002. The average farmer had about 33 years of experience, completed more than 13 years of formal education, and spent about 70 percent of total work time in crop production. About 80 percent of the farmers considered conservational tillage systems beneficial to the environment with the lowest of 77 percent for sample I and the highest of 89 percent for sample IV. Based on the results of the t-tests of the equality of sample means, I failed to reject the equality of sample means for all variables except for stated values of improved safety for samples I and II, stated values of improved safety and the proportion of farmers considering conservational tillage beneficial for samples

I and IV, stated values of improved safety and on-farm reduction in herbicide toxicity for samples II and III, and stated values of improved safety and proportion of farmers considering conservation tillage beneficial for samples III and IV.

Table 7.2. Summary Statistics of the Explanatory Variables in the Valuation Model

Variable	Sample I Representing 1996 and 2001 (N=222) ^a	Sample II Representing 1996 and 2001 Where $0 < V_i < 1$ (N=34) ^a	Sample III Representing All Years (N=459) ^a	Sample IV Representing All Years Where $0 < V_i < 1$ (N=71) ^a
Stated Value of Improved Safety	4.89 (8.49)	13.48 (10.98)	5.61 (8.60)	13.47 (10.05)
On-Farm Reduction in Herbicide Toxicity	0.81 (2.19)	0.32 (2.43)	1.05 (2.59)	1.02 (2.30)
Farm Acres in 2002	1,183.9 (944.6)	1,002.0 (733.5)	1,193.0 (1,016.7)	1,141.0 (784.2)
Number of Years as Principal Operator	32.6 (10.9)	32.9 (9.5)	33.7 (11.6)	32.2 (10.7)
Farmer's Years of Education	13.8 (2.2)	13.6 (1.9)	13.5 (2.1)	13.4 (2.0)
Considers Conservation Tillage as Beneficial	0.77 (0.42)	0.85 (0.36)	0.78 (0.41)	0.89 (0.32)
Proportion of Work Time in Crop Production	0.69 (0.29)	0.68 (0.30)	0.70 (0.29)	0.75 (0.27)

^a The first number the mean and the number in parentheses, its standard deviation.

Estimation using the OLS procedure was conducted for sample containing responses for 1995 and 2001 growing seasons in $0 < V_i < 1$ category (sample II) and sample containing

responses for all years in $0 < V_i < 1$ category. At the same time, samples I and III were characterized by a high degree of censoring of the stated values of improved herbicide safety: a considerable number of valuation responses were equal to zero. Since it is necessary to account for these observations when estimating the relationship of a censored variable to other variables, the tobit model (Tobin, 1958) was used for estimation for these samples. The tobit model not only captures the effect of the explanatory variables on the dependent variable, but also the effect on the probability of non-zero response.

In the general formulation by Greene (2002), the tobit model is presented as:

$$(7.3.1) \quad y_i^* = \beta' \mathbf{x}_i + \varepsilon_i,$$

where ε_i is a normally distributed error term with zero mean and standard deviation σ . The dependent variable is censored for all non-positive values, and only the censored random variable y_i is observed, such that:

$$(7.3.2) \quad \begin{aligned} y_i &= 0 & \text{if } y_i^* \leq 0 \\ y_i &= y_i^* & \text{if } y_i^* > 0 \end{aligned}$$

In this model, predicted values of the observed variable y_i given censoring can be computed as:

$$(7.3.3) \quad E[y_i | \mathbf{x}_i] = \Phi\left(\frac{\beta' \mathbf{x}_i}{\sigma}\right) \left(\beta' \mathbf{x}_i + \sigma \frac{\phi(\beta' \mathbf{x}_i / \sigma)}{\Phi(\beta' \mathbf{x}_i / \sigma)} \right),$$

where $\phi(\cdot)$ is the pdf and $\Phi(\cdot)$ is the cdf of normal distribution. Then, the marginal effects in this model given censoring are:

$$(7.3.4) \quad \frac{\partial E[y_i | \mathbf{x}_i]}{\partial \mathbf{x}_i} = \beta \Phi\left(\frac{\beta' \mathbf{x}_i}{\sigma}\right).$$

There is no uniform opinion in the literature concerning the best measure of the goodness of fit for the tobit models. Veall and Zimmerman (1994) review a number of potential measures, and propose to use a measure due to McKelvey and Zainova, which was most closely related to the underlying, continuous data OLS- R^2 :

$$(7.3.5) \quad MZ R^2 = \frac{\sum_{i=1}^n (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^n (\hat{y}_i - \bar{y})^2 + n\sigma^2},$$

where $\hat{y}_i$ is predicted value, and $\bar{y}$ is the mean. The term in the numerator is a measure of explained variation while the term in the denominator is the sum of explained and unexplained variation.

7.4. Estimation Results of the Valuation Function

Estimation of the model was conducted in the SAS software package. The OLS results for the sample containing responses for 1995 and 2001 growing seasons in $0 < V_i < 1$ category (sample II) and the sample containing responses for all years in $0 < V_i < 1$ category are presented in Table 7.3. According to the goodness-of-fit measures the model does not explain farmer's stated values well. But the results indicate that there is a statistically significant relationship at the 90 percent confidence level between stated values of environmental and human health benefits resulting from improved safety of herbicides applied on RR soybeans and the actual changes in herbicide safety experienced by the farmers and measured by the herbicide risk index for both samples. In addition, farm acres in

2002 used as a proxy for income level had explanatory power for the stated values in sample IV.

