Estimating Environmental and Human Health Benefits of Reducing Pesticide Use Through Integrated Pest Management Programs

by

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ESTIMATING ENVIRONMENTAL AND HUMAN HEALTH BENEFITS OF REDUCING PESTICIDE USE THROUGH INTEGRATED PEST MANAGEMENT PROGRAMS

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(ABSTRACT)

Estimates of the social benefits of integrated pest management (IPM) are fundamental to an informed assessment of the value of public expenditures for IPM research and extension. This study evaluates a subset of the potential social benefits if IPM adoption - reductions in the environmental and human health costs of pesticide use. A methodology is developed to estimate the environmental and human health costs of pesticide use associated with the production of any crop. The cost estimates for production under "conventional" (i.e. non-IPM) pest management are compared to the cost estimates associated with production under an IPM program to generate estimates of the environmental and human health benefits of IPM adoption.

The development of the methodology resulted in: (1)a new algorithm for assigning levels of IPM adoption to agricultural producers; (2)the design and administration of a contingent valuation survey to estimate society's willingness to pay (WTP) to avoid pesticide related risks to the environment and human health; (3)a new technique for detecting payment vehicle bias in contingent valuation surveys; (4)a set of criteria for assigning to pesticidal active ingredients (a.i.) levels of relative risk that a.i.'s pose to eight environmental and

human health categories; and (5)the assignment of relative risk levels to more than one hundred pesticidal active ingredients. All of these results are directly applicable to other studies of this kind.

The analysis of Virginia apple production results in several recommendations regarding the design of future chemical use surveys conducted by United States Department of Agriculture. The analysis of the Early Leaf Spot Advisory system (ELSA) for Virginia peanut production estimates the environmental and human health benefits of ELSA to be approximately $840,000 per year.

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Introduction

Effective pest control is essential to the economic viability of the agricultural sector. To protect the quantity and quality of their harvest, farmers employ a variety of pest control methods, many of which rely heavily on chemical pesticides. The fast and dramatic effect pesticides often have on pest populations coupled with their relatively low "out-of-pocket" cost of application has led many farmers to regard pesticides as a form of crop insurance. The amount of pesticides applied to agricultural crops, therefore, may not be the amount that maximizes net returns, but rather the amount that ostensibly minimizes the inherent financial risk due to pests.

Pesticides are toxic substances developed to kill or physically impair living organisms. Although some pesticides are toxic only to the pests they were developed to combat, many more affect a broad spectrum of species, including humans. Likewise, some pesticides quickly breakdown into non-toxic substances, while others migrate from the target area in a toxic state. Pesticide migration can compromise the health of humans and other non-target species, and jeopardize the quality of environmental amenities. Such adverse affects from pesticide use are known as social or external costs, i.e., costs that are not fully borne by those who employ the pesticides. The challenge to agricultural researchers is to reduce the external costs of farming while addressing the financial concerns of farmers. Reducing the use of pesticides is a potential vehicle for reducing the external costs associated with agricultural production.

Integrated pest management (IPM) was conceived as a means of easing farmers' reliance on chemical pesticides while maintaining agricultural production and preserving profitability. IPM does not exclude any pest control option from its arsenal, integrating biological, cultural, and chemical control methods for optimal pest management (Osteeen, Bradley, and Moffitt, 1981). Empirical studies have shown that IPM strategies for many crops lead to lower levels of pesticide use. In addition, researchers have shown IPM can reduce income variability and, at the same time, maintain or increase yields and net returns (Greene, 1983; Hall, 1977). Therefore, producers may be over-applying pesticides from both a private and a social perspective.

Problem Statement

Budget deficits and increased public concern for the integrity of our environment and the safety of our food supply are challenging the capabilities of our public institutions. The federal government, as well as many state and local governments, have run up large budget deficits. To recover from fiscal imbalances, budgets are being trimmed. To make the necessary budget decisions, many policy makers and public administrators are requiring more rigorous justification for the activities they fund.

This study assesses a subset of the potential social benefits from public investments in integrated pest management: reductions in the external costs of pesticide use. Estimates of the social benefits of IPM are fundamental to an informed assessment of the value of public expenditures for IPM research and extension. While the private sector is currently providing IPM services, IPM research and development will continue to rest primarily with the public sector. There are a number of reasons why IPM research is largely a public responsibility: 1) from the very definition of external costs, there is no direct incentive for producers to invest in research aimed at reducing the external costs of pest control; and 2) IPM strategies revolve around management techniques as opposed to specific, patentable products, therefore, financial returns to IPM research are not likely to be captured by investors.

There is an array of potential benefits from IPM programs. These programs may reduce or eliminate the development of pest resistance to pesticides, increase farm profitability, decrease yield and income variability, and reduce the threat pesticides pose to environmental and human health. Because this study cannot address all of these issues, and in recognition of the public concern for food safety and environmental quality, the value of the reduced threat to environmental and human health is the focus here.

Nature of Environmental and Human Health Effects from Pesticide Exposure

Numerous effects of pesticides on environmental and human health have been documented. Pesticides have been found to cause fish kills in Louisiana (azinphos-methyl) (Marcus, 1991), to contribute to ozone depletion (methyl bromide) (Los Angeles Times, July 1992), and to kill birds in Virginia (carbofuran) (Cohn, 1990). At the height of the 1990 growing season, the United States Geological Survey tested rainwater in 23 states and discovered detectable levels of pesticides, demonstrating the potential for some agrochemicals to migrate substantial distances through the atmosphere (Shryer, 1991).

There are four primary vehicles for pesticide migration: leaching, run-off, wind, and as residue on harvested crops. Factors that influence the propensity of pesticides to migrate via each of these vehicles range from controllable cultural practices to the uncontrollable weather. Certain pesticides also tend to bioaccumulate in the fat cells of living organisms, due to an inability to metabolize certain pesticidal compounds. Bioaccumulation can lead to a situation where the water of a particular source does not contain toxic concentration levels of pesticides, but the fish living in the water source are toxic to eat.

Harmful effects of pesticide migration may be divided into six broad categories: 1) acute human health effects; 2) chronic human health effects; 3) contamination of groundwater; 4) contamination of surface water; 5) atmospheric contamination; and 6) effects on non-target organisms. This study defines contamination due to pesticides as the introduction of pesticides into an environment which results in such deleterious effects as harm to non-target living organisms, hazards to human health, impairment of environmental quality for both economic and recreational human activities, and reduction of amenities.

Acute Human Effects. Acute health effects usually result from a limited number of exposures to an active ingredient. The symptoms of acute pesticide poisoning vary with the pesticide, the amount of active ingredient, and the vector of exposure. For example, the symptoms of acute exposure to the class of pesticides known as carbamates range from abdominal cramps to headaches, muscle twitching to convulsions, weakness to temporary paralysis of extremities, unconsciousness to coma, even death (Hallenbeck and Cunningham-Burns, 1985). Vectors of exposure to carbamates include inhalation and dermal exposure, and ingestion of contaminated drinking water and food (Howard, 1991).

Chronic Human Effects. Chronic health effects from pesticides usually result from repeated low-level exposure to the active ingredient. As with acute health effects, symptoms of chronic pesticide poisoning depend on a variety of factors. The exposure vector, the time period over which exposure occurred, the active ingredient, and physical characteristics of the victim all influence the severity of the chronic effects of a particular pesticide. Extending the previous example, health effects from chronic carbamate exposure include anorexia, cholinesterase depression, muscle weakness, renal damage, albuminuria, and glycosuria. In addition, carbamates are suspected of prenatal damage and effects on reproductive systems. Specific carbamate compounds are suspected of causing a multitude of other afflictions including carcinogenesis and mutagenesis.

Effects on Groundwater Quality. Pesticides are appearing in the nation's groundwaters in increasing numbers. "In 1983, 12 states experienced groundwater contamination from pesticides applied to agricultural land. In 1984, a total of 12 pesticides were discovered in the groundwaters of 18 states. By 1985, 23 states discovered groundwater contamination from 17 different pesticides." (Patrick, Ford and Quarles, 1987, p. 85) The primary concern with pesticides contaminating groundwater is the water's ability to serve as a vector for human poisoning. Contaminated groundwater may also contaminate surface water, although the threat is relatively small due to the amount of time it generally takes groundwater to reach surface water systems (Phillips and Shabman, 1991).

Effects on Surface Water Quality. Pesticides migrate to surface water primarily by agricultural runoff -- either adsorbed to soil particles or in solution. Spills, rainwater, and drift from ground or aerial spraying are other common means for pesticides to enter surface waters. Pesticide spills are potentially the most damaging, as the concentration of the chemicals is greater in a spill than from other means of contamination. Surface water contamination can adversely effect human recreational and economic activities, aesthetic qualities of the ecosystem, and the living organisms within the ecosystem.

Atmospheric Effects. Pesticides enter the atmosphere as vapor, as drift from application, by wind erosion of treated soils, and from volatilization of pesticide deposits on terrestrial and aquatic surfaces (Wheatley, 1973). Known atmospheric effects include ozone depletion and contamination of rainwater.

Effects on Non-Target Species. Birds, arthropods, mammals, reptiles, aquatic species, and plant life all suffer from unintended contact with pesticides. As with humans, these species are subject to both lethal and sublethal doses of pesticides. "Sublethal doses could have three types of ecological effect: (1) on the ability of individuals to survive; (2) on their reproductive ability; and (3) on the genetic constitution of future generations" (Thompson, 1973, p. 123).

Pesticide monitoring in the United States is still in its infancy. Tracking the migration of pesticides and detecting their presence is a complex task; and if the metabolites of pesticides are also considered, the complexity of the endeavor is compounded. In addition, combinations of pesticides entering an environment may have synergistic effects that are well beyond the state-of-the-art capabilities of pesticide monitoring and detection. But even at the present state of pesticide monitoring, one thing is certain: the more we look for pesticides in our environment, the more we find them.

Objectives and Hypotheses

The overriding objective of this study is to examine the ability of integrated pest management programs to reduce the environmental and human health costs associated with pesticide use[1], i.e., the external costs of controlling pests. This objective implies two testable hypotheses:

* The external costs of pesticide use are greater than zero.

* IPM programs can reduce the external costs of pesticide use.

To test these hypotheses, a methodology is developed to compare the external costs of different pest management strategies. Externalities can be measured in two ways: (1) as a measure of the actual damage incurred from an activity, or (2) as a measure of the risk[2] of damage from an activity. In the case of pesticides, it is currently impossible to accurately determine the actual damage to environmental and human health incurred from their use. State-of-the-art of pesticide monitoring is incapable of identifying all of the resources and species affected, and measuring the extent of damage each incurs. With that in mind, a methodology is developed to compare the relative risk to a series of environmental and human health categories (rather than individual species) associated with the pesticide loadings of different pest management strategies. The methodology encompasses the following specific components:

* Estimation of society's willingness to pay to avoid perceived risks to human health and the environment from pesticide use through a contingent valuation survey.

* Estimation of the marginal effect of pest management practices on pesticide use through an econometric model.

* Development of a set of defensible criteria for assigning levels of relative risk to pesticidal active ingredients with respect to eight environmental categories: (1) ground water, (2) surface water, (3) acute human health, (4) chronic human health, (5) aquatic species, (6) birds, (7) mammals, and (8) arthropods.

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[1] Within the context of this study, "external costs" refer exclusively to the environmental and human health costs, external to the private costs of production, associated with pesticide use.

[2] Within the context of this paper, the term "risk" is used to refer to the potential for a pesticide to inflict external costs.

* Development of an algorithm to define levels of IPM adoption that is flexible enough to be applied across crops and locations.

The methodology is applied to apple and peanut production in Virginia to illustrate its respective strengths and weaknesses. In addition, the results of the contingent valuation survey are used to examine the issue of payment vehicle bias.

Organization of the Thesis

The thesis is divided into six chapters, including the introductory chapter. Each chapter is further divided into sections focusing on individual topics related to the chapter. The second chapter is a review of literature relevant to this study. Five bodies of literature are reviewed: (1) evaluations of the social costs of pesticide use and the environmental benefits of IPM programs; (2) techniques used to measure external costs; (3) the potential biases of contingent valuation surveys; (4) criteria for identifying IPM adopters; and (5) characteristics of IPM adopters.

Chapter III presents an overview of the methodology -- namely, how the willingness to pay estimates, the results of the econometric models, and the IPM adoption algorithm are combined to generate estimates of the reduction in external costs from IPM adoption.

Chapter IV presents the contingent valuation survey (CVS) designed for this study, and develops a new test for identifying payment vehicle bias in contingent valuation surveys. The results of the CVS are also analyzed with respect to their applicability to IPM evaluations across the country.

Chapter V applies the methodology of Chapter III to evaluate IPM programs developed for Virginia apple and peanut production. The study areas, IPM practices, and pesticides used on the two crops of interest are identified. An econometric model is specified and estimated for the apple evaluation, resulting in a series of recommendations regarding the design of future chemical use surveys conducted by the U.S. Department of Agriculture. The analysis of the peanut program illustrates the magnitude of the external costs of pesticide use and the ability of IPM programs to significantly reduce those costs.

The final chapter reviews the major accomplishments of the thesis, and examines the implications for pesticide and IPM related policies that emerge from the analysis.

Chapter II: Literature Review

Section 2.1 Introduction

The purpose of the following literature review is three-fold: first, to examine other studies that have considered health and environmental effects of pesticide use; second, to legitimize the evaluative techniques the study employs; and third, to identify potential shortcomings of the study. To these ends, the review is divided into five sections. In section 2.2, studies concerned with the social costs of pesticide use and the environmental benefits of integrated pest management are reviewed. Accepted economic techniques for measuring external costs are reviewed in section 2.3. Section 2.4 is an overview of the inherent biases associated with the contingent valuation method. Section 2.5 covers the literature concerned with defining IPM adoption. In Section 2.6 studies examining farm and farmer characteristics of IPM adopters are reviewed.

Section 2.2 Social Costs of Pesticide Use and Environmental Benefits of IPM

There is considerable interest in measuring the environmental benefits of integrated pest management programs. One of the primary motivations behind the development of IPM is concern for the environmental implications and long-run sustainability of pesticide intensive agriculture. However, relatively few studies have attempted to quantify the environmental benefits of IPM, due, in part, to measurement difficulties. The result is a literature replete with conclusions that IPM is "good" for the environment, yet lacking substantive evidence in support of these claims.

Several studies have concluded that IPM programs that reduce the amount of pesticides applied to a crop represent a savings in the environmental costs associated with the production of the crop. In 1976, Sprott et al. concluded "short-season cotton production uses fewer pounds of insecticide, implying an environmental benefit" (p. 2). In the following year, Hall concluded "the traditional trade-offs inherent in balancing economic, social, and environmental benefits and costs are not relevant to IPM. Pesticide use can be reduced while avoiding economic loss" (p. 6). And Burrows (1983) concludes, "...by reducing pesticide use, [IPM] conveys benefits at a lower social cost" (p. 810). Conclusions of this nature rely on three fundamental assumptions: (1) society values the resources that are adversely affected by agricultural pesticide use; (2) a reduction in the total amount of pesticidal active ingredient applied to a crop results in a reduction in the adverse effects of the use of pesticides; and (3) the social value of the reduction in adverse effects is greater than the value of any social benefits that may be forfeited when pesticide use is reduced.

In 1980, Pimentel et al. attempted to address the first assumption through a preliminary assessment of the environmental and social costs of pesticides. "Included in this preliminary assessment are analyses of the costs due to: human pesticide poisonings and fatalities; livestock and livestock product losses; increased control expenses resulting from pesticide-related destruction of natural enemies and pesticide resistance; crop pollination problems and honey bee losses; crop and crop product losses; fish and wildlife losses; and governmental expenditures to reduce environmental and social costs resulting from pesticide use" (p. 127). To estimate the annual economic costs of human pesticide poisonings and human cancer due to pesticide use, the number of pesticide poisonings was multiplied by the estimated cost of treatment, the number of days of lost work, and the "overall worker average daily wage;" this product was then added to the estimated cost of pesticide induced fatalities and the cost of human cancer due to pesticides. Table 2.1 illustrates these calculations. The total annual cost of human pesticide poisonings was estimated to be nearly $184 million.

The annual value of honey bee poisonings was estimated to be $55 million. This figure was derived from $11.1 million in bees "...that are killed outright or die during the winter because of pesticide damage" (p. 131), $21.1 million in losses from partial kills, reduced honey production, and the movement of colonies, and an additional $22.5 million in losses due to pesticide induced restrictions on the areas in which honey producers may locate.

Table 2.1 Calculated Economic Costs of Human Pesticide Poisonings and Human Cancer Annually in the U.S.[1]

Human Poisoning Costs	Total Costs
1. *Cost of hospitalized poisonings*	
2,831 hospitalized poisonings[2] * 3.7 days in hospital[3] * $127.70/day hospital fee[4]................................	$1,337,619
2,831 hospitalized poisonings * 3.7 days in hospital * $16.04/day doctor fee[5]....................................	168,014
1,000 worker hospitalized poisonings[6] * 6.67 days lost work[7] * $34/day[8]..	226,780
2. *Cost of nonhospitalized poisonings*	
30,000 physician treated * 1.5 physician visits[9] * $20/visit[10]	900,000
40% Nonhospitalized physician treated[11] * 42,200[12] physician treated * 6.67 days lost work * $34/day[13]	3,828,046
3. *Cost of emergency room treated poisonings*	
12,200 Emergency Room poisonings * $25/visit[14]	305,000
4. *Cost of fatalities*	
52 Accidental Fatalities[15] * $1 million[16]..........	52,000,000
5. *Cost of human cancer due to pesticides*	
0.5% cancer[17] * $25,000 million[18]................	125,000,000
Total..	$183,765,459

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[1] This table is reprinted from Pimentel, et. al. , p. 129.

[2] EPA 1976.

[3] Average 3.7 day stay in hospital for pesticide poisoning (M. Daniel-Guido, Nutrition Action, Washington, D.C., pers. comm. 1978).

[4] Hospital cost/day exclusive of doctor fee (HH 1976).

[5] Average cost of general practitioner's or internist's visit in the hospital (AMA 1977).

[6] Estimated from EPA 1076.

[7] Average number of days of work lost per pesticide incident (State of California 1974).

[8] Wage computed by averaging wage of agrichemical workers with that of farmers and agricultural workers (USDL 1975, USDA 1977).

[9] Assume each poisoning victim visits a medical doctor 1.5 times.

[10] Fee per visit including medication (AMA 1977).

[11] Assume 40% of nonhospitalized physician-treated cases were employed adults. Estimated from EPA (1976) which states 39% of hospitalized poisonings were children under 4 years old and Lisella et. al. (1975) who state 68% of all poisonings were children.

[12] 30,000 physician-treated poisonings + 12,200 emergency room treated poisonings = 42,200.

[13] Overall worker average daily wage (USDA 1977).

[14] Lisella et. al. 1975.

[15] A total of 52 accidental deaths from pesticides of a total of 217 pesticide poisoning fatalities.

[16] Estimated value of human life assumed to be $1 million.

[17] Assumed incidence of cancer due to pesticides.

[18] Epstein 1978.

To estimate the value of fishery and wildlife losses due to pesticides, the value of direct fish kills, Lake Ontario fishing restrictions, the contamination of the James River Fishery, the cost of pesticide monitoring of wildlife, and the cost of re-establishing endangered species threatened by pesticide use were added together. The total was approximately $11 million in annual fishery and wildlife costs.

The annual cost of state and federal government pesticide pollution controls was estimated to be $140 million. When this figure was added to the cost of pesticide related human poisonings, honey bee poisonings, and fishery and wildlife losses, the total estimated annual environmental and human health costs associated with pesticide use in the U.S. was $390 million (presumably expressed in 1980 dollars). While the accuracy of the numbers generated by Pimentel et al. may be contested due to their rough manner of calculation, the resources affected by the use of agricultural pesticides are clearly valued by society, and substantial external costs are associated with the use of pesticides. In other words, the first assumption does appear reasonable.

The second assumption, on the other hand, is more dubious. By assuming that a reduction in the total amount of pesticidal active ingredients applied to a crop results in a reduction in the adverse effects of the use of pesticides, one is essentially treating pesticides as a homogenous group. In reality, different pesticidal compounds have different toxicological, mobility, and persistence characteristics. As such, pesticides vary with respect to their ability to adversely affect non-target species and other resources. If highly toxic, highly mobile, persistent pesticides are substituted for relatively benign chemicals, it is difficult to argue that society is better off simply because the total amount of pesticides has been reduced. Recognition of this fact served as the impetus for the development of an environmental impact quotient (EIQ) by Kovach, et al. (1992).

The EIQ assigns a number to an active ingredient based on eleven characteristics of the ingredient: (1) dermal toxicity, (2) chronic toxicity, (3) systemicity, (4) fish toxicity, (5) leaching potential, (6) surface loss potential, (7) bird toxicity, (8) soil half-life, (9) bee toxicity, (10) beneficial arthropod toxicity, and (11) plant surface half-life. These characteristics are weighted by an importance ranking and combined to generate a quotient capable of comparing, in an ordinal sense, the environmental impact of different active ingredients. If one accepts their weights, the EIQ can be used by farmers to assist in their choice of agricultural chemicals, and may help researchers in their efforts to develop farming systems that have fewer environmental repercussions.

Unfortunately, the EIQ is not as helpful in developing estimates or facilitating comparisons of the external costs of different pest management strategies. There are two reasons for this assertion: (1) the EIQ is not a cardinal measure; and (2) society may value the individual elements of the EIQ at weights different from those imposed by the EIQ equation.

The lack of cardinality of the EIQ prevents an absolute comparison of the external costs of different farming systems. For example, if the EIQ of system A is 50, and the EIQ of system B is 100, one might conclude that system A imposes fewer external costs than system B. However, one cannot conclude that the external costs associated with system A are half as much as those of system B. As a strictly ordinal measure, the EIQ may be an acceptable tool for guiding pesticide selection into less hazardous chemistries, but it is not an appropriate measure for comparing the value of public investment in different pest management strategies.

The second shortcoming of the EIQ is equally troublesome from an analytical economic perspective. If society values the individual elements of the EIQ at rates contrary to the weights the EIQ assigns to those elements, then the EIQ fails not only as a cardinal measure of external costs, but also may not accurately reflect the ordinal preferences of society. For example, to calculate the EIQ, the impacts on fish and humans are given weights of one, the impact on birds and bees are given weights of three, and the impact on beneficial arthropods is given a weight of five. But society may value all of these elements equally, or in relative degrees contrary to those imposed by the EIQ. As a result, chemicals with equal EIQ's may not have equal external costs associated with them. Furthermore, a chemical with a lower EIQ may impose a greater external cost than chemicals with higher EIQ's.

In short, by recognizing the importance of the individual characteristics of a pesticide in determining the pesticide's impact on the environment, the EIQ represents a step forward in providing an indication of the external costs of different pest management strategies. Nonetheless, the noted shortcomings of the EIQ challenge its relevance as an evaluative tool.

Higley and Wintersteen (H & W) (1992) also recognize the importance of differentiating between pesticides when examining the environmental impact of pesticide use. H & W identify eight environmental categories -- the same eight categories that are the focus of this study -- and, through the use of a contingent valuation survey, estimate the per acre costs inflicted on each category from the use of particular insecticides. The methodology H & W use to generate these estimates serves as the foundation for the methodology developed in the following chapter.

While the methodology developed by H & W and that used for this study both partition the environment into eight distinct categories, both examine the relative risk individual pesticides pose to each of these categories, and both use a contingent valuation survey of similar design to generate estimates of the value of avoiding adverse effects to these categories, there is a fundamental difference in the two methodologies. The H & W study was designed to facilitate the development of "environmental economic injury levels" to help producers make pesticide application decisions. As such, the contingent valuation survey of the H & W study was administered to farmers to elicit the farmers' monetary willingness to internalize the environmental risks of pesticide use.

In contrast, the overriding objective of this study is to evaluate the *external* costs of pesticide use. Therefore, the contingent valuation survey for this study is administered to the general population.

With respect to the third assumption, regarding the social value of the reduction in adverse effects being greater than the value of social benefits that may be forfeited by reducing pesticide use, the literature search revealed no documented analyses. While such a cost/benefit analysis is beyond the scope of this study, the methods for measuring the external costs of pesticide use developed and tested in the study do provide some of the key elements for such an analysis.

Section 2.3 Techniques Used to Measure Environmental Costs

An entire subdiscipline, environmental economics, is dedicated to the development and evaluation of techniques for measuring the social value of environmental amenities. "These techniques fall into two categories: indirect market methods, which attempt to infer from actual choices, such as choosing where to live, the value people place on environmental goods; and direct questioning approaches, which ask people to make tradeoffs between environmental and other goods in a survey context" (Cropper and Oates, 1992, p. 700). Within these two categories there are three methods that are widely used by environmental economists: the travel cost method (TC), the hedonic price technique (HP), and the contingent valuation method (CV).

The Travel Cost Method. The travel cost method has been used primarily to derive values for outdoor recreation sites and activities (Anderson and Bishop, 1986). The area around a recreational site is divided into zones. Zones are defined as areas in which, regardless of where you are in the zone, differences in travel costs to the site are negligible. "Trip" demand equations for the recreational service are derived by regressing the per capita number of trips from each zone to the recreational service on the travel costs involved in utilizing the service (e.g., entrance fees, lodging, food, transportation expenditures, etc.). The trip demands are then combined to generate an aggregate demand equation for the site. Environmental quality parameters can be incorporated into the aggregate demand equations to estimate the value of changes in the environmental quality of the site.

While the TC method is able to estimate the value of environmental amenities associated with a specific site, the ubiquitous nature of the environmental effects of agricultural pesticides precludes the use of the TC in this study. It is the value of the total environmental effects of pesticide use, not the value of a change in the environmental quality of a specific site, that is the focus of this study.

Hedonic Pricing Techniques. Hedonic pricing techniques infer the value of environmental amenities from the price of other commodities. For example, when one buys a home, one is purchasing more than just the interior living space. Social and environmental qualities of the area surrounding the home also play a role in determining the market value of the house. HP techniques attempt to disaggregate the price of commodities into a set of values for their various quality characteristics.

With respect to this study, hedonic pricing techniques may be able to generate estimates of the value of some of the environmental categories, but not all. For example, a hedonic pricing study on the cost of property may be able to isolate the value of groundwater quality, and possibly surface water quality. However, HP techniques would not be able to identify the value of marginal changes in the quality of the wildlife categories examined in this study. Furthermore, hedonic pricing techniques are not able to isolate the value of environmental quality changes due to specific types of pollution (e.g., pesticide migration); rather, the value of quality changes from all types of pollution are measured by HP techniques. And, in addition, HP estimates do not account for the non-use values (e.g., existence and bequest values) associated with environmental resources.

The Contingent Valuation Method. The contingent valuation method is a direct questioning technique that places respondents in a hypothetical market and asks them to make tradeoffs between the availability of environmental amenities and direct costs to the respondent. The most appealing aspect of the CV method is its flexibility. Because CV surveys place consumers in a hypothetical market, the survey can be designed to elicit willingness to pay estimates for any commodity the researchers desire. For example, CV surveys have been used to estimate the value of visibility in National Parks (Rae, 1983), waterfowl (Hammack and Brown, 1974), and nationwide improvements in water quality (Mitchell and Carson, 1981).

Such flexibility has particular appeal to this study. By sampling from the general population, a CV survey may address the non-use values overlooked by HP and TC methods. However, the contingent valuation method is not without its own problems, foremost of which are its potential biases. These biases are described in the following section.

Section 2.4 Potential Biases of Contingent Valuation Surveys

There are five primary sources of potential bias in contingent valuation surveys: (1) strategic bias; (2) hypothetical bias; (3) starting-point bias; (4) vehicle bias; and (5) information bias.

Strategic Bias. "Strategic bias occurs when respondents deliberately shape their answers to influence the study's outcome in a way that serves their personal interest" (Mitchell and Carson, 1989, p. 238). The implications of strategic bias for the accuracy of information emanating from CV surveys is obvious, generating considerable criticism of the technique in its earliest years of development. Empirical investigations of the existence of strategic bias in CV surveys, however, have allayed much of the concern. "... While acknowledging the absence of a basis for categorical conclusions in this regard, we suggest that at a minimum, a basis does exist for diminishing the 'priority' position in research agendas that the strategic bias hypothesis has enjoyed over the past decade" (Cummings, Brookshire, and Schulze, 1986, p. 26).

Hypothetical Bias. One of the fundamental criticisms of the CV method is the possibility of hypothetical bias. Many economists have rejected the CV method because they believe the hypothetical context of CV surveys fails to carry the import of an actual market transaction and, therefore, will not reveal the respondent's preferences (or demand for a particular good) accurately.

Mitchell and Carson consider the term "hypothetical bias" to be a misnomer. "It is important to note that there is no unique bias attributable to a scenario's lack of realism. The only unique effect of a scenario's lack of realism is not bias, but random, directionless error" (1989, p. 216). To reduce this "random error," Mitchell and Carson suggest pretesting to explore the survey instrument's weaknesses prior to administration, permitting the respondent ample time to think about the topic prior to asking the valuation questions, and avoiding putting pressure on uncertain respondents to answer the valuation questions. By thoughtful design of the CV survey instrument, most of the biases related to the hypothetical nature of the contingent market (with respect to both payment and the commodity being valued) may be resolved (Cummings, Brookshire, and Schulze, 1986).

Starting-Point Bias. Starting point bias occurs in bidding games in which the interviewer begins the bidding process with an initial bid. "It is possible that the [initial bid] will influence the respondent in some way, perhaps by suggesting the range over which the 'bidding game' would be played by the interviewer, perhaps by causing the respondent to agree too readily with bids in the vicinity of the initial bid in order to keep the game as short as possible" (Pearce and Turner, 1990, p. 150). While researchers have not come to a consensus with respect to the empirical evidence of starting-point bias, the use of "open-ended" valuation questions has been recognized as a way to avoid starting-point bias (Anderson and Bishop, 1986).

Vehicle Bias. Vehicle bias arises when respondents have such a strong aversion to or affection for the vehicle by which they are asked to pay for the commodity in question that their survey responses are affected. In choosing a payment vehicle a researcher should take two things into account: (1) the vehicle should be a realistic means by which the respondent would actually pay for the good, which will help reduce hypothetical bias; and (2) to avoid vehicle bias, respondents should be emotionally neutral toward the vehicle (Anderson and Bishop, 1986).

Information Bias. Information bias may be divided into three categories: (1) starting point and vehicle biases; (2) biases resulting from the order in which information is provided in the CV survey; and (3) biases resulting from the quantity and quality of information included in the survey instrument (Cummings, Brookshire, and Schulze, 1986). While there are survey design techniques for mitigating the effects of starting-point and vehicle biases, no such techniques are currently available for avoiding biases introduced by the ordering and/or amount of information in a CV survey. The researcher must simply try as much as possible to present information in a balanced, impartial manner.

Section 2.5 IPM Adoption Definitions

The IPM literature is extensive, covering a range of disciplines including entomology, plant pathology, horticulture and weed science, agronomy, sociology, economics, and more. Norton and Mullen (1994) published an annotated bibliography that included 173 articles related to the economics of IPM alone. Needless to say, there is a rich IPM literature in the other disciplines as well. And yet, despite the flurry of interest and concerted research efforts aimed at developing and evaluating IPM programs, a single definition of what constitutes the adoption of an IPM program has not emerged.