Table 7.3. The OLS Estimation Results of the Valuation Function for the Samples Containing Responses in $0 < V_i < 1$ Category

Explanatory Variable	Sample II Representing 1996 and 2001 Where $0 < V_i < 1$ (N=34) ^a	Sample IV Representing All Years Where $0 < V_i < 1$ (N=71) ^a
Constant	23.61 (23.11)	20.36* (11.75)
On-Farm Reduction in Herbicide Toxicity	1.85** (0.84)	1.12** (0.56)
Farm Acres in 2002	-0.004 (0.003)	-0.004** (0.002)
Farmer's Years of Being Principal Operator	-0.18 (0.25)	-0.04 (0.12)
Farmer's Years of Formal Education	-0.34 (1.29)	-0.32 (0.69)
Considers Conservation Tillage as Beneficial	3.37 (5.60)	-0.63 (3.85)
Percent of Work Time in Crop Production	2.25 (8.07)	3.41 (4.83)
R-Square	0.26	0.12
R-Square Adjusted	0.10	0.04

^a The first number is the estimated coefficient and the number in parentheses, its standard deviation.

*** Indicating a coefficient statistically significant at the 99 percent level.

** Indicating a coefficient statistically significant at the 95 percent level.

* Indicating a coefficient statistically significant at the 90 percent level.

As mentioned in the previous section, special estimation technique was required for the remaining two samples containing responses in all V_i categories (samples I and III) because of sample censoring. The tobit model was estimated for these samples, and estimation results are presented in Table 7.4. Based on the MZ R^2 measure, the model explains 18 percent of the variation in sample III.

I failed to establish any significant relationships between on-farm change in herbicide safety and farmers' valuation of this change for the sample representing responses in 1996 and 2001 (sample I). On the other hand, the larger sample representing all years (sample III) showed a statistically significant relationship at the 85 percent level between stated values and actual changes in herbicide safety experienced by the farmers. In addition, farmers' attitudes towards conservation tillage, a measure of environmental attitudes, also had explanatory power for the stated values in both samples. The corresponding coefficients have the expected signs. The results also show that the higher level of education has negative effect on values in sample III, as well as farm acres in 2002 used as a proxy for income level. Inclusion of the squared term of farm acreage in the model did not affect the coefficient on farm acreage and general fit of the model.

Table 7.4. The Tobit Estimation Results of the Valuation Function for the Samples Containing Responses in All V_i Categories

Explanatory Variable	Sample I Representing 1996 and 2001 (N=222) ^a	Sample III Representing All Years (N=459) ^a
Constant	-4.80 (10.52)	2.85 (6.78)
On-Farm Reduction in Herbicide Toxicity	-0.40 (0.53)	0.51 ^b (0.33)
Farm Acres in 2002	-0.001 (0.001)	-0.001* (0.001)
Farmer's Years of Being Principal Operator	0.12 (0.12)	-0.02 (0.07)
Farmer's Years of Formal Education	-0.27 (0.59)	-0.87** (0.40)
Considers Conservation Tillage as Beneficial	12.09*** (3.05)	11.82*** (2.12)
Percent of Work Time in Crop Production	-6.61 (4.13)	1.76 (2.75)
Value of Log-Likelihood Function	-398.71	-836.40
McFadden's Pseudo- R^2	0.03	0.03
MZ R^2	0.04	0.18
Number of Valid Observations	181	361
Number of Non-Censored Values	85	182

^a The first number is the estimated coefficient and the number in parentheses, its standard deviation.

^b The coefficient was statistically significant at the 85 percent level.

*** Indicating a coefficient statistically significant at the 99 percent level.

** Indicating a coefficient statistically significant at the 95 percent level.

* Indicating a coefficient statistically significant at the 90 percent level.

To obtain the marginal effects of the explanatory variables the coefficients in the Table 7.4 have to be adjusted for the probability that the observation will fall in the uncensored part of the distribution (Equation 7.3.4). The adjustment is a function of the explanatory variables, and therefore would be different for each observation. It is customary in the literature to report the marginal effects calculated for the mean values of the explanatory variables, or to present a distribution of marginal values. The marginal effects of the change in herbicide safety on stated values calculated based on the mean values of explanatory variables are reported in Table 7.5.

The valuation results for four samples are summarized in Table 7.5. The table contains the mean on-farm reduction in average herbicide toxicity per acre measured by the herbicide risk index and mean stated value of improved herbicide safety per acre. The marginal effects of the change in herbicide safety are reported as well. The marginal effects for samples II and IV are equivalent to the OLS coefficients, while the marginal effects for samples I and III are transformations of the tobit coefficients.