In 1987, Rajotte et al. conducted The National Evaluation of Extension's Integrated Pest Management (IPM) Programs covering twelve states, eight field and orchard crops, plus stored grains and an urban IPM program. It is the most comprehensive IPM evaluation effort to date. To facilitate the evaluation, three levels of IPM use -- non-IPM, low IPM, and high IPM -- were identified for nine of the twelve programs studied. For the other three programs, producers were characterized as either IPM or non-IPM producers. The lack of consistency in the number of levels of IPM available for use makes it difficult to aggregate the results of the evaluation across the crops and locations.

Separate criteria for assigning a level of IPM adoption to a producer were developed for each crop. For ten of the twelve programs, these criteria are based exclusively on the degree of scouting used by the producer, and who, exactly, scouts for pests (e.g., pesticide dealer, professional scouting consultant, farm employee, etc.). The problem with criteria of this sort is they do not recognize other IPM practices that are currently available for use on a crop, nor are they capable of incorporating practices that may be developed in the future. Therefore, as an IPM program evolves, the adoption criteria will also need to change, making it difficult to compare adoption rates over time.

In 1992, Hollingsworth et al. developed a point system for determining whether or not apple orchards in Massachusetts are grown under IPM. Different management techniques are assigned point values, with practices considered "essential to IPM" receiving a higher value than other practices. An orchard is considered to be grown under IPM if the grower scores 70% or more of the four hundred and twenty-five possible IPM points. Here, IPM adoption is a binary variable -- either a grower uses IPM or does not.

By incorporating alternative practices into the adoption definition, the Massachusetts criteria provide a more comprehensive picture of the extent to which a producer has embraced the concept of integrated pest management. As such, the Massachusetts criteria represent an improvement over those used by Rajotte et al. Nonetheless, there are some fundamental questions that remain with respect to the Massachusetts criteria.

The first issue is how the points are assigned to the various practices. It is unclear from the Hollingsworth et al. article whether or not the economic viability of a practice is considered in the identification of and assignment of points to alternative pest management practices. Are points assigned based on the ability of the practice to reduce pesticide use, on the profitability of adopting the practice, on a combination of profitability and efficacy, or on some other criteria? Furthermore, how should points be assigned to practices that are mutually exclusive or perfect substitutes?

The second issue has to do with the evolution of an IPM program. Namely, if new practices are introduced, old practices become obsolete, and/or an old practice is no longer economically viable from a producer's perspective, how are the points to be adjusted, if at all?

The third issue is easily resolved, but no less important. The binary adoption variable may be overly restrictive. When a crop has many alternative practices available, a producer who uses many of the practices may fail to accumulate the required number of points to be considered an IPM adopter.

Similarly, producers of a crop with few alternative practices may need to use all those available to be considered IPM producers. From an evaluative perspective one should ask whether finer gradations of adoption are more appropriate. If point systems of this nature are to be developed and used to determine IPM adoption for other crops, these issues must be addressed.

Section 2.6 Characteristics of IPM Adopters

Although a uniform definition of IPM adoption has yet to be embraced by the agricultural research and extension community, there have been number of studies examining the characteristics of farms and farmers that use IPM techniques.

Harper et al. (1990) used a maximum likelihood logit model to examine the relationship between various farm and farmer characteristics and the use of sweep nets for determining insect thresholds. They also looked at how the adoption of sweep nets affected the use of insecticides to control the rice stink bug. The signs of the coefficients of variables that were significant at the 20% level in the sweep net adoption model were as follows: education (-); proportion of neighboring land in pasture (-); proportion of rice acreage planted to semi-dwarf varieties (+); regional location (+); and attendance at field days (+). The signs of the coefficients of significant variables in the insecticide use model were as follows: sweep net (+); farmer age (+); education (+); field size (+); neighboring land in pasture or grain sorghum (+); regional location (+); per acre nitrogen application (+); county extension demonstrations (-); three of the four field days had positive parameters, the other field day had a negative parameter.

Fernandez-Cornejo et al. (1992) also used a logit model to examine the influence of farm and farmer characteristics on the adoption of one or more IPM techniques. They applied their model to vegetable farms in Florida, Texas and Michigan. The variables that were significant at the 10% level were: farm size (+), operator labor (+), unpaid family labor (+), debt/asset ratio (+ in the Florida and

Texas models, - in the Michigan model), irrigation (+), livestock production (-), and number of vegetables (+).

Ridgley and Brush (1992) looked at IPM adoption by California pear producers. The variables they found to significantly affect "overall" adoption of IPM at the 5% level were the following: education (+), fresh market strategy (+), family farm (+), and cooperative extension influence (+).

McNamara et al. (1991) examined factors affecting IPM adoption by Georgia peanut producers. The factors that were significant at the 10% level were: farmer age (+), education (+), percent total income from farming (+), yield (+), extension requests (+), forward contracting (+), and receipt of extension IPM literature (+).

Section 2.7 Concluding Remarks on the Literature Review

In the early IPM literature, social benefits of IPM were asserted based on its documented ability to reduce the total pounds of pesticides applied to productive acreage. However, no study actually undertook the task of estimating the magnitude of the presumed benefits. The study described in the following chapters endeavors to generate estimates of a portion of the social benefits of IPM programs, namely, reductions in the external costs of pesticide use.

The methodology of Chapter III draws on the existing IPM literature: the variation in the toxicity, mobility and persistence characteristics of pesticidal compounds, as noted by Kovach et al., is accounted for; the empirical IPM adoption literature guides the specification of the pesticide use models; and the work of Higley and Wintersteen serves as the foundation for the design of the contingent valuation survey used to estimate society's willingness-to-pay to avoid pesticide risks. Because the agricultural research community has not embraced a single definition of IPM adoption, a new definition is developed for use in this study and proposed for use in future evaluations of IPM programs.

Chapter III: Methodology

Section 3.1 Introduction

The model presented here can be used to estimate realized or potential reductions in the external costs of pesticide use attributable to the adoption of various levels of integrated pest management. The model is flexible enough to be applied to any crop in any location. There are, however, substantial data requirements that may preclude its application in certain situations.

The model is comprised of two principal components: (1) the ability of integrated pest management programs to reduce the risks pesticides pose to the environment and human health -- hereafter referred to simply as the environment, and (2) society's willingness to pay to reduce those risks. Estimation of these components involves defining the environment, identifying the risks individual active ingredients pose to the environment, and defining integrated pest management adoption. These issues are addressed in the following sections of this chapter.

Section 3.2 Fundamental Assumptions and Features of the Model

Two assumptions lie at the heart of the model. First, a linear and equal-proportional relationship between the amount of active ingredients applied to the study area and the degree of risk that pesticides pose to the environment is assumed. That is, a ten percent reduction in the amount of pesticides applied leads to a ten percent reduction in the degree of risk posed to the environment.

The second assumption is that the relationship between the external costs of pesticide use and the degree of risk posed by pesticide use is also linear and equal-proportional. The import of these two assumptions is that any change in the total pounds of active ingredient applied per year (lbs. a.i./year) results in an equal proportionate change in external costs. The interaction between pesticide use and external costs is illustrated in Figure 3.1 on the following page. The difference between the external costs without IPM and with IPM is the savings attributable to IPM programs.

Total pounds of active ingredient (a.i.) applied per year is not, in fact, the best measure of risk[1]. Pesticides differ with respect to their toxicity, mobility and persistence. That is, some pesticides pose a greater degree of risk to the environment than others. If IPM adopters are using less total pounds of active ingredients but are substituting highly toxic chemicals for relatively benign ones, it is difficult to argue risk has been reduced. In addition, a given pesticide may pose different levels of risk to different components of the environment. Therefore, the substitution of one pesticide for another may reduce the risk to one environmental component while raising the risk to others. To address this problem, the model divides the environment into eight broad categories and identifies three levels of pesticide risk (high, moderate, and low). Active ingredients are assigned one risk level for each environmental category.

One could use finer gradations of the environment, e.g., specific species. However, the toxicological data needed to assess the risk associated with a given active ingredient has not been consistently collected at the species level. Throughout this study, the eight environmental categories are referenced by the subscript i, where

$$i \in \{\text{ground water, surface water, acute human health, chronic human health, aquatic species, birds, mammals, arthropods}\}.$$

The environmental categories are the same as those mentioned in Chapter I, with the exception of the atmosphere. The costs associated with atmospheric deterioration are not considered here because data regarding the atmospheric effects of individual active ingredients is extremely limited.

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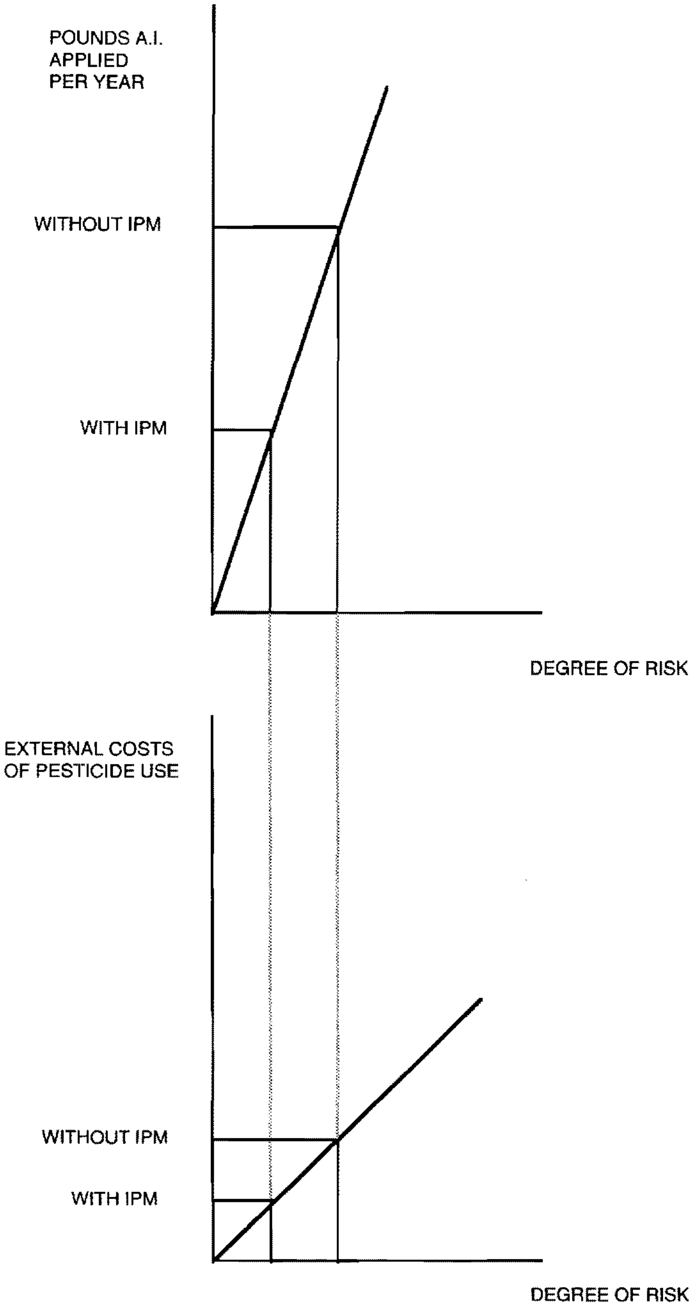
[1] The terms "pesticide" and "active ingredient" are used interchangeably within this paper. Formally, a "pesticide" may have more than one active ingredient. Nonetheless, many of the references cited in this chapter do not make a distinction between the two terms. For convenience, this convention is adopted here as well.

Figure 3.1 Assumed Relationship Between Pesticide Use and Degree of Risk and External Costs



The three levels of risk for each of the eight environmental categories imply twenty-four risk/environment classifications of pesticides. The risk levels are referenced by the subscript j. The twenty-four risk/environment pesticide classes are denoted by the subscript ij ($i=1$ to 8, $j=1$ to 3).

Rather than measure the change in the total pounds of all active ingredients, the model is designed to measure the change in the total pounds of each ij pesticide class attributable to IPM adoption. This information is coupled with estimates of society's willingness to pay to avoid risk level j to environmental category i to estimate the savings in external costs resulting from IPM adoption.

Section 3.3 Criteria for Assigning Risk Levels to Pesticides

The criteria used to classify active ingredients are developed in this section.

Ground Water Criteria. The assignment of ground water risk to an active ingredient is based on the Pesticide Leaching Matrix developed by the United States Department of Agriculture Soil Conservation Service. The matrix, presented below, accounts for both soil and pesticide properties (Becker et al., 1989).

Table 3.1 Pesticide Leaching Matrix

Soil Leaching Rating	Pesticide Leaching Ratings		
	Large	Medium	Small
High	High	High	Moderate
Intermediate	High	Moderate	Low
Nominal	Moderate	Low	Low

Unfortunately, not all pesticides have been assigned a "Pesticide Leaching Rating." When leaching ratings are not available, Gustafson's groundwater ubiquity score (GUS) is used to assign the groundwater risk level to the pesticide. The GUS is defined in terms of the soil half-life of the pesticide, $t_{1/2}^{soil}$, and the pesticide's soil sorption index, K_{OC}. Measures of $t_{1/2}^{soil}$ and K_{OC} are attained from Reviews of Environmental Contamination and Toxicology (Wauchope et al., 1992).

$$GUS = \log_{10}(t_{1/2}^{soil}) * (4 - \log_{10}(K_{OC}))$$

Gustafson classifies pesticides as "leachers" ($GUS > 2.8$), "nonleachers" ($GUS < 1.8$), and "transition" ($1.8 < GUS < 2.8$). Within this study, Gustafson's classifications translate to "high", "low", and "moderate" groundwater risk, respectively.

Surface Water Criterion. The assignment of surface water risk to an active ingredient is based on the Surface Runoff Matrix developed by the United States Department of Agriculture Soil Conservation Service. The matrix, presented below, accounts for both soil and pesticide properties (Becker et al., 1989).

Table 3.2 Surface Runoff Matrix

Soil Surface Loss Rating	**Pesticide Surface Loss Ratings**		
	Large	Medium	Small
High	High	High	Moderate
Intermediate	High	Moderate	Low
Nominal	Moderate	Low	Low

As with the Pesticide Leaching Matrix, not all pesticides have been assigned a "Surface Loss Rating." When runoff ratings are not available, three pesticide characteristics are evaluated: (1) water solubility, (2) soil K_{OC}, and (3) soil half-life. The U.S. Environmental Protection Agency (EPA) has defined "Red Flag" values for each characteristic (water solubility > 30 ppm; soil $K_{OC} < 300$; and soil half-life > 21 days). Within this study, if two or more of the red flag values are exceeded, the pesticide is considered a high risk to surface water. If one red flag value is exceeded, a moderate level of risk is assigned to the pesticide. A low level is assigned if none of the red flag values are exceeded.

Acute Human Health Criterion. The assignment of acute human health risk levels are based on the signal words assigned by the EPA to the formulated product (Becker et al., 1989). Because the EPA requires all pesticides to be labelled, every pesticide has a corresponding signal word. A risk level may, therefore, be assigned to any pesticide using this method. The table presented below has combined the two "CAUTION" relative toxicity categories into one relative risk category.