The value of reduced herbicide toxicity per acre for each sample was calculated as a product of the marginal value of the change in herbicide safety and mean reduction in the average herbicide toxicity per acre experienced by the farmers in the corresponding sample. For example, the average farmer in sample IV was willing to pay \$1.12 per acre for a one-unit improvement in herbicide safety as measured by the herbicide risk index. This result indicates that given the average per acre reduction in herbicide toxicity experienced by the farmers in the sample (1.02 index units), RR soybeans were valued more by the farmers by \$1.15 per acre than conventional soybeans, just in terms of additional herbicide environmental and human safety. Farmers' valuations of the actual reduction in herbicide

safety per acre were estimated to be \$0.59 for sample II, \$0.27 for sample III, and \$1.15 for sample IV. The coefficient on the change in herbicide safety was not statistically significant for sample I. Therefore, the marginal effect was not calculated.

The elasticity of SMVs with respect to the change in herbicide safety was estimated based on sample means and ranged from 0.04 for sample II to 0.08 for sample IV. Such elasticity values indicate that the farmers' stated marginal values of improved herbicide safety are relatively inelastic.

The results presented in Table 7.5 show some variation in the values of reduced herbicide toxicity per acre. First of all, elimination of responses assigning zero value to additional herbicide safety in the samples including responses in $0 < V_i < 1$ category only (samples II and IV) has resulted in larger values of the coefficient estimates on the on-farm change in herbicide toxicity in the valuation model. As a result, the values of reduced herbicide toxicity per acre are also higher for these samples. This example illustrates how inclusion of biased valuation responses may affect the estimation results in stated preference models.

There is still a divergence between estimated values of reduced herbicide toxicity per acre for samples II and IV containing the responses most representative of the underlying value. The value of reduced herbicide toxicity per acre was estimated to be \$0.59 for sample II and \$1.15 for sample IV. It was previously suggested in Section 6.3.3 that the results for sample II are superior since they rely on complete information, while some assumptions were made to fill out data gaps in sample IV. However, the number of observations used to estimate the value of reduced herbicide toxicity per acre for sample II was lower at this stage of analysis due to missing values (only 34 observations). In addition, I failed to reject the

hypothesis that the mean on-farm reduction in average herbicide toxicity is zero for this sample. I believe that the value of reduced herbicide toxicity per acre estimated for sample IV is superior than for sample II because it relies on a larger number of observations (71).

Table 7.5. Comparison of the Valuation Results for Different Samples

Result	Sample I Representing 1996 and 2001 (N=222) ^a	Sample II Representing 1996 and 2001 Where $0 < V_i < 1$ (N=34) ^a	Sample III Representing All Years (N=459) ^a	Sample IV Representing All Years Where $0 < V_i < 1$ (N=71) ^a
On-Farm Reduction in the Average Herbicide Toxicity ^{b,c}	0.81*** (2.19)	0.32 (2.43)	1.05*** (2.59)	1.02*** (2.30)
	\$/Acre/Year			
Stated Value of Improved Safety ^c	4.89*** (8.49)	13.48*** (10.98)	5.61*** (8.60)	13.47*** (10.05)
Marginal Effect of the Change in Safety on Stated Values ^c	NS	1.85** (0.84)	0.26 ^d	1.12** (0.56)
Value of Reduced Herbicide Toxicity per Acre		0.59	0.27	1.15
Elasticity of SMV with Respect to Change in Toxicity		0.04	0.05	0.08

^a The first number is the mean and the number in parentheses, its standard deviation.

^b The value represents on-farm average per acre changes, where the difference is taken as RR-conventional.

^c Values represent sample means.

^d The value is statistically different from zero at the 85 percent confidence level.

^e The marginal effects for Samples II and IV are equivalent to the OLS coefficients. The marginal effects for Samples I and III are transformations of the tobit coefficients.

*** Indicating a value statistically different from zero at the 99 percent confidence level.

** Indicating a value statistically different from zero at the 95 percent confidence level.

* Indicating a value statistically different from zero at the 90 percent confidence level.

NS Indicating a value not statistically significant at the 90 percent level.

8. Conclusions

This study develops a methodology intended to analyze the environmental and human health impacts of pesticides, which could contribute to the development of a comparable measure of pesticide risks. Its primary application is in the area of evaluation of the environmental impacts of alternative pest management strategies, individual pesticides, and seed biotechnologies in regulatory decisions. Without this input, such evaluations could suffer from serious biases and result in erroneous conclusions.

The specific application was to the changes in herbicide use associated with the adoption of Roundup Ready soybeans. The information on actual herbicide choices made by the soybean farmers combined with the information about different production-related and safety attributes of the herbicides was used to establish which herbicide attributes matter most to the farmers in their choice decisions. In particular, information on the farmers' preferences for herbicide environmental and human safety attributes was used to calculate the relative weights of the herbicide risk index incorporating all the relevant herbicide safety information.

The improvement on the previous attempts to develop pesticide environmental and human health safety rankings was made by creating a pesticide risk index, a single, simple measure of risk that combines complex information about environmental and human health effects of pesticides. The use of revealed preference information to estimate the relative weights of the index categories resulted in the relative index weights based on a cardinal scale, and characterized by greater potential reliability compared to the previous measures.

The risk indices of the individual herbicides developed in this study were used to calculate the average toxicity of herbicides used on conventional and Roundup Ready soybeans, and the corresponding change in herbicide toxicity for two samples of soybean farmers. The first sample included responses about 1996 and 2001 growing seasons for which the complete information required for the calculations of the changes in herbicide toxicity was available. The second sample included responses for all years when RR soybeans were grown. For this sample certain assumptions were made about the proportion of acres treated with herbicides.