Table 3.3 EPA Signal Words and Assignment of Relative Risk Levels

Signal Word	Relative Risk	Relative Toxicity Ranking	Oral LD_{50}[2] (mg/kg)	Dermal LD_{50}[3] (mg/kg)	Inhal. LC_{50}[4] (ug/l)	Eye Effect	Skin Effect
Danger or Danger/Poison	High	Highly toxic	0-50	0-200	0-200	Corrosive	Corrosive
Warning	Moderate	Moderately toxic	50-500	200-2000	200 - 2000	Irritation for 7 days	Severe Irritation
Caution	Low	Slightly toxic	>500	>2000	>2000	Irritation for < 7 days	Moderate Irritation

Chronic Human Criteria. Criteria for assigning chronic health risk levels are by far the most difficult to establish. There are considerable data gaps in the chronic effects literature, and many of the studies that have been conducted have produced contradictory or inconclusive results. The lack of reliable data poses special challenges to the assignment of chronic health risk levels.

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[2] The orally ingested dose of a pesticide which kills 50% of the test population animals.

[3] The dose of a pesticide applied to the skin which kills 50% of test population animals.

[4] The concentration of a pesticide in air over a pre-determined period of time that kills 50% of the test population animals.

To assign chronic health risk levels, the results of tests evaluating the teratogenicity, mutagenicity, and carcinogenicity of each pesticide are consulted. The results of each test are classified with respect to how conclusive they are. The classifications and their definitions are as follows: (1) "Negative" -- conclusive evidence that the pesticide is not a teratogenic, mutagenic, or carcinogenic agent; (2) "No evidence" -- to date, there is no evidence indicating the pesticide is a teratogenic, mutagenic, or carcinogenic agent; (3) "Inconclusive" -- contradictory results have been observed, or available studies have been indeterminant; (4) "Data Gap" -- reliable studies have not been conducted; (5) "Possible" -- no conclusive information to date, however, the pesticide has certain physical properties that warrant further testing; (6) "Probable" -- the same as "possible", however the physical properties of "probable" pesticides lend themselves more readily to teratogenic, mutagenic, or carcinogenic effects than do pesticides classified "possible"; (7) "Positive" -- conclusive evidence is available demonstrating the pesticide is a teratogenic, mutagenic, or carcinogenic agent. The following table describes how the result classifications are used to assign a level of chronic risk to a pesticide.

Table 3.4 Criteria for Assigning Chronic Health Risk

Risk Level		
HIGH	MODERATE	LOW
One or more "Positive" classification	One or more "Data Gap", "Possible", or "Probable" classification	Results of all three tests are classified either "Negative", "No Evidence", or "Inconclusive", or some combination thereof

Aquatic Species Criteria. Studies of the effects of pesticides on aquatic species have revealed that a given pesticide does not affect all aquatic species to the same degree. For example, abamectin has a 96-hour LC_{50} value of 3.2 ppb for rainbow trout, whereas its LC_{50} for the eastern oyster is 430 ppb. Because we do not discern between aquatic species in this study, the highest level of risk a pesticide poses to any aquatic species is the risk level assigned to that pesticide.

In recognition of the fact that a pesticide cannot pose a risk to aquatic species if it does not reach surface water, the aquatic species risk level is weighted by the surface water risk level. A high or moderate surface water risk will not alter the aquatic species risk. A low surface water risk will, however, drop a high aquatic species risk to a moderate risk, and a moderate aquatic species risk to a low risk. The risk assignment criteria for aquatic species are summarized in the table below.

Table 3.5 Risk Assignment Criteria for Aquatic Species

Risk Level		
HIGH	MODERATE	LOW
96-hr LC_{50}[5] < 1 ppm and HIGH or MODERATE Surface Water Risk	1 ppm $< LC_{50} < 10$ ppm and HIGH or MODERATE Surface Water Risk or $LC_{50} < 10$ ppm and LOW Surface Water Risk	$LC_{50} > 10$ ppm or 1 ppm $< LC_{50} < 10$ ppm and LOW Surface Water Risk

Avian and Mammalian Criteria. As with aquatic species, the assignment of risk to a pesticide with respect to the avian and mammalian categories are based on the highest level of risk the pesticide poses

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[5] The concentration of active ingredient that kills half of the test population within 96 hours. All LC_{50}'s in Table 3.5 are 96-hour LC_{50}'s.

to any species within the category. These risk levels are not weighted by a mobility factor due to the ability of these species to enter the target area.

Table 3.6 Criteria for Assigning Avian and Mammalian Risk

Risk Level		
HIGH	MODERATE	LOW
LD_{50} < 50 ppm	50 ppm < LD_{50} < 500 ppm	LD_{50} > 500 ppm

There are some pesticides for which toxicological tests have not been conducted. The data needed to assign risk levels to these pesticides is simply not available. In these cases, a subjective decision must be made regarding the pesticide's risk level. Within this study, a pesticide is assumed to pose a moderate level of risk to any category where "data gaps" exist. The risk levels can be adjusted when the necessary data become available.

Arthropod Criteria. In most cases, the toxicity of pesticidal compounds to arthropods has not been formally assessed. To assign an arthropod risk level to an active ingredient, a variety of references are consulted: EXTOXNET, Smith (1993), Higley and Wintersteen (1992), Kovach et al. (1992), Worthing et al. (1987), U.S. Environmental Protection Agency, and the Royal Society of Chemistry[6]. If any of these references report an active ingredient is "highly toxic" or "extremely toxic" to any arthropod species, a high level of risk is assigned to that pesticide. If none of the references report the active ingredient is highly toxic to arthropods and any reference reports the a.i. is "moderately toxic" to any arthropod, a

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[6] Complete citations of these references appear in the bibliography.

moderate level of risk is assigned. A low level of risk is assigned to pesticides that none of the references have identified as posing a high or moderate level of risk to arthropods[7].

Section 3.4 Estimating the Effects of IPM Adoption on Pesticide Use

Using the criteria developed in section 3.3, the pesticides applied within the study area are classified with respect to risk level, j, and environmental category, i. The total pounds of an active ingredient class applied per year to the entire study area is denoted Use_{ij}. Use_{ij} is comprised of two elements, as depicted in Equation 3.1. The first element is the amount of class ij active ingredients applied to all crops within the study area other than the study crop. The second element, Use_{ij*}, represents the amount of class ij active ingredients applied to the study crop.

$$Use_{ij} = \sum_{a=1}^{n-1}(Use_{ija}) + Use_{ij*} \tag{3.1}$$

$$\textit{where } n = \textit{number of crops grown within the study area}$$

An IPM program for the study crop affects Use_{ij}, and hence the external costs in the study area, through Use_{ij*}. Regression analysis is used to examine the relationship between Use_{ij*} and various levels of IPM. Equation 3.2 represents the general form of this relationship.

$$Use_{ij*} = f\ (\textit{IPM adoption, acreage of study crop, pest severity, farmer characteristics}) \tag{3.2}$$

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[7] For Kovach et. al., active ingredients for which the Bee Effects component (BEE) of the Environmental Impact Quotient is greater than 30 and/or the Beneficials Effects component (BENE) is greater than 50 are considered to pose a high risk to arthropods. A.i.'s for which $15 < BEE <= 30$ and/or $25 < BENE <= 50$ are considered a moderate risk to arthropods. A.i.'s for which $BEE <= 15$ and/or $BENE <= 25$ are considered low risk.

Four levels of IPM adoption are identified by the model: (1) high level adoption (HIGH); (2) mid level adoption (MID); (3) low level adoption (LOW); and (4) no adoption (NON). The criteria for assigning an adoption level to a producer are developed in section 3.7, below.

The proposed specification of the econometric model is represented by Equation 3.3. The relationship between acreage planted to the study crop (ACRES) and pesticide use is hypothesized to be logarithmic. The rationale behind this hypothesis is that the larger the acreage, the more managerial skill/inputs are likely to be applied, which should reduce per acre pesticide use. Total use would then be increasing at a decreasing rate.

$$\begin{aligned}
Use_{ij*} &= \alpha_0 + \alpha_1 * Education + \alpha_2 * Income\% + \alpha_3 * Severity \\
&+ \alpha_4 * IPM_{Low} + \alpha_5 * IPM_{Mid} + \alpha_6 * IPM_{High} \\
&+ \beta_1 * \ln(ACRES) + \beta_2 * IPM_{Low} * \ln(ACRES) \\
&+ \beta_3 * IPM_{Mid} * \ln(ACRES) + \beta_4 * IPM_{High} * \ln(ACRES)
\end{aligned} \tag{3.3}$$

The Education variable refers to the highest education level attained by the principal operator of the farm. It is a discrete variable measured in years. The "Income %" variable refers to the percentage of the farm owner's income that is generated by the crop in question. The Severity variable is an index of the severity of pest infestation. It may be discrete or continuous, depending on the available data.

The IPM adoption levels are dummy variables that affect both the slope and the intercept of the regression line. The variable representing the level the producer employs is set equal to one; the remaining IPM adoption variables are set equal to zero.

To estimate the realized reductions in external costs attributable to an IPM program, the model needs an estimate of the proportional change in Use_{ij} induced by the adoption of IPM on the study crop.

This entails comparing an estimate of the current level of Use_{ij} (Use_{ij} with IPM) to an estimate of what the level of Use_{ij} *would be* in the absence of the IPM program (Use_{ij} without IPM). The realized proportional reduction of Use_{ij} is expressed by Equation 3.4.

$$Realized_{ij} = 1 - \frac{E[Use_{ij}\ with\ IPM]}{E[Use_{ij}\ without\ IPM]} \tag{3.4}$$

The derivations of Use_{ij} with IPM, and Use_{ij} without IPM are illustrated in Equations 3.5 and 3.6, respectively.

$$E[Use_{ij}\ with\ IPM] = \sum_{a=1}^{n-1} E[Use_{ija}] + \sum_{k=1}^{4} E[Use_{ijk*}] \tag{3.5}$$

The subscript k is used to reference the IPM adoption levels, where k ϵ {NON, LOW, MID, HIGH}. The first element of Equation 3.5 is as described in Equation 3.1 above. The second element is the total amount of pesticide class ij applied to the study crop -- the sum of the amount applied under each adoption level.

$$E[Use_{ij}\ without\ IPM] = \sum_{a=1}^{n-1} (E[Use_{ija}]) + E[Use_{ij*,\ w/o}] \tag{3.6}$$

In Equation 3.6, $\text{Use}_{ij*,\ w/o}$ represents the amount of class ij that would have been applied to the study crop in the absence of the IPM program, i.e., if k=NON for all producers.

The derivation of Use_{ijk*} and $\text{Use}_{ij*,\ w/o}$ are illustrated by Equations 3.7 and 3.8, respectively. The coefficient estimates used in these equations are obtained from the estimation of Equation 3.3, above.

$$E[Use_{ijk*}] = \hat{\alpha}_0 + \hat{\alpha}_1 * E[Education_k] + \hat{\alpha}_2 * E[Income\%_k] + \hat{\alpha}_3 * E[Severity_k] + \hat{\beta}_k * \ln(ACRES_k) \tag{3.7}$$

Where E[Education$_k$] = mean education level of producers using IPM level k

E[Income %$_k$] = mean percentage of farm owner's income, for farms using IPM level k, generated by the study crop

E[Severity$_k$] = mean pest severity level afflicting farms using IPM level k

ACRES$_k$ = number of study crop acres on which IPM level k is used

$$E[Use_{ij*,\ w/o}] = \hat{\alpha}_0 + \hat{\alpha}_1 * E[Education] + \hat{\alpha}_2 * E[Income\%] + \hat{\alpha}_3 * E[Severity] + \hat{\beta}_{NON} * \ln(ACRES) \tag{3.8}$$

Where E[Education] = mean education level of all study crop producers

E[Income %] = mean percentage of all farm owner's income generated by the study crop

E[Severity] = mean pest severity level afflicting all study crop farms

ACRES = total number of study crop acres

The estimation of potential reductions in Use$_{ij}$ is very similar to the estimation of realized reductions described above. The difference is that while realized reductions focus on the use of pesticide class ij resulting from the current extent of IPM adoption, potential reductions focus on the use of class ij that would result if all the study crop acres adopted a given level of IPM. The derivation of potential reductions is illustrated in Equations 3.9 through 3.11.

$$Potential_{ijk} = 1 - \frac{E[Use_{ij} \text{ with all IPM } k]}{E[Use_{ij} \text{ without IPM}]} \tag{3.9}$$

The denominator of Equation 3.9 is the same as in Equation 3.4. The numerator is defined as follows.

$$E[Use_{ij} \text{ with IPM } k] = \sum_{a=1}^{n-1} E[Use_{ija}] + E[Use_{ij*,\,k}] \tag{3.10}$$

and

$$\begin{aligned} E[Use_{ij*,\,k}] = \hat{\alpha}_0 + \hat{\alpha}_1 * E[Age] + \hat{\alpha}_2 * E[Education] + \\ \hat{\alpha}_3 * E[Severity] + \hat{\beta}_k * \ln(ACRES) \end{aligned} \tag{3.11}$$

Where E[Age], E[Education], E[Severity], and ACRES are defined per Equation 3.8

Equations 3.4 and 3.9 may be used to estimate realized and potential savings in external costs attributable to an IPM program. Exactly how this estimation is done is the subject of the next section.

Section 3.5 Estimating the Savings in External Costs from IPM Adoption

A contingent valuation survey was designed and administered to estimate a household's willingness to pay to avoid each risk level to each environmental category. This variable is defined as WTP_{ij}. By combining WTP_{ij} with $Realized_{ij}$ or $Potential_{ijk}$, realized or potential savings in external costs attributable to an IPM program may be calculated. The linearity assumptions described in section 3.2 greatly simplify this calculation.

To estimate the total savings, the savings for each ij class (Realized Save_{ij} or Potential Save_{ijk}) must first be calculated. This calculation involves multiplying household willingness to pay to avoid the use of pesticide class ij by the number of households within the study area (Pop) and the proportionate reduction in the use of pesticide class ij.

$$\textit{Realized Savings}_{ij} = \textit{WTP}_{ij} * \textit{Pop} * \textit{Realized}_{ij} \qquad (3.12)$$

$$\textit{Potential Savings}_{ijk} = \textit{WTP}_{ij} * \textit{Pop} * \textit{Potential}_{ijk} \qquad (3.13)$$

The total savings in the external costs of pesticide use from IPM adoption on the study crop may be calculated by simply summing over all risk/environmental category classifications.

$$\textit{Total Realized Savings}_{IPM} = \sum_{i=1}^{8} \sum_{j=1}^{3} \textit{Realized Savings}_{ij} \qquad (3.14)$$

$$\textit{Total Potential Savings}_{k} = \sum_{i=1}^{8} \sum_{j=1}^{3} \textit{Potential Savings}_{ijk} \qquad (3.15)$$

There are two aspects of the model yet to be explained, namely "How does one define a study crop and study area?" and "What constitutes IPM adoption?" These issues are addresed in the next two sections of this chapter.

Section 3.6 Defining the Study Crop and Area

There are two primary considerations in selecting a study crop and area: (1) the existence of an established IPM program for the crop, and (2) the availability of data regarding the use of pesticides within the study area and extent of adoption of IPM practices on the study crop. The study area may be large or small, as long as the pest complex and the available pest management practices are consistent throughout. Defining the study area in county units can be useful, because that is how the necessary agricultural production data are generally expressed.

A producer survey is needed to identify the pesticides and the pest management practices used on the study crop in the study area. In some instances, production data are available through secondary sources, such as the United States Department of Agriculture (USDA) or state extension services. More often than not, a survey will need to be designed and administered to collect primary data. In this thesis, secondary data collected by the National Agricultural Statistics Services (NASS), USDA, were used to evaluate apple IPM programs in Virginia.

The producer survey must provide three basic types of farm-level data: (1) farm characteristics, e.g., study crop acreage, farmer education level, percentage of farm income generated by the study crop, pest severity indices, etc.; (2) pest management practices employed, e.g., scouting, trap crops, pheromone traps, resistant varieties, etc.; and (3) the total pounds of each pesticidal active ingredient applied per year. While producers do not typically have pesticide use data in the form needed, their records should indicate, for each pesticide, the application rates, the number of applications, and the acreage treated at each rate. This information plus the pounds of active ingredient per pound of pesticide can be used to calculate the total pounds of each a.i. applied per year.