The results for the sample representing all years show that the average herbicide toxicity on conventional soybeans was estimated to be 2.45 index units, while the average herbicide toxicity on RR soybeans was 1.40 index units. On average, the farmers experienced a reduction in herbicide toxicity of 1.05 index units (43 percent) while switching to RR soybeans.

Similarly, the farmers in the sample representing 1996 and 2001 growing seasons experienced reduction in the average per acre herbicide toxicity on RR soybeans compared to conventional soybeans. The average herbicide toxicity for this sample was estimated to be 1.47 risk index units on RR soybeans and 2.37 risk index units on conventional soybeans. The average reduction in herbicide toxicity resulting from adoption of RR soybeans was estimated to be 0.81 index units (35 percent).

The study contributes to the literature on the environmental and human impacts of GE crops adoption. Previously, there was no uniform opinion formed in the literature concerning these impacts. The studies relying on the measurements of environmental impacts of pesticides used on GE and conventional crops based on the volume of pesticides and/or the

volume of pesticide active ingredients applied arrived at contradicting conclusions. I believe that the measurement methods used in these studies are inadequate since they ignore the information on pesticide toxicity which is crucial for determining the environmental and health impacts of pesticides. Therefore, I propose the herbicide risk index developed in this study as an alternative, improved measure of pesticide use.

In addition, to measuring the change in herbicide use on RR soybeans by the risk index, I estimated the average change in herbicide use by the volume-based measures. The results show that, on average, the farmers in both samples experienced an increase in the volume of pesticides (pesticide active ingredients) applied per acre of RR soybeans compared to conventional soybeans. For the sample containing farmers responses for all years, the average herbicide volume applied on conventional soybeans was 3.11 (1.17) pounds per acre, while the average volume applied on RR soybeans was 3.68 (1.50) pounds per acre. The difference was statistically significant and constituted 0.57 (0.33) pounds per acre. For the sample representing responses for 1996 and 2001 growing seasons, the average herbicide volume applied on conventional soybeans was 2.29 (0.86) pounds per acre, while the average herbicide volume applied on RR soybeans was 3.53 (1.44) pounds per acre. The difference was statistically significant and constituted 1.24 (0.59) pounds per acre, indicating an increase in the volume of herbicides applied on RR soybeans compared to conventional soybeans.

These results show that the conclusions about the impact of GE crop adoption on pesticide use and therefore environmental quality are highly dependent on the methods used to measure pesticide use. Since the reason for measuring differences in pesticide use in the first place is as an indicator of environmental impact changes, I believe that the measure of

pesticide use difference based on pesticide toxicity is superior to the measures based on volume alone.

The stated preference valuation technique was used to estimate farmers' valuation of additional herbicide safety. The results for the sample representing all years (Sample IV) indicate that, to the average farmer, the value of a one-unit improvement in herbicide safety measured by the herbicide risk index was \$1.12 per acre. Given the average per acre reduction in herbicide toxicity experienced by the farmers in the sample (1.02 index units), RR soybeans were valued more by the farmers by \$1.15 per acre than conventional soybeans just in terms of additional herbicide environmental and human safety resulting from reduced herbicide use. For the average farm in the sample (1,141 acres), the value of additional herbicide safety would be equal to \$1,312 per year in the case of full adoption of RR soybeans.

Similarly for the sample representing responses for 1996 and 2001 growing seasons (Sample II), the value of a one-unit improvement in herbicide safety measured by the herbicide risk index was estimated to be \$1.85 per acre. Given the average per acre reduction in herbicide toxicity experienced by the farmers in this sample (0.32 index units), RR soybeans were valued more by \$0.59 per acre than conventional soybeans in terms of additional herbicide safety.

The value of additional herbicide environmental and human safety is also great if considered on the scale of the entire country. The U.S. farmers planted 74 million soybean acres in 2001, out of which 53 million acres were planted to GE varieties (NASS, 2004). Assuming that these acres were planted to RR varieties, the additional value to the farmers of additional herbicide safety on soybeans would be close to \$60 million based on the results for

the sample including all reference years. Further, this value incorporates only the benefits specific to the farmers. If the entire society is considered, including all people adversely affected by the negative herbicide externality, the estimate of the positive impact of RR soybean adoption on social welfare would be even greater. Finally, the elasticity of the farmers' stated marginal values with respect to the change in herbicide toxicity was estimated to be 0.08 for this sample indicating that the farmers' valuation of the improvements in herbicide safety is relatively inelastic at the data means.

Further work in this area would include testing the proposed methodology on a different data set containing more accurate measures of herbicide effectiveness and exposure to pesticides. Estimation of the herbicide choice model with such a data set may affect the coefficients on the herbicide attributes improving their accuracy. In addition, since the results imply a positive welfare effect associated with improved safety of herbicides applied on RR soybeans, the above method can be used further to explain adoption of these varieties.