Pesticide use data for the other crops grown in the study area are also needed. Some states collect accurate pesticide use data on a regular basis, other states have extension agents and other agricultural experts estimate pesticide use, and still other states do not have any type of data regarding pesticide use.

A single study cannot be expected to collect the necessary pesticide use data for crops other than the study crop. Yet, without this data the model cannot be employed. The study crop and area should be selected with this in mind.

Section 3.7 Defining Levels of IPM Adoption

Over the past twenty-five years, integrated pest management has generated substantial interest from agricultural producers, researchers, and extension services. Hundreds of studies have been conducted evaluating various aspects of IPM programs. Yet, despite the volume of literature, the agricultural community has not embraced a definition of IPM adoption. Instead, most studies have developed unique criteria for assigning a level of IPM adoption to a producer. This lack of a common measure of what constitutes IPM adoption makes it difficult to aggregate results across studies.

The variability in adoption criteria is understandable. IPM programs are a conglomeration of pest management practices designed to combat the particular pests that afflict a crop in a specific geographical location. Because pest complexes vary across crops and locations, IPM programs vary as well. An adoption definition that is flexible enough to overcome this tendency toward program-specific criteria must be founded on those aspects of IPM that transcend crops and regions.

The "integration" of pest management practices is the underlying principle of IPM. Equation 3.16 represents an algorithm for assigning a level of IPM adoption to a producer based on the degree to which the producer has integrated the relevant pest management practices. By focussing on the degree of integration (DOI) rather than the specific practices that are adopted, the criteria for assigning an adoption level are maintained across programs, even though the available practices change.

To implement the algorithm, the pests that pose an economic threat to a crop are divided into classes -- broad groups that share fundamental characteristics (e.g., arthropods, weeds, fungi/diseases). Three factors are then considered: (1) how important is each class of pest compared to the other pest classes that affect the crop; (2) what IPM practices are available to the producer for controlling each pest class; and (3) what IPM practices does the producer actually employ. The proportion of available practices that the producer employs for each class is weighted by the importance of the class to determined the producer's IPM adoption level.

$$DOI = \frac{\sum_{c=1}^{n}\left(\frac{employ_c}{available_c} * importance_c\right)}{\sum_{c=1}^{n} importance_c} \tag{3.16}$$

Where n = number of relevant pest classes

importance ϵ {0, 1, 2, 3}

$available_c$ = number of IPM practices available to control pest class c

$employ_c$ = number of IPM practices producer employs to control class c

A discrete scale of zero to three is used to rank the relative importance of controlling each pest class, where zero means it is not at all important and three means it is very important to control the class. The importance of controlling a class is based on the relative threat of economic damage it poses to the crop. In other words, a pest class with an importance ranking of three poses a serious economic threat to the crop, and a class with an importance level of zero poses no economic threat.

An IPM practice is considered "available" only if, on average, it is cost effective in controlling the relevant pest class with respect to the crop and location. For example, if narrow row spacing of a crop reduces pest populations but adversely effects yields more than enough to offset the *producer's* economic gains from lowering the pest population, it is not an "available" practice. In addition, if two techniques are substitutes or mutually exclusive, one or the other would be considered available, but not both.

A producer may be assigned one of four levels of IPM adoption depending on their DOI score. Because the DOI is a continuous variable, the adoption levels are defined by continuous ranges. The DOI range for each adoption level is as follows: no adoption, DOI = [0, 0.1); low adoption, DOI = [0.1, 0.25]; mid level adoption, DOI = (0.25, 0.6]; high level adoption, DOI = (0.6, 1]. The adoption ranges selected are based strictly on the subjective opinion of this researcher.

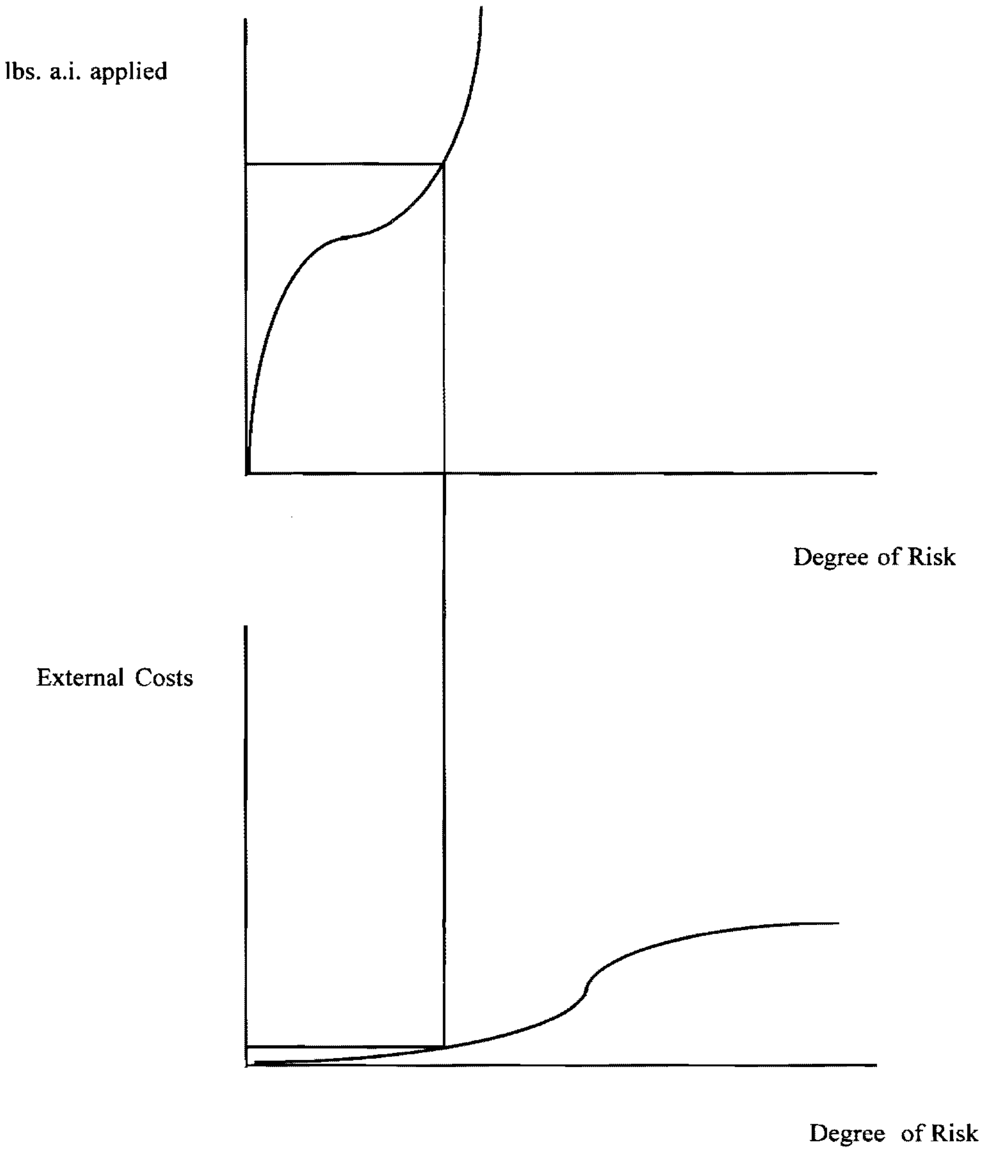
Section 3.8 Concluding Remarks on the Model

There are considerable obstacles to measuring the savings in the external costs of farming attributable to IPM programs. The most tenuous facets of the model described above are the two linearity assumptions discussed in Section 3.1. Rather than linear, the relationships between the amount of pesticides applied to the study area and the degree of risk pesticides pose to the environment and human health on the one hand, and the degree of risk and the external costs of pesticide use on the other, are more likely to be those illustrated by Figure 3.2. Over small ranges, however, the linearity assumptions may not be unreasonable.

Another drawback of the model is its extensive data requirements. If they can be met, however, the model's flexibility more than offsets this drawback. A substantial amount of the data generated for use in this study is relevant to similar studies. For example, the WTP_{ij} estimates presented in the next chapter can be used anywhere in the United States. In addition, the pesticide risk levels assigned for use in this study are valid for other studies.

The model is rather myopic with respect to the study area. The population affected by the use of pesticides is restricted to the study area. As a result, the migration of pesticides applied within the study area to ecosystems outside the study area is not considered. In addition, existence, option, and bequest values are not accounted for anyone residing outside the study area. Together, these imply pop_i is underestimated, leading to conservative estimates of Realized $Savings_{IPM}$ and Potential $Savings_k$.

Figure 3.2 Hypothesized Relationship Between Pounds of Active Ingredient and Degree of Risk and External Costs



Conversely, not considering the potential migration of pesticides applied outside the study area into the study area may cause estimates of realized_{ij} and potential_{ijk} to be inflated. This would tend to pump up estimates of Realized Savings_{IPM} and Potential Savings_{k}. The cumulative effect of these estimation errors is difficult to assess. Within this study, the errors are assumed to offset each other, with their cumulative effect equal to zero.

Two potentially substantial contributors to the external costs of farming, namely fertilizer use and soil erosion, are not presently included in the model due to time, resource, and funding constraints. There is, however, nothing inherent to the model that precludes their consideration. They may be readily added to give a more complete picture of the value of IPM programs.

Despite limitations due to its strong assumptions, the model described above does provide: (1) a set of consistent criteria for assigning relative risk levels to pesticides; (2) an algorithm for assigning levels of IPM adoption; and (3) a strategy for estimating the savings in the external costs of pesticide use attributable to IPM programs. Although the model is applied to apple and peanut production in Virginia in this study, it can be readily adapted and applied to other IPM programs in other states.

Chapter IV: Estimating WTP_{ij}

Section 4.1 Introduction

To estimate the savings in external costs attributable to integrated pest management programs, the model developed in Chapter III needs an estimate of society's willingness to pay to avoid pesticide risks to the eight environmental categories. Unfortunately, avoiding pesticide risks to the environment is not a market commodity. There is no market price revealing its social value. There are reasonable market proxies for some of the environmental categories (e.g., insurance premiums for pesticide applicators may reflect the social value of avoiding acute human pesticide risks), but not all of the categories have such proxies. Furthermore, no one proxy is suitable for more than one category. To obtain the necessary willingness to pay estimates, one of the non-market valuation techniques reviewed in Chapter II must be employed. Of the available techniques, the method of contingent valuation was chosen. This decision was based on the fact that society's willingness to pay to avoid pesticide risks to each of the environmental categories could be estimated with a single, well designed survey.

In this chapter, the contingent valuation survey (CVS) designed for the study is discussed, along with the administration of the survey. The results of the survey are also presented and used to examine the issue of payment vehicle bias in CVS's.

Section 4.2 Estimating Society's Willingness to Pay to Avoid Pesticide Risks

The CVS for this study was designed to elicit estimates of society's willingness to pay (WTP) to avoid risks to the environment and human health from pesticide use. The survey is comprised of three parts: (1) an introduction; (2) a questionnaire; and (3) demographic information. A copy of the survey is printed in the Appendix to Chapter IV.

A brief overview of the value of pesticides as an agricultural input, and the potential for pesticides to damage the environment and human health serves as the survey's introduction. Examples of possible damages incurred from pesticide use are also presented. A short cover letter establishing the legitimacy of the research accompanies the introduction.

The questionnaire begins by asking the respondent's average monthly grocery bill. This question serves two purposes: (1) it is relatively easy to answer, thereby getting the respondent involved in the survey without too much effort; and (2) it serves as a baseline to which the respondent can relate their answers to the willingness to pay questions.

The willingness to pay questions are formatted as follows. A brief definition, to be applied within the context of the survey, of "high risks to the environment and human health from pesticide use" is provided. Conveying a concept as complex as risk exposure concisely and in language that is accessible to the entire survey population is a considerable challenge. Inevitably, some respondents will have a more sophisticated idea of risk exposure than others in the survey population. One must, however, write to the lowest common denominator. As a result, the survey's definitions of risk exposure are comprised of generalized terms (e.g., "very likely," "somewhat likely") that are subject to individual interpretation. A degree of precision is sacrificed for brevity, and to avoid discouraging potential respondents through the use of language they may perceive as intimidating.

Next, the respondent is asked their willingness to pay to avoid high risks via two payment vehicles: (1) an increase in their monthly grocery bill; and (2) an increase in their yearly federal income tax liability. These vehicles were chosen because they are plausible means by which consumers would pay for prohibiting or restricting the use of an entire class of pesticides.

In the absence of cheap substitutes, short run farm costs would likely increase if the use of a class of pesticides was prohibited. This increase would, in turn, be passed on to the consumer in the form of higher food prices.

For reasons discussed in Chapter I, federal and state agencies are the primary source of funds for research aimed at finding effective substitutes for pesticides. State and federal income taxes are the most probable means by which these agencies would generate funds to support research of this kind. State income taxes are not included as a vehicle in the survey because it is not a viable vehicle for the entire survey population -- some states do not levy a tax on income.

After answering the WTP questions, the respondent is asked to identify how important they feel it is to avoid high risks to each of the eight environmental and human health categories considered in the study. A zero to six scale, where zero means not at all important and six means very important, is used for this purpose.

The same format -- risk definition, willingness to pay questions, and assignment of importance levels -- is repeated for moderate and low risks.

The demographic information collected at the end of the survey consists of the respondent's income, gender, age, family size, and whether the respondent lives in an urban or rural area. These variables are not used in this study, but were collected for future analysis.

Section 4.3 Administration of the Survey

The survey was administered by mail to a random sample of three thousand United States residents. The pool of potential respondents was generated from a data base containing motor vehicle registration records, and all local telephone directories within the United States. In states where disclosure of motor vehicle registration information is prohibited, names and addresses were drawn exclusively from local telephone directories.

Initially, the survey was to be administered in accordance with the Dillman method for mail surveys (Dillman, 1978). The Dillman method consists of three separate mailings: (1) mailing the survey to all addresses drawn for the sample; (2) mailing a reminder postcard seven to ten days later to all the sample addresses; and (3) one week after the postcard, mailing a second survey, with a reminder, to those addresses that are deliverable and have not yet returned a completed questionnaire. Unfortunately, due to budget considerations, the Dillman method was not employed. Instead, one mailing of the survey was sent to all of the sample addresses, the reminder postcard was not sent, and 833 addresses, selected at random from those that were deliverable and had not returned a completed survey, were sent a second survey twenty-five days after the first survey was posted.

A breakdown, by state, of the number of addresses drawn, the number of undeliverable addresses, the number of usable responses, and the response rate as a percentage of deliverable addresses is presented in Appendix Table A4.1. The number of undeliverable addresses is the number of surveys returned to sender after the first mailing. This is, in all likelihood, an underestimate of undeliverable addresses. Consequently, the response rate reported in Table A4.1 is also underestimated. This assertion is based on the fact that, in some instances, surveys that were not returned to sender after the first mailing were returned to sender after the second mailing. It is, therefore, reasonable to conclude that some undeliverable surveys were never returned to sender.

Virginia represents the largest portion of the pool because that is where the pilot survey was conducted. In addition, an interstate comparison of willingness to pay estimates is of interest. Financial constraints precluded drawing sufficient sample sizes from each state to facilitate such a comparison. As a result, it was decided to compare as many states as possible. Because this study is concerned with Virginia apple and peanut production, the number of potential Virginia respondents was increased to ensure Virginia had a sufficient number of responses to be included as one of the comparison states.

Section 4.4 Survey Results

The purpose of the contingent valuation survey is to estimate the WTP_{ij} values for the model developed in the preceding chapter. To minimize the length of the questionnaire, the CVS asked respondents to reveal their willingness to pay to avoid a given level of risk to the environment as a whole (i.e., WTP_j), rather than their willingness to pay for each category (WTP_{ij}). The importance rankings are used to infer the respondents' WTP_{ij} from their revealed WTP_j.

A respondent's willingness to pay, through a particular vehicle, to avoid a level of risk to an environmental category is calculated using equation 4.1.

$$WTP_{ij} = \frac{Importance_i}{\sum_{i=1}^{8} Importance_i} * WTP_j \tag{4.1}$$

At the heart of equation 4.1 is the assumption that the proportion of total importance a category receives is equal to the proportion of WTP_j that the respondent would grant to the category. The following example is used to illustrate this calculation.

A respondent is willing to pay $10.00 extra per month in groceries or $120.00 extra per year in federal income tax to avoid high risks to the environment and human health from pesticide use. The level of importance the respondent assigns to each environmental and human health category is shown in Table 4.1. Their willingness to pay to avoid high risks to each category would then be the figures reported in the column "$WTP_{i,\,High}$/Month."

The country-wide results of the contingent valuation survey are presented in Tables 4.2 and 4.3.

Section 4.5 The Issue of Payment Vehicle Bias

The contingent valuation method has received a lot of attention in the economic literature. There are considerable arguments against this valuation technique, foremost of which are its potential biases described in Chapter II. Of the many biases to which contingent valuation surveys are subject, the issue of payment vehicle bias has received relatively little attention.

Table 4.1 An Example of the WTP_{ij} Calculation

Willingness to pay in increased monthly grocery bill to avoid high risks to the environment and human health from pesticide use	$10.00

Category (i)	Importance Level	Importance Level/TOTAL	$WTP_{i, High}$/Month
Acute Human Health	4	.1	$1.00
Chronic Human Health	5	.125	$1.25
Groundwater	5	.125	$1.25
Surface Water	6	.15	$1.50
Aquatic Species	6	.15	$1.50
Avian Species	5	.125	$1.25
Mammalian Species	5	.125	$1.25
Arthropods	4	.1	$1.00
TOTAL	40		$10.00

Table 4.2 Willingness to Pay Estimates, by Vehicle and Risk Level for the United States

	Mean	Minimum	Median	Maximum
Monthly Grocery Bill	$293.43 (163.05)	$40.00	$280.00	$1500.00
WTP through an increase in monthly grocery bill to avoid high risks	$52.51/mo. (95.02)	$ 0	$25.00	$880.00
Percent increase in monthly grocery bill to avoid high risks	19.34% (32.00)	0 %	10.00%	312.5%
WTP through an increase in yearly federal income tax to avoid high risks	$69.96/yr. (149.09)	$ 0	$ 0	$1200.00
WTP through an increase in monthly grocery bill to avoid moderate risks	$37.95/mo. (88.73)	$ 0	$20.00	$860.00
Percent increase in monthly grocery bill to avoid moderate risks	13.27% (27.51)	0 %	5.7 %	266.67%
WTP through an increase in yearly federal income tax to avoid moderate risks	$49.49/yr. (109.31)	$ 0	$ 0	$1000.00
WTP through an increase in monthly grocery bill to avoid low risks	$28.06/mo. (84.73)	$ 0	$9.00	$820.00
Percent increase in monthly grocery bill to avoid low risks	9.70% (25.24)	0 %	2.2 %	266.67%
WTP through an increase in yearly federal income tax to avoid low risks	$32.23/yr. (72.80)	$ 0	$ 0	$600.00

Table 4.3 U.S. Willingness to Pay Estimates by Vehicle, Environmental Category, and Risk Level

Environmental Category	High Risk			Moderate Risk			Low Risk		
	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Acute Human									
Groceries ($/Month)	6.00	9.69	443	4.56	9.61	434	3.32	9.46	432
Tax ($/Year)	8.98	20.09	434	6.37	14.34	423	4.21	9.80	423
Chronic Human									
Groceries ($/Month)	7.08	13.61	443	5.28	12.77	434	3.84	11.77	432
Tax ($/Year)	9.61	20.64	434	6.81	14.82	423	4.48	10.13	423
Ground Water									
Groceries ($/Month)	6.97	13.34	443	5.20	12.72	434	3.82	11.78	432
Tax ($/Year)	9.50	20.46	434	6.69	14.69	423	4.40	9.96	423
Surface Water									
Groceries ($/Month)	6.76	12.61	443	4.89	11.62	434	3.68	11.58	432
Tax ($/Year)	9.18	19.70	434	6.42	14.36	423	4.22	9.59	423
Aquatic Species									
Groceries ($/Month)	6.65	12.46	443	4.84	11.61	434	3.58	10.82	432
Tax ($/Year)	9.13	19.90	434	6.31	14.21	423	4.13	9.42	423
Avian Species									
Groceries ($/Month)	6.26	11.97	443	4.65	11.49	434	3.43	10.69	432
Tax ($/Year)	8.29	17.68	434	5.85	13.25	423	3.74	8.62	423
Mammalian Species									
Groceries ($/Month)	6.27	11.99	443	4.56	10.85	434	3.45	10.69	432
Tax ($/Year)	8.30	17.90	434	5.89	13.45	423	3.87	8.93	423
Arthropods									
Groceries ($/Month)	5.51	9.60	443	4.09	9.31	434	3.07	9.32	432
Tax ($/Year)	7.42	16.07	434	5.26	12.41	423	3.48	8.38	423

The possibility of payment vehicle bias in contingent valuation surveys has serious analytical implications. If the choice of vehicle is capable of skewing data, the following questions may arise. "Which vehicle, if any, generates the 'true' data?" "How should a vehicle-induced divergence of responses be reconciled?" "Is it legitimate to conduct a CVS with only one vehicle?" And, ultimately, "Can accurate conclusions be drawn from a contingent valuation survey?"

Conclusive answers to these questions are not within the scope of this study. However, by examining the possibility of vehicle bias in the data generated by this survey, suggestions for the design of future surveys should emerge. In addition, if vehicle bias is detected, the techniques used to reconcile the difference between the vehicles' WTP estimates may be applicable to other studies.

A vehicle for eliciting willingness to pay estimates should meet the following criteria: (1) the vehicle should be tangible to the respondent, i.e. the respondent should readily understand how the vehicle enters their budget constraint; and (2) the vehicle should be a plausible means by which the resource would enter into the actual market. While both of the vehicles used in this study satisfy these criteria, as a pair they are not ideal for examining the issue of payment vehicle bias.

The vehicles used in the CVS are expressed in different time intervals. Income taxes are paid yearly, while groceries are likely to be purchased on a monthly or weekly basis. To avoid burdensome calculations on the part of the respondent, the income tax vehicle is expressed as willingness to pay per year. To minimize the gap between the income tax and grocery payment interval, the grocery vehicle is expressed as WTP per month.

Considering the difference in payment intervals, there are a number of reasons why the means of the WTP estimates from the two vehicles may not coincide. For example, a respondent may be unable or unwilling to perform the calculation necessary to equate their WTP responses, even if they are indifferent to the choice of vehicle. Comparison of the means, therefore, is not a satisfactory test for payment vehicle bias when payment intervals differ. An alternative test is needed.

The test developed here compares the number of respondents that "overtly reject" one vehicle to the number of respondents that "overtly accept" the other vehicle. A respondent is said to overtly reject a vehicle if their WTP through that vehicle is zero and their WTP through the other vehicle is greater than zero. Overt acceptance of a vehicle is defined as a positive WTP response for the vehicle. If the respondent's WTP for both vehicles is zero, it is unclear whether they are protesting (i.e., rejecting) one or both vehicle(s), or they accept one or both vehicle(s) and are simply revealing their true valuation of the resource.

Table 4.4 shows the number of respondents that overtly rejected each vehicle, the number of respondents that overtly accepted each vehicle, and the number of overt rejections as a percentage of overt acceptances. Row III of table 4.4 shows that, for all three risk levels, over thirty percent of the respondents that overtly accepted the grocery vehicle also overtly rejected the income tax vehicle. This should be sufficient evidence to conclude the survey population has rejected the income tax vehicle. The willingness to pay estimates generated from the income tax vehicle are, therefore, biased and should not be used for analysis. While the reasons for rejection of the tax vehicle cannot be determined, one can speculate that the negative attitude toward the word "taxes" by a significant portion of the U.S. population contributed to this vehicle rejection.

The grocery bill vehicle, on the other hand, appears to have been accepted by the survey population. With respect to high risks, less than three percent of respondents overtly rejected, while more than eighty-three percent of respondents overtly accepted the grocery bill vehicle. With respect to moderate risks, the grocery bill vehicle was overtly accepted by more than seventy-six percent and overtly rejected by less than two percent of respondents. Similarly, to avoid low risks, more than sixty-three percent overtly accepted the grocery bill vehicle, with an overt rejection rate of less than five percent. Considering the low overt rejection and high overt accpetance rates, the willingness to pay estimates generated by the grocery bill vehicle should be reasonable approximations to the value society places on avoiding pesticide

Table 4.4 A Test for Payment Vehicle Bias

	High Risks	Moderate Risks	Low Risks
I. # of responses where Grocery WTP > 0 and Income Tax WTP = 0	129	116	86
II. # of responses where Grocery WTP > 0	367	333	276
III. I. as a percentage of II.	35.15%	34.84%	31.16 %
IV. # of responses where Income Tax WTP > 0 and Grocery WTP = 0	6	4	9
V. # of responses where Income Tax WTP > 0	233	208	188
VI. IV. as a percentage of V.	2.58 %	1.92 %	4.79 %

risks to the environment and human health. The grocery bill estimates are used for analysis in the remainder of this study.

Section 4.6 Eliminating Outliers From the CVS Data Set

It is standard practice in the analysis of CVS results to "trim" the data of outliers. A WTP response for a non-market commodity in excess of five percent of the respondent's annual income is generally considered unrealistic (Desvousges et al., 1993; Mitchell and Carson, 1989). If a respondent is willing to pay more than five percent of their annual income, it is assumed the respondent has not fully recognized the budgetary implications of their stated willingness-to-pay. Such responses are said to suffer from hypothetical bias. As with any biased data, these responses should not be included in the final analysis.

The contingent valuation literature is not clear as to why five percent should be chosen as the cut-off for outliers. Nonetheless, in the absence of a compelling argument in favor of a different cut-off value, the five percent level is adopted for this study.

To determine if a response is an outlier, the respondent's stated monthly willingenss-to-pay through an increase in their grocery bill to avoid each level of pesticide risk is first converted to a yearly figure -- the WTP responses to avoid high, moderate, and low pesticide risks are added together, and the sum is multiplied by twelve. If the result of this calculation is in excess of five percent of the upper bound of the respondent's stated annual income range, all responses from that questionnaire are dropped from the data set.

Tables 4.5 and 4.6 present the willingness-to-pay estimates for the country after the data has been purged of outliers. The elimination of outliers resulted in forty-six (10.4 %) fewer WTP to avoid high risks responses, forty-two (9.7 %) fewer moderate WTP responses, and forty-four (10.2 %) fewer low WTP responses in the data set. All willingness-to-pay values in the remainder of this paper are derived from the CVS data set after it has been purged of outliers.

Table 4.5 Willingness to Pay Estimates, by Vehicle and Risk Level for the U. S., Without Outliers

	Mean	Minimum	Median	Maximum
Monthly Grocery Bill	$291.93 (160.21)	$40.00	$280.00	$1500.00
WTP through an increase in monthly grocery bill to avoid high risks	$35.50/mo. (41.14)	$ 0	$25.00	$400.00
Percent increase in monthly grocery bill to avoid high risks	13.69% (15.65)	0 %	10.00%	120.0%
WTP through an increase in yearly federal income tax to avoid high risks	$67.13/yr. (145.00)	$ 0	$ 0	$1200.00
WTP through an increase in monthly grocery bill to avoid moderate risks	$22.77/mo. (26.64)	$ 0	$20.00	$200.00
Percent increase in monthly grocery bill to avoid moderate risks	8.47% (9.75)	0 %	5.7 %	66.67%
WTP through an increase in yearly federal income tax to avoid moderate risks	$48.53/yr. (109.51)	$ 0	$ 0	$1000.00
WTP through an increase in monthly grocery bill to avoid low risks	$13.78/mo. (21.50)	$ 0	$9.00	$200.00
Percent increase in monthly grocery bill to avoid low risks	5.31% (8.38)	0 %	2.2 %	66.67%
WTP through an increase in yearly federal income tax to avoid low risks	$30.47/yr. (72.20)	$ 0	$ 0	$600.00

Table 4.6 U.S. Willingness to Pay Estimates by Vehicle, Environmental Category, and Risk Level, Without Outliers

Environmental Category	High Risk			Moderate Risk			Low Risk		
	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Acute Human									
Groceries ($/Month)	4.28	4.68	397	2.89	3.44	392	1.74	2.75	388
Tax ($/Year)	8.66	19.75	390	6.26	14.41	380	4.00	9.80	380
Chronic Human									
Groceries ($/Month)	4.59	4.85	397	3.14	3.68	392	1.89	2.87	388
Tax ($/Year)	9.27	20.25	390	6.72	14.94	380	4.26	10.14	380
Ground Water									
Groceries ($/Month)	4.56	4.75	397	3.08	3.62	392	1.86	2.91	388
Tax ($/Year)	9.21	20.18	390	6.60	14.81	380	4.20	9.97	380
Surface Water									
Groceries ($/Month)	4.40	4.62	397	2.93	3.43	392	1.76	2.79	388
Tax ($/Year)	8.80	19.17	390	6.32	14.45	380	4.00	9.56	380
Aquatic Species									
Groceries ($/Month)	4.37	4.64	397	2.88	3.42	392	1.75	2.84	388
Tax ($/Year)	8.84	19.61	390	6.22	14.28	380	3.93	9.39	380
Avian Species									
Groceries ($/Month)	4.15	4.48	397	2.72	3.23	392	1.63	2.67	388
Tax ($/Year)	7.92	17.06	390	5.71	13.21	380	3.51	8.49	380
Mammalian Species									
Groceries ($/Month)	4.13	4.46	397	2.71	3.25	392	1.65	2.69	388
Tax ($/Year)	7.93	17.31	390	5.76	13.43	380	3.65	8.84	380
Arthropods									
Groceries ($/Month)	3.76	4.33	397	2.49	3.11	392	1.50	2.54	388
Tax ($/Year)	6.99	15.18	390	5.08	12.27	380	3.23	8.21	380

Section 4.7 Comparing WTP_{ij}'s for Individual States

Even though this study is concerned with the evaluation of apple and peanut IPM programs in Virginia, the contingent valuation survey was administered to a sample of the entire United States population. This was done so the data can be used to evaluate IPM programs in other states. To ensure the country-wide estimates are valid for each state, individually, the sample mean for each state should be compared to the sample mean of every other state. As mentioned above, sample sizes sufficient to facilitate such a comparison were not drawn for each state.

The minimum number of observations needed to ensure the statistical validity of a comparison of sample means has not been conclusively defined in the statistics literature. However, a sample size of fifteen is generally agreed to be sufficient (Schulman, 1992). With this in mind, the sample means for each state with more than fifteen usable responses are compared using the Kruskal-Wallis non-parametric F-test.

Ten states had fifteen or more usable responses at the conclusion of the survey: Virginia, New York, Pennsylvania, Florida, Ohio, Michigan, Wisconsin, Illinois, Texas, and California. In addition, there are eighteen useable responses for which the state in which the respondent resides is unknown. Together, the "unknown" responses constitute an eleventh "state" (Unknown), also included in the F-test. The WTP_{ij} sample means for each of the eleven comparison states are presented in Appendix tables A4.2 through A4.9.