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Appendix 1. List of Herbicides Mentioned by Farmers

Herbicide Name Mentioned by Farmers	Herbicide Brand Name	Herbicide Generic Name
2,4-d	2,4-D 6 Amine	<i>dymethylamine</i>
2,4-DB	2,4-D 6 Amine	<i>dymethylamine</i>
Assure/Assure II	Assure II	<i>quizalofor p-ethyl</i>
Authority	Authority	<i>sulfentrazone</i>
Authority Broadleaf	Canopy XL	<i>sulfentrazone+chlorimuron ethyl</i>
Axiom	Axiom DF	<i>flufenacet+metribuzin</i>
Backdraft	Backdraft	<i>imazaquin+glyphosate</i>
Basagran	Basagram T/O	<i>bentazon</i>
Blazer	Ultra Blazer	<i>acifluorfen</i>
Boundary	Boundary 6.5 EC	<i>metolachlor+metribuzin</i>
Broadstrike+Dual	Broadstrike+Dual	<i>flumetsulam+metolachlor</i>
Broadstrike+Treflan	Broadstrike+Treflan	<i>flumetsulam+trifluralin</i>
Canopy	Canopy	<i>metribuzin+chlorimuron ethyl</i>
Canopy XL	Canopy XL	<i>sulfentrazone+chlorimuron ethyl</i>
Classic	Classic	<i>chlorimuron ethyl</i>
Clearout	Glyphosate	<i>glyphosate</i>
Cobra	Cobra	<i>lactofen</i>
Command	Command 4EC	<i>clomazone</i>
Concert	Classic	<i>chlorimuron ethyl</i>
Conclude Extra	Conclude Xtra G	<i>clethodim</i>
Domain	Axiom DF	<i>flufenacet+metribuzin</i>
Dual	Dual II Magnum	<i>metolachlor</i>
Dual II	Dual II Magnum	<i>metolachlor</i>
Dual II Magnum	Dual II Magnum	<i>metolachlor</i>
Extreme	Extreme	<i>imazethapyr+glyphosate</i>
FirstRate	FirstRate	<i>cloransulam-methyl</i>
Flexstar	Reflex	<i>fomesafen</i>
Freedom	Lasso	<i>alachlor</i>
Frontier	Frontier 6.0	<i>dimethenamid</i>
Frontrow	FirstRate	<i>cloransulam-methyl</i>
Fusilade DX	Fusilade DX	<i>fluazifor</i>
Fusion	Fusion	<i>fluazifor+fenoxaprop</i>
Galaxy	Basagram T/O	<i>bentazon</i>
Glyfos	Glyphosate	<i>glyphosate</i>
Glyphomax	Glyphosate	<i>glyphosate</i>
Glyphosate	Glyphosate	<i>glyphosate</i>
Glystar Plus	Glyphosate	<i>glyphosate</i>
Gramoxone Extra	Gramoxone Extra	<i>paraquat</i>
Guantlet	Canopy XL	<i>sulfentrazone+chlorimuron ethyl</i>
Harmony	Harmony GT XP	<i>thifensulfuron</i>
Harmony GT	Harmony GT XP	<i>thifensulfuron</i>
Lasso/Lasso II	Lasso	<i>alachlor</i>
Lasso MicroTech	Lasso	<i>alachlor</i>
Lexone	Sencor DF	<i>metribuzin</i>

Appendix 1. (Continued)

Herbicide Name Mentioned by Farmers	Herbicide Brand Name	Herbicide Generic Name
Mirage	Glyphosate	<i>glyphosate</i>
Partner	Lasso	<i>Alachlor</i>
Permit	Permit	<i>halosulfuron</i>
Phoenix	Cobra	<i>Lactofen</i>
Pinnacle	Harmony GT XP	<i>thifensulfuron</i>
Poast/Poast Plus	Poast	<i>sethoxydim</i>
Preview	Sencor DF	<i>metribuzin</i>
Prowl	Prowl 3.3 EC	<i>pendimethalin</i>
Pursuit	Pursuit	<i>imazethapyr</i>
Pursuit Plus	Pursuit Plus EC	<i>imazethapyr+pendimethalin</i>
Python	Python WDG	<i>flumetsulam</i>
Raptor	Raptor	<i>Imazamox</i>
Rattler	Glyphosate	<i>glyphosate</i>
Reflex	Reflex	<i>Fomesafen</i>
Reliance STS	Classic	<i>chlorimuron ethyl</i>
Resource	Resource	<i>flumiclorac</i>
Rezult	Basagram T/O	<i>Bentazon</i>
Roundup/Roundup Ultra	Glyphosate	<i>glyphosate</i>
Scepter	Scepter 70 DG	<i>imazaquin</i>
Scepter OT	Scepter 70 DG	<i>imazaquin</i>
Select	Conclude Xtra G	<i>Clethodim</i>
Sencor	Sencor DF	<i>metribuzin</i>
Sonalan	Sonalan 10 G	<i>ethalfuralin</i>
Squadron	Squadron	<i>pendimethalin+imazaquin</i>
Steel	Steel	<i>imazethapyr+imazaquin+pendimethalin</i>
Stellar	Stellar	<i>flumiclorac+lactofen</i>
Storm	Storm	<i>bentazon+acifluoren</i>
Synchrony STS	Synchrony STS	<i>chlorimuron+thifensulfuron</i>
Tornado	Reflex	<i>Fomesafen</i>
Touchdown	Glyphosate	<i>glyphosate</i>
Treflan	Trifluralin 4EC	<i>Trifluralin</i>
Tri-4	Trifluralin 4EC	<i>Trifluralin</i>
Tri-Scept	Trifluralin 4EC	<i>Trifluralin</i>
Trifluralin	Trifluralin 4EC	<i>Trifluralin</i>
Trilin	Trifluralin 4EC	<i>Trifluralin</i>
Trust	Trifluralin 4EC	<i>Trifluralin</i>
Turbo	Dual II Magnum	<i>metolachlor</i>
Typhoon	Reflex	<i>Fomesafen</i>
Ultra Blazer	Ultra Blazer	<i>acifluorfen</i>
Valor	Valor	<i>flumioxazin</i>