The null hypothesis of the F-test is that the mean willingness-to-pay to avoid a given level of risk to a given environmental category is the same for each comparison state. This hypothesis is represented by equation 4.2. In all twenty-four tests, the null hypothesis is sustained. Tables 4.7 through 4.9 present the results of these tests.

$$\begin{aligned} H_0:\ \mu_{ij,VA} &= \mu_{ij,NY} = \mu_{ij,PA} = \mu_{ij,FL} = \mu_{ij,OH} = \mu_{ij,MI} \\ &= \mu_{ij,WI} = \mu_{ij,IL} = \mu_{ij,TX} = \mu_{ij,CA} = \mu_{ij,Unknown} \end{aligned} \tag{4.2}$$

Table 4.7 Results of the Kruskal-Wallis Non-Parametric F-Test for Each Environmental Category at the High Risk Level

<table>
<tr><td colspan="5">H_0: $\mu_{i,\,high,\,s} = \mu_{i,\,high,\,t}$ for all s, t $\in \{$VA, PA, NY, FL, OH, MI, IL, WI, TX, CA, Unknown$\}$</td></tr>
<tr><th>Environmental Category, i</th><th>Degrees of Freedom</th><th>Chi-Squared Observed</th><th>P-Value</th><th>Conclusion</th></tr>
<tr><td>Acute Human Health</td><td>10</td><td>8.80</td><td>.552</td><td>Fail to Reject H_0</td></tr>
<tr><td>Chronic Human Health</td><td>10</td><td>8.90</td><td>.542</td><td>Fail to Reject H_0</td></tr>
<tr><td>Ground Water</td><td>10</td><td>9.75</td><td>.463</td><td>Fail to Reject H_0</td></tr>
<tr><td>Surface Water</td><td>10</td><td>9.35</td><td>.499</td><td>Fail to Reject H_0</td></tr>
<tr><td>Aquatic Species</td><td>10</td><td>10.11</td><td>.431</td><td>Fail to Reject H_0</td></tr>
<tr><td>Mammalian Species</td><td>10</td><td>9.60</td><td>.477</td><td>Fail to Reject H_0</td></tr>
<tr><td>Avian Species</td><td>10</td><td>9.12</td><td>.521</td><td>Fail to Reject H_0</td></tr>
<tr><td>Arthropods</td><td>10</td><td>7.17</td><td>.710</td><td>Fail to Reject H_0</td></tr>
</table>

Table 4.8 Results of the Kruskal-Wallis Non-Parametric F-Test for Each Environmental Category at the Moderate Risk Level

H_0: $\mu_{i, mod, s} = \mu_{i, mod, t}$ for all s, t $\in$ {VA, PA, NY, FL, OH, MI, IL, WI, TX, CA, Unknown}				
Environmental Category, i	Degrees of Freedom	Chi-Squared Observed	P-Value	Conclusion
Acute Human Health	10	8.93	.539	Fail to Rejct H_0
Chronic Human Health	10	8.43	.587	Fail to Reject H_0
Ground Water	10	8.52	.578	Fail to Reject H_0
Surface Water	10	8.30	.600	Fail to Reject H_0
Aquatic Species	10	8.30	.600	Fail to Reject H_0
Mammalian Species	10	6.87	.737	Fail to Reject H_0
Avian Species	10	7.79	.650	Fail to Reject H_0
Arthropods	10	5.74	.837	Fail to Reject H_0

Table 4.9 Results of the Kruskal-Wallis Non-Parametric F-Test for Each Environmental Category at the Low Risk Level

H_0: $\mu_{i,\,low,\,s} = \mu_{i,\,low,\,t}$ for all s, t $\in$ {VA, PA, NY, FL, OH, MI, IL, WI, TX, CA, Unknown}

Environmental Category, i	Degrees of Freedom	Chi-Squared Observed	P-Value	Conclusion
Acute Human Health	10	4.64	.914	Fail to Reject H_0
Chronic Human Health	10	4.71	.910	Fail to Reject H_0
Ground Water	10	4.23	.937	Fail to Reject H_0
Surface Water	10	4.17	.939	Fail to Reject H_0
Aquatic Species	10	4.86	.901	Fail to Reject H_0
Mammalian Species	10	5.73	.837	Fail to Reject H_0
Avian Species	10	5.25	.874	Fail to Reject H_0
Arthropods	10	4.82	.903	Fail to Reject H_0

Section 4.8 Ordinal Preferences Revealed by the CVS

The results of the contingent valuation survey are not limited to the willingness-to-pay estimates discussed above. The zero-to-six ranking scale used to disaggregate the willingness-to-pay responses can also be used to reveal the ordinal preferences of society with respect to pesticide risk mitigation.

Because the same scale is used to rank the importance of avoiding all twenty-four risk/environmental category classifications, the mean importance level can be compared between each class. By ordering the mean importance levels from largest to smallest, society's preference as to the order in which to address pesticide risks is revealed. The means and standard deviations of the importance rankings are presented in Table 4.10.

The ordinal rankings show that people are most concerned about risks to groundwater -- avoiding pesticides that pose a high or moderate risk to groundwater are two of the top five rankings. Avoiding pesticides that pose a high risk to acute human health is not among the top five rankings. A possible explanation for this apparent anomoly is that the respondents viewed threats to acute human health as risks associated with handling or applying pesticides. Therefore, the person at risk willingly engaged in the risky behavior. Groundwater contamination, on the other hand, is more insidious. If an aquifer is contaminated, the health risks are not likely to be limited to the person or household that applied the pesticide. Rather, entire communities can be affected. The reluctance of people to be exposed to risks involuntarily may account for the high and moderate risk to groundwater both being placed above high risks to acute human health. The same rationale may be used to explain the palcement of high risks to surface water above high risks to acute human health.

The ranking of high risks to aquatic species above high risks to acute human health is harder to interpret. Possible explanations include: (1) as with surface water and groundwater, people view aquatic species as a potential vector for involuntary risk exposure; or (2) the identification of pesticide runoff as a substantial contributor to the decay of surface water systems (e.g., the Chesapeake Bay) and to the fishing

Table 4.10 Ordinal Ranking of Mean Importance Levels:
Revealed Social Preferences with Respect to Pesticide Risk Mitigation

Risk Level/Environmental Category	Mean Importance Level	Std. Dev.
High Risk to Groundwater	5.18	1.37
High Risk to Chronic Human Health	5.14	1.49
High Risk to Surface Water	4.96	1.49
High Risk to Aquatic Species	4.90	1.56
Moderate Risk to Groundwater	4.78	1.56
High Risk to Acute Human Health	4.75	1.66
Moderate Risk to Chronic Human Health	4.74	1.66
High Risk to Avian Species	4.66	1.65
High Risk to Mammalian Species	4.62	1.67
Moderate Risk to Surface Water	4.53	1.66
Moderate Risk to Aquatic Species	4.40	1.71
Moderate Risk to Acute Human Health	4.37	1.77
High Risk to Non-Target Arthropods	4.25	1.88
Moderate Risk to Avian Species	4.20	1.79
Moderate Risk to Mammalian Species	4.20	1.80
Low Risk to Groundwater	3.91	1.93
Low Risk to Chronic Human Health	3.90	1.97
Moderate Risk to Non-Target Arthropods	3.89	1.96
Low Risk to Surface Water	3.75	1.94
Low Risk to Acute Human Health	3.60	2.00
Low Risk to Aquatic Species	3.60	2.02
Low Risk to Avian Species	3.45	2.04
Low Risk to Mammalian Species	3.45	2.07
Low Risk to Non-Target Arthropods	3.19	2.15

and shell fish industries those systems support has produced the perception that the risk to aquatic species is greater than the risk to acute human health. A combination of these or other factors may be responsible for the placement of high risks to aquatic species. At any rate, the importance rankings offer valuable insight into how society would prioritize the mitigation of pesticide risks.

Section 4.9 Concluding Remarks on the Contingent Valuation Survey

The CVS for this study was designed to elicit estimates of society's willingness to pay to avoid various levels of pesticide risks to the environment and human health. While budget considerations limited the second round mailing of the survey, the survey design is sound and the estimates it produced are not intuitively unreasonable. Furthermore, the estimates have withstood a series of tests and should be suitable for evaluating IPM programs across the country.

A secondary, but potentially more significant result of the CVS is the revelation of society's ordinal preferences with respect to pesticide risk mitigation. Knowledge of these preferences is useful in setting pesticide research and regulatory priorities.

The substantial evidence indicating payment vehicle bias in this survey suggests that other surveys may be subject to this bias as well. Unfortunately, it is difficult, if not impossible, to determine ex ante which vehicle a survey population will be biased against. Therefore, if society may actually pay for a non-market good through more than one vehicle, all relevant vehicles should be included in the pretesting of a contingent valuation survey. This should provide researchers with the data necessary to identify bias-inducing payment vehicles. If all of the relevant vehicles are not included in a pretest, the vehicle that generates the best estimates may be erroneously excluded from the final survey instrument.

Finally, the "Overt Rejection Rate" test (ORR) for payment vehicle bias developed in Section 4.5 is useful for comparing vehicles with different payment intervals. In addition, the ORR test may be used to compare vehicles with identical payment intervals. In fact, in some instances, it may provide more convincing evidence of payment vehicle bias than a test on the means. It is, therefore, recommended that the ORR test supplement a test on the means when examining the issue of payment vehicle bias in contingent valuation surveys.

Chapter V: IPM and Pesticide Use in Virginia Apple and Peanut Production

Section 5.1 Introduction

In this chapter background information about the study crops -- apples and peanuts -- is provided, including production profiles for their respective study areas. The pesticide-use models for apple production are also specified, their concomitant hypotheses developed, and the results of the models presented and analyzed.

The reported success of the early leaf-spot peanut IPM program in Virginia is evaluated with respect to the savings in external costs generated from its adoption. The results of the contingent valuation survey are applied to reported reductions in pesticide use to estimate these savings. An econometric model is not developed to estimate the reductions in pesticide use for the peanut programs. Rather, the external cost components are calculated based on pesticide use reductions estimated by Phipps (1994).

Section 5.2 1991 Virginia Apple Production

In 1991, 420 million pounds of apples were produced in four areas of Virginia: (1) the Shenandoah Valley; (2) the Piedmont area; (3) the Roanoke area; and (4) the Southwest area. The overwhelming majority of apple production was further concentrated in seven counties throughout the Shenandoah Valley and Piedmont areas. These counties and their respective production of apples are listed in Table 5.1. Figure 5.1 illustrates where these counties are located in the state.

The four Shenandoah Valley counties were chosen as the apple study area based on their levels of apple production. In 1991, these four counties accounted for 56% of the nearly two million apple trees in Virginia. At an average of 86 trees per acre, there were approximately 12,740 apple acres in these

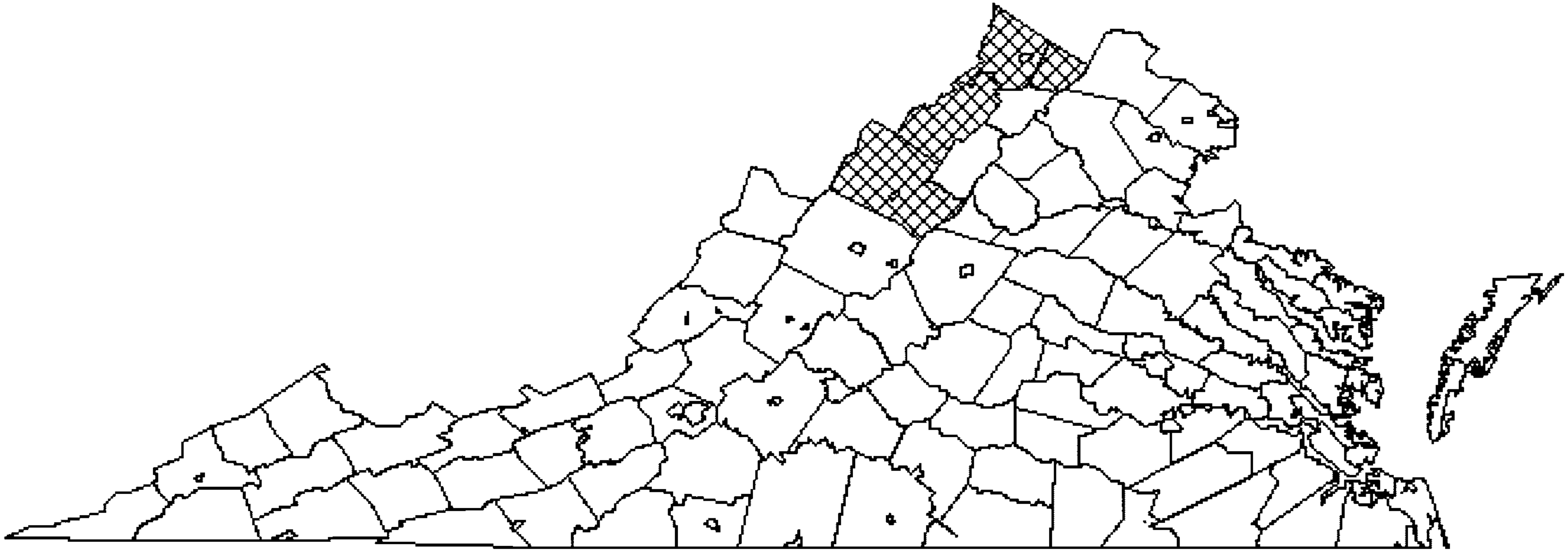


Figure 5.1 Apple Study Area

counties in 1991 (VASS, 1991). Although it is not a precondition for a study area, the fact that the counties are contiguous has additional appeal.

Section 5.3 Other Crops Grown in the Apple Study Area

Both orchard and field crops were grown in the apple study area in 1991. The orchard crops were apples and peaches, and the field crops were corn (for grain and silage), soybeans, winter wheat, barley, alfalfa hay, and "other hay" (VASS, 1991). Table 5.2 provides a profile of the agricultural production in the study area. County specific information for 1991 is available for all the crops except peaches. The peach data for the four apple study area counties are taken from the 1992 Census of Agriculture.

In 1992, 280,501 peach trees were grown on 2,984 acres in Virginia -- ninety-four trees per acre. Of those trees, 244,452 or 87% were of fruit bearing age. It is assumed that each county had the same number of bearing peach trees in 1991 as in 1992. It is also assumed that the trees of fruit bearing age were planted at the same density as trees of non-bearing age, i.e., ninety-four trees per acre. Furthermore, because the number of bearing trees is not reported for Shenandoah County, it is assumed that 87% of the peach trees in Shenandoah County were of fruit bearing age in 1991.

The pesticides used on the crops grown in the apple study area are classified with respect to risk levels in Tables A5.1 through A5.7 of the Appendix to Chapter V.

Section 5.4 Virginia Apple Production Data

The data used in the analysis of Virginia apple IPM programs come from the 1991 Fruit and Nut Chemical Usage Survey conducted by the National Agricultural Statistics Service (NASS) of the Economic Research Service (ERS). The data are summarized in Agricultural Chemical Usage 1991 Fruit and Nuts Summary, published by the ERS. Access to the farm level data needed to estimate the regression equations developed below was granted by the Resources and Technology Division of the ERS.

Table 5.1 Major Apple Producing Counties

Area and County	1991 Apple Production (1,000 pounds)
SHENANDOAH VALLEY	
Clarke (CLK)	49,441
Frederick (FRD)	179,519
Rockingham (RKM)	45,456
Shenandoah (SHN)	33,740
TOTAL	308,156
PIEDMONT	
Albemarle (ALB)	21,367
Nelson (NEL)	17,798
Rappahannock (RAP)	14,812
TOTAL	53,977

Table 5.2 1991 Study Area Production Profile[1]

ORCHARD CROP	ACRES	BEARING TREES	NON-BEARING TREES
Apples	12,740	951,002	145,545
Peaches	886	77,466	13,583

FIELD CROP	ACRES PLANTED	ACRES HARVESTED
Corn	454,000	449,000
Soybeans	3,900	3,100
Winter Wheat	7,200	6,000
Barley	7,200	5,700
Alfalfa Hay	NA	207,000
Other Hay	NA	1,032,000

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[1] It is assumed that the study area has 56% of the state total of both bearing and non-bearing apple trees.