Appendix 2. The Total Number of Herbicide Applications at Different Stages of Production

Herbicide Brand Name	Conventional Soybeans			RR Soybeans			All Soybeans
	Pre-Emergent	Post-Emergent	Total	Pre-Emergent	Post-Emergent	Total	
2,4-D 6 Amine	5	2	7	8	2	10	17
Assure II	3	14	17				17
Authority	8		8	7		7	15
Axiom DF	3	1	4	4		4	8
Backdraft	1		1				1
Basagram T/O	7	26	33				33
Boundary 6.5 EC	8		8	3		3	11
Broadstrike+Dual	2		2				2
Broadstrike+Treflan	1		1				1
Canopy	22	1	23	6		6	29
Canopy XL	23	3	26	14		14	40
Classic	5	35	40		4	4	44
Cobra	5	18	23				23
Command 4EC	7		7				7
Conclude Xtra G	2	33	35				35
Dual II Magnum	28	2	30	3		3	33
Extreme				3	4	7	7
FirstRate	10	39	49	2	2	4	53
Frontier 6.0	2	2	4	1		1	5
Fusilade DX	1	6	7				7
Fusion	3	33	36		1	1	37
Glyphosate	18	8	26	56	423	479	505
Gramoxone Extra	4		4	3		3	7
Harmony GT XP	3	17	20		1	1	21
Lasso	17	4	21	4		4	25
Lorox DF	6		6	1		1	7
Permit		1	1				1
Poast	3	18	21		1	1	22
Prowl 3.3 EC	84	7	91	24		24	115
Pursuit	24	74	98	2	4	6	104
Pursuit Plus EC	33	28	61	7	1	8	69
Python WDG	6	3	9				9
Raptor	8	44	52				52
Reflex	16	64	80		2	2	82

Appendix 2. (Continued)

Herbicide Brand Name	Conventional Soybeans			RR Soybeans			All Soybeans
	Pre-Emergent	Post-Emergent	Total	Pre-Emergent	Post-Emergent	Total	
Resource		3	3				3
Sencor DF	22	1	23	1		1	24
Scepter 70 DG	18	8	26				26
Sonalan 10 G	2		2				2
Squadron	23	3	26		1	1	27
Steel	5		5				5
Stellar		1	1				1
Storm	1	7	8				8
Synchrony STS	5	14	19		1	1	20
Trifluralin 4EC	146	6	152	36		36	188
Ultra Blazer	3	16	19		1	1	20
Valor		1	1				1
All Herbicides	593	543	1136	185	448	633	1769

Appendix 3. Herbicide Characteristics: Human Health Effects

Herbicide Brand Name	EPA Rating	Acute Human				Chronic Human
		Eye	Dermal	Ingestion	Inhalation	
2,4-D 6 Amine	Danger	High	Moderate	Low	Low	High
Assure II	Danger	Moderate	Low	Low	Low	Moderate
Authority	Caution	Moderate	Low	Low	Moderate	Moderate
Axiom DF	Caution	Moderate	Low	Low	Low	Moderate
Backdraft	Caution	Low	Low	Low	Low	Non-toxic
Basagram T/O	Caution	Low	Low	Low	Low	High
Boundary 6.5 EC	Caution	Moderate	Low	Low	Low	Non-toxic
Broadstrike+Dual	Warning	High	Moderate	Low	Low	Moderate
Broadstrike+Treflan	Caution	Moderate	Low	Low	Low	Moderate
Canopy	Caution	Low	Low	Low	Low	Moderate
Canopy XL	Caution	Moderate	Low	Low	Moderate	Moderate
Classic	Caution	Low	Low	Low	Moderate	Non-toxic
Cobra	Danger	High	High	Low	Low	High
Command 4EC	Warning	Moderate	Low	Low	Low	Low
Conclude Xtra G	Warning	Moderate	Moderate	Low	Low	Low
Dual II Magnum	Caution	Low	Low	Low	Low	Non-toxic
Extreme	Warning	Moderate	Non-toxic	Non-toxic	Non-toxic	Low
FirstRate	Caution	Low	Low	Low	Low	Non-toxic
Frontier 6.0	Warning	Moderate	Low	Low	Low	Moderate
Fusilade DX	Caution	Low	Moderate	Low	Moderate	High
Fusion	Caution	Low	Moderate	Low	Moderate	High
Glyphosate	Warning	Moderate	Non-toxic	Non-toxic	Low	Low
Gramoxone Extra	Warning	Moderate	Low	High	High	Low
Harmony GT XP	Warning	Moderate	Moderate	Low	Low	High
Lasso	Warning	High	High	Low	Non-toxic	Moderate
Lorox DF	Caution	Moderate	Low	Low	Low	Non-toxic
Permit	Caution	Low	Low	Low	Non-toxic	Low
Poast	Warning	Moderate	Moderate	Low	Low	Low
Prowl 3.3 EC	Caution	Low	Low	Low	Low	Non-toxic
Pursuit	Caution	Low	Low	Low	Non-toxic	Non-toxic
Pursuit Plus EC	Caution	Low	Low	Low	Non-toxic	Non-toxic
Python WDG	Caution	Low	Low	Low	Non-toxic	Non-toxic
Raptor	Caution	Non-toxic	Low	Non-toxic	Low	Non-toxic
Reflex	Danger	High	Low	Low	Low	Moderate
Resource	Warning	Moderate	Moderate	Low	Low	Low
Sencor DF	Caution	Low	Non-toxic	Low	Moderate	Low