The ERS survey is very thorough with respect to pesticide use data. However, producer characteristics (e.g., percentage of income from apple production, highest education level of farm manager, etc.) are not included in the survey. Therefore, to examine the relationship between pesticide use and IPM adoption, Equation 3.3 must be modified to accommodate the data constraints.

Section 5.5 Assigning Levels of IPM Adoption to Virginia Apple Producers

The Degree of Integration (DOI) formula developed in Section 3.7 is used to assign levels of IPM adoption to the apple producers in the ERS survey. For easy reference, Equation 3.16 is restated here.

$$DOI = \frac{\sum_{c=1}^{n} \left(\frac{employ_c}{available_c} * importance_c \right)}{\sum_{c=1}^{n} importance_c}$$

where n = number of relevant pest classes

$importance_c \in \{0, 1, 2, 3\}$

$available_c$ = number of IPM practices available to control pest class c

$employ_c$ = number of IPM practices the producer employs to control pest class c

To implement the DOI formula, the pests that afflict Virginia apple crops are first divided into pest classes. Three classes are identified: (1) fungi/disease; (2) insects; and (3) weeds. A measure of relative importance must then be assigned to each pest class.

Effective control of both fungi and insects is essential to the economic viability of any apple orchard in Virginia. If fungal diseases and insect pests are not controlled, the likelihood of reaping a profitable yield from a Virginia apple orchard is virtually nil. Therefore, both insect pests and fungal diseases receive an importance ranking of three for the DOI definition. That is, from the economic perspective of a producer, it is very important to control both insects and fungi.

The control of weeds, on the other hand, is not as important. Once a tree has reached fruit bearing age, weeds do not impair the productive capacity of the trees. Weeds do, however, provide breeding grounds for some insect pests and diseases, and may hinder management and harvesting efforts. Weeds, therefore, receive a relative importance ranking of one -- i.e., if weeds are not controlled problems may arise, but their control is far less important to the economic viability of an orchard than is the control of insects or fungi.

The next step in implementing the DOI definition is to identify the alternative pest management practices available to control each pest class. In the ERS apple survey, farmers are asked about their use of fourteen possible pest management practices. These practices are categorized in Table 5.3 with respect to the class of pest they are intended to combat. Several of the practices are available for the control of more than one pest class.

Although the ERS survey intended to collect information about the use of non-pesticide sprays, that information is not present in the ERS data set for 1991 Virginia apple producers. The ERS has labelled the data associated with the non-pesticide spray variable "missing." As a result, the use of non-pesticide sprays is not considered an available practice when applying the DOI definition to the 1991 ERS Virginia apple data. With this in mind, Table 5.3 indicates that there were ten alternative practices available for controlling insect pests, six alternative practices available for controlling fungal disaeses, and three alternative practices available for controlling weeds.

Table 5.3 Categorization of Available Virginia Apple Pest Management Practices

Control Category	Target Pest Class		
	INSECTS	FUNGI	WEEDS
Scouting	Scouting for insects	Scouting for disease	Scouting for weeds
Cultural Practices	Pruning Canopy Irrigation Practices Mowing/Tillage Practices Trap Cropping Resistant Varieties Location of Other Crops	Pruning Canopy Irrigation Practices Mowing/Tillage Practices Debris Removal	Mowing/Tillage Practices
Biological Controls	Beneficial Insects		
Specialized Sprays	Reduced Application Rates Non-pesticide Sprays	Reduced Application Rates Non-pesticide Sprays	Reduced Application Rates Non-pesticide Sprays
Passive Monitoring	Pheromone Traps		

Equation 5.1 represents the DOI formula with the "importance" and "available" variables taking on their respective values for each pest class.

$$DOI = \frac{(\frac{employ_{Insects}}{10}*3) + (\frac{employ_{fungi}}{6}*3) + (\frac{employ_{weeds}}{3}*1)}{7}$$

Each producer receives a DOI score depending on the number of alternative practices he/she employs. Table 5.4 lists the available practices and the conditions under which a producer would be considered to have employed each practice, i.e., the "conditions for employment." The conditions for employment are based on the definitions of the various practices provided in the ERS Fruit and Nut Chemical Use Surveys Interviewers Manual.

Table 5.4 Conditions for Employment of Alternative Pest Management Practices

Pest Management Practice	Conditions for Employment
Scouting for Insects	Orchard scouted for insects by a professionally trained employee of the apple operation *and* scouting reports were the major factor in deciding when to apply pesticides to the orchard
Scouting for Fungi/Disease	Orchard scouted for fungi/disease by a professionally trained employee of the apple operation *and* scouting reports were the major factor in deciding when to apply pesticides to the orchard
Scouting for Weeds	Orchard scouted for weeds by a professionally trained employee of the apple operation *and* scouting reports were the major factor in deciding when to apply pesticides to the orchard
Beneficial Insects	Insects were introduced into the orchard because of their value in biological control
Trap Crops	Crops were planted to attract insects away from the apple crop
Pheromone Traps	Traps laden with chemical sexual attractants were used to capture insects to estimate population levels
Pruning Canopy	Pruning and leaf removal was done specifically to control fungi
Debris Removal	Dead fruit, trees, limbs, vines, etc. were removed to control insects
Location of Other Crops	Decisions for where to plant other crops on the operation were influenced by the effect pests associated with the other crop might have or by the usefulness of the other crop as a means of keeping pests off the apple crop
Reduced Application Rates	Any strategies, e.g., alternate row spraying or special equipment, used to reduce the rate or number of pesticide applications
Irrigation Practices	Use of any practices involving irrigation to control pests, e.g., timing of irrigation
Tillage Practices	Mowing or tillage of orchard to control pests
Resistant Varieties	Any or all of the operation's apple trees were chosen because of their resistance to one or more pests

Producers with DOI scores below 0.1 are considered non-IPM producers. Low IPM producers have DOI scores in the range [0.1, 0.25]. The DOI range for mid-IPM producers is (0.25, 0.6]. High-IPM producers have DOI scores in the range (0.6, 1].

Section 5.6 Specification and Results of the Apple Pesticide Use Models

The models developed in this section are designed to examine the following questions: (1) Is there a negative relationship between IPM adoption and overall pesticide use in 1991 Virginia apple production?; (2) Do Virginia apple producers employing different levels of IPM systematically use different classes of pesticides?; (3) If the answer to (2) is "Yes," What are the environmental implications (with respect to risk) of this substitution of chemicals?; (4) if the answer to (2) is "No," Are IPM adopters systematically using less of every class of pesticide?; and (5) Is there a difference in the ability of the individual IPM practices to reduce pesticide use?

The first question serves as a baseline from which to explore the relationship between IPM adoption, pesticide use, and environmental risk. To examine this question, the dependent variable in Equation 3.3 is changed from the use of pesticide class ij to total pesticide use, irrespective of environmental risks. Equation 5.2 represents the total pesticide use model[2].

$$\begin{aligned} TotalUse = {} & \alpha_0 + \alpha_1 * IPM_{Low} + \alpha_2 * IPM_{Mid} + \alpha_3 * IPM_{High} \\ & + \beta_0 * \ln(ACRES) + \beta_1 * IPM_{Low} * \ln(ACRES) \\ & + \beta_2 * IPM_{Mid} * \ln(ACRES) + \beta_3 * IPM_{High} * \ln(ACRES) \end{aligned} \tag{5.2}$$

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[2] Total Use is the total pounds of active ingredient of all pesticides, except Bacillus Thur. (Bt), applied to a producer's acreage of bearing apple trees. Bt is not included in Total Use due to complications in converting the units in which Bt is expressed into pounds of active ingredient.

ln(ACRES) is the natural log of the number of acres of bearing apple trees.

As in equation 3.3, the IPM variables are dummy variables where, for each producer, $IPM_{Low} = 1$ if $0.1 <= DOI <= .25$,
$IPM_{Mid} = 1$ if $.25 < DOI <= .6$, and $IPM_{High} = 1$ if $.6 < DOI$.

For an apple producer to be included as an observation in estimating Equation 5.2, and the other regression models of this chapter, they must meet three criteria. First, the producer must have harvested some amount of apples in 1991. Second, the pesticide use data the producer provided in the survey must have been characterized as "usable" by the ERS. Third, the producer must have applied some amount of pesticide to their apple acreage. The reason for the third requirement is that it is unclear from the data whether producers who did not apply pesticides avoided them because their employment of alternative pest management practices was effective, or due to market restrictions regarding pesticides (e.g., those producers may have intended to sell their fruit on the organic market).

Of the one hundred and forty-three producers represented in the survey, ninety-two meet the above criteria. Throughout the remainder of this chapter these ninety-two producers will be referred to as the "sample producers."

The farmer characteristic variables of Equation 3.3 are not present in Equation 5.2 because they are not included in the ERS survey data. Because the education level of the farm manager (McNamara, 1991; Thomas, 1988; Ridgely, 1992), and the percentage of income from farming (McNamara, 1991; Napit, 1988; Thomas, 1988) have both been shown to be positively correlated with the IPM adoption variables, their absence from Equation 5.2 and the other models of this chapter may introduce an omitted variables bias into the pesticide use models[3]. Unfortunately, this risk of bias is unavoidable.

The pest severity variable is not in Equation 5.2 either. While the ERS survey did ask some producers about the severity of particular pests, there are two reasons that warrant its exclusion from Equation 5.2. First, the sample size is significantly reduced when only the producers with pest severity

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[3] Harper et. al. (1990) showed that education had a positive effect on the amount of insecticides used by Texas rice producers. If this relationship were to hold for Virginia apple producers, omission of the education variable would likely bias the IPM coefficients in the positive direction. In other words, omission of the education variable may dilute the significance of the IPM coefficients.

Miranowski (1980) showed that the per acre value of corn production had a positive influence on corn producers' demand for insecticides and herbicides. If the per acre value of corn production is accepted as a proxy for the percentage of the farm owner's income generated by corn, then omission from equation 5.2 of the percentage income from apple production variable may further dilute the IPM coefficients. In fact, considering the omission of each of the variables in question is hypothesized to result in a positive (upward) bias on the coefficients of the IPM variables, one may speculate that omission of both variables could change the hypothesized sign of the IPM coefficients from negative to positive.

records are used. Of the ninety-two sample producers, forty-six were asked to identify the target pest and its relative severity for each pesticide application. Twenty-three producers identified the target pest and its severity for all pesticide applications. Without this information for all pesticide applications (or some other measure of severity for each pest) it is impossible to develop a consistent measure of aggregate pest severity. Furthermore, of the twenty-three observations with complete severity data, none are identified as high-IPM adopters according to the DOI definition; and, if the producers are stratified by the market for which their fruit was intended, there are zero observations for mid-IPM adopters growing for the processed fruit market. For these reasons, Equation 5.2 and the other models of this chapter do not include a pest severity variable.

Two hypotheses are tested with Equation 5.2: (1) IPM adopters apply fewer pesticides than non-adopters; and (2) as the level of IPM adoption increases, the amount of pesticides applied decreases. These hypotheses are represented by inequalities 5.3.

$$\begin{aligned} H_0^{\alpha}&: 0 > \alpha_1 > \alpha_2 > \alpha_3 \\ H_0^{\beta}&: 0 > \beta_1 > \beta_2 > \beta_3 \end{aligned} \qquad (5.3)$$

One issue concerning the pesticide use data must, however, be resolved before model 5.1 is run. There is evidence that the amount of pesticides, in general, and fungicides in particular, applied to apples grown for the fresh market is higher than the amount applied to apples grown for the processed market (Rajotte et al., 1985). Whether this is the case for the data at hand should be determined prior to running model 5.1. Equation 5.4 is designed to examine this issue[4].

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[4] Inquiry into the relationships between total insecticide use and the market variables (Equation A5.1), total herbicide use and the market variables (Equation A5.3), and total fungicide use and the market variables (Equation A5.4) is pursued in the Appendix to Chapter V.

$$\begin{aligned} TotalUse &= \alpha_0 + \alpha_1 * Fresh \\ &+ \beta_0 * \ln(ACRES) + \beta_1 * Fresh * \ln(ACRES) \end{aligned} \tag{5.4}$$

Where Fresh = 1 if the producer grows for the fresh market

Fresh = 0 if the producer grows for the processed market

The results of estimating Equation 5.4 are presented in Table 5.5. The p-values indicate that each of the parameter estimates is significantly different than zero. It is, therefore, reasonable to conclude that apple producers are applying different amounts of pesticides depending on the market for which their fruit is grown.

Table 5.5 Results from Equation 5.2, Total Pesticide Use versus Fresh/Processed Market

Descriptive Statistics:	R^2 = .5740	Adjusted R^2 = .5594	F Value = 39.517
Independent Variable	**Estimate**	**Std. Dev.**	**P-Value**
Intercept	-32314	4867.01	.0001
ln(Bearing Acres)	11421	1203.54	.0001
Fresh	28297	5277.79	.0001
Fresh * ln(Bearing Acres)	-8989.39	1366.05	.0001

The results of Equation 5.4 suggest two possible modifications to Equation 5.2. One possibility is to stratify the sample producers prior to estimation with respect to the market for which their fruit was intended. Equation 5.2 would, then, be run twice: once for fresh producers, and once for processed producers. An alternative approach is to develop a set of interaction terms between the IPM and market dummy variables, thereby stratifying the producers within the model. The latter approach is pursued below. Theoretically, the results of the two strategies should be equivalent.

Table 5.6 gives a breakdown of the number of observations for each IPM adoption level in each market. Because there are no high-IPM producers in the fresh market, and only one in the processed market, a model that includes the high-IPM variables will not be full rank and least-squares solutions for the parameters will not be unique. In short, the parameter estimates generated by such a model would be biased. Therefore, the high-IPM variables are dropped from the Total Use model. Equation 5.5 represents the Total Use model in which producers are stratified by market.

Table 5.6 Number of Observations in Each Strata

Level of IPM Adoption	Number of Producers Growing for Each Market	
	Fresh Market	Processed Market
Non-IPM (DOI < 0.1)	12	5
Low-IPM (0.1 <= DOI <= 0.25)	17	6
Mid-IPM (0.25 < DOI <= 0.6)	41	10
High-IPM (0.6 < DOI)	0	1
TOTAL	70	22

$$\begin{aligned} TotalUse = {} & \alpha_0 + \beta_0 * \ln(ACRES) \\ & + \alpha_1 * IPM_{Low} + \beta_1 * IPM_{Low} * \ln(ACRES) \\ & + \alpha_2 * IPM_{Mid} + \beta_2 * IPM_{Mid} * \ln(ACRES) \\ & + \alpha_3 * Fresh + \beta_3 * Fresh * \ln(ACRES) \\ & + \alpha_4 * Fresh * IPM_{Low} + \beta_4 * Fresh * IPM_{Low} * \ln(ACRES) \\ & + \alpha_5 * Fresh * IPM_{Mid} + \beta_5 * Fresh * IPM_{Mid} * \ln(ACRES) \end{aligned} \qquad (5,5)$$

Table 5.7 presents the results of Equation 5.5. The high value of the adjusted R^2 in conjunction with the high p-values for most parameter estimates suggest this model is suffering from collinearity. Inspection of the variance inflation factors (VIF's) associated with each variable reinforces this suspicion.

Table 5.7 Total Pesticide Use versus IPM Adoption, Stratified by Market

Descriptive Statistics: R^2 = .7227 Adj. R^2 = .