Appendix 3. (Continued)

Herbicide Brand Name	EPA Rating	Acute Human				Chronic Human
		Eye	Dermal	Ingestion	Inhalation	
Scepter 70 DG	Caution	Low	Low	Low	Low	Non-toxic
Sonalan 10 G	Caution	Moderate	Low	Non-toxic	Non-toxic	High
Squadron	Danger	High	Low	Low	Moderate	Moderate
Steel	Danger	High	Low	Low	Low	High
Stellar	Danger	High	Moderate	Low	Low	High
Storm	Danger	High	Low	Low	Low	High
Synchrony STS	Caution	Low	Low	Low	Low	High
Trifluralin 4EC	Caution	Moderate	Low	Low	Low	Moderate
Ultra Blazer	Danger	High	Low	Low	Low	Moderate
Valor	Caution	Low	Low	Low	Low	High

Appendix 4. Herbicide Characteristics: Environmental Effects

Herbicide Brand Name	Fish	Birds	Mammals	Ground Water	Surface Water
2,4-D 6 Amine	Moderate	Moderate	High	Moderate	Low
Assure II	High	Non-toxic	High	Low	Low
Authority	Moderate	Moderate	Low	High	High
Axiom DF	Low	Moderate	Low	High	High
Backdraft	Non-toxic	Non-toxic	Low	High	High
Basagram T/O	Non-toxic	Low	Low	Moderate	High
Boundary 6.5 EC	Moderate	Moderate	Low	Moderate	Moderate
Broadstrike+Dual	Moderate	Low	Moderate	High	Moderate
Broadstrike+Treflan	High	Non-toxic	Low	Low	High
Canopy	Low	Moderate	Low	High	High
Canopy XL	Moderate	Moderate	Low	High	High
Classic	Non-toxic	Non-toxic	Low	High	High
Cobra	High	Non-toxic	High	Low	Low
Command 4EC	Moderate	Non-toxic	Moderate	Moderate	Moderate
Conclude Xtra G	Low	Non-toxic	Moderate	Low	High
Dual II Magnum	Moderate	Low	Low	High	Moderate
Extreme	Moderate	Non-toxic	Moderate	Low	High
FirstRate	Low	Non-toxic	Low	Moderate	High
Frontier 6.0	Moderate	Non-toxic	Moderate	Low	High
Fusilade DX	High	Non-toxic	Low	Low	High
Fusion	High	Non-toxic	Low	Low	High
Glyphosate	Moderate	Non-toxic	Moderate	Low	Low
Gramoxone Extra	Low	Non-toxic	Moderate	Low	High
Harmony GT XP	Non-toxic	Low	Moderate	High	Moderate
Lasso	Moderate	Low	Moderate	High	Moderate
Lorox DF	Low	Low	Low	Moderate	Moderate
Permit	Non-toxic	Non-toxic	Low	Moderate	Low
Poast	Moderate	Low	Moderate	Low	High
Prowl 3.3 EC	High	Low	Low	Low	Moderate
Pursuit	Non-toxic	Non-toxic	Low	Low	High
Pursuit Plus EC	High	Non-toxic	Low	Low	High
Python WDG	Non-toxic	Non-toxic	Low	Low	High
Raptor	Non-toxic	Non-toxic	Low	Low	Low
Reflex	Moderate	Low	High	High	Moderate
Resource	Moderate	Non-toxic	Moderate	Moderate	Moderate

Appendix 4. (Continued)

Herbicide Brand Name	Fish	Birds	Mammals	Ground Water	Surface Water
Sencor DF	Low	Non-toxic	Low	High	High
Scepter 70 DG	Non-toxic	Non-toxic	Low	High	High
Sonalan 10 G	High	Non-toxic	Low	Low	High
Squadron	Non-toxic	Non-toxic	High	High	High
Steel	Non-toxic	Non-toxic	High	High	High
Stellar	Moderate	Non-toxic	High	Low	Low
Storm	Low	Non-toxic	High	High	Moderate
Synchrony STS	Non-toxic	Non-toxic	Low	Low	High
Trifluralin 4EC	High	Non-toxic	Low	Low	High
Ultra Blazer	Low	Moderate	High	Low	Moderate
Valor	Moderate	Non-toxic	Low	Low	Moderate

Appendix 5. Herbicide Production-Related Characteristics

Herbicide Brand Name	Grass Weed Response (%)	Broadleaf Weed Response (%)	Application Cost (\$/Acre)	Persistence (Days)	Active Ingredients (%)	Rate of Application (Lbs/Acre)	Rate of Application (Lbs of AI/Acre)
2,4-D 6 Amine	15	85	1.76	10	67	1.06	0.71
Assure II	92	15	10.67	60	10	0.6	0.06
Authority	35	66	11.12	40	75	0.25	0.19
Axiom DF	66	30	18.98	40	68	1.07	0.73
Backdraft	32	54	8.59	60	17	3.88	0.66
Basagram T/O	15	57	20.4	10	44	2.27	1
Boundary 6.5 EC	66	30	12.02	40	72	1.4	1.01
Broadstrike+Dual	66	30	10.94	10	82	2.34	1.92
Broadstrike+Treflan	76	23	5.21	60	43	1.74	0.75
Canopy	45	79	13.55	70	75	0.37	0.28
Canopy XL	45	79	17.17	40	56	0.41	0.23
Classic	17	72	6.41	40	25	0.04	0.01
Cobra	23	79	10.11	7	23	2.43	0.56
Command 4EC	77	65	20.2	24	47	2.13	1
Conclude Xtra G	94	80	12.4	3	13	1.08	0.14
Dual II Magnum	66	30	17.86	10	82	1.55	1.27
Extreme	94	88	13.76	47	24	3.37	0.81
FirstRate	15	58	7.69	10	84	0.01	0.01
Frontier 6.0	60	60	18.98	60	63	1.75	1.1
Fusilade DX	92	15	12.19	20	24	0.75	0.18
Fusion	92	15	9.08	20	31	0.48	0.15
Glyphosate	94	88	7.54	41	41	2.439	1
Gramoxone Extra	87	91	6.59	60	37	1.27	0.47
Harmony GT XP	15	59	0.96	12	75	0.01	0.004
Lasso	66	33	14.58	10	44	5.68	2.5
Lorox DF	50	49	11.59	60	50	1	0.5
Permit	40	62	9.77	30	75	0.04	0.03
Poast	93	15	14.72	5	18	2.33	0.42
Prowl 3.3 EC	76	23	9.73	60	37	4.86	1.8
Pursuit	72	55	15.87	60	23	0.09	0.02
Pursuit Plus EC	72	55	14.08	60	33	3.79	1.25
Python WDG	21	74	9.13	10	80	0.06	0.05
Raptor	68	73	15.39	30	12	0.25	0.03
Reflex	15	72	11.44	60	23	1.09	0.25
Resource	15	54	5.32	40	10	0.2	0.02

Appendix 5. (Continued)

Herbicide Brand Name	Grass Weed Response (%)	Broadleaf Weed Response (%)	Application Cost (\$/Acre)	Persistence (Days)	Active Ingredients (%)	Rate of Application (Lbs/Acre)	Rate of Application (Lbs of AI/Acre)
Sencor DF	36	66	9.73	30	41	0.49	0.2
Scepter 70 DG	32	54	5.6	60	70	0.17	0.12
Sonalan 10 G	76	25	11.8	60	10	5	0.5
Squadron	77	68	14.07	60	26	3.35	0.87
Steel	62	73	16.4	60	29	3.17	0.92
Stellar	22	68	8.14	7	34	0.32	0.11
Storm	25	80	16.24	30	43	1.74	0.75
Synchrony STS	17	82	2.39	5	42	0.02	0.01
Trifluralin 4EC	76	23	5.21	60	43	1.74	0.75
Ultra Blazer	25	78	12.34	41	20	1.85	0.37
Valor	15	80	14.85	30	51	0.2	0.1

Appendix 6. Herbicide Risk Indices

Herbicide Brand Name	Index Value
2,4-D 6 Amine	1.78
Assure II	1.32
Authority	1.77
Axiom DF	1.68
Backdraft	1.40
Basagram T/O	1.64
Boundary 6.5 EC	1.28
Broadstrike+Dual	1.94
Broadstrike+Treflan	1.68
Canopy	1.56
Canopy XL	1.77
Classic	1.49
Cobra	2.16
Command 4EC	1.36
Conclude Xtra G	1.98
Dual II Magnum	1.16
Extreme	1.04
FirstRate	1.40
Frontier 6.0	1.68
Fusilade DX	2.11
Fusion	2.11
Glyphosate	0.65
Gramoxone Extra	1.96
Harmony GT XP	1.90
Lasso	2.23
Lorox DF	1.28
Permit	0.91
Poast	1.98
Prowl 3.3 EC	1.16
Pursuit	1.31
Pursuit Plus EC	1.31
Python WDG	1.31
Raptor	0.71
Reflex	1.56
Resource	1.74

Appendix 6. (Continued)

Herbicide Brand Name	Index Value
Sencor DF	1.19
Scepter 70 DG	1.40
Sonalan 10 G	1.58
Squadron	1.89
Steel	1.88
Stellar	1.78
Storm	1.64
Synchrony STS	1.64
Trifluralin 4EC	1.68
Ultra Blazer	1.56
Valor	1.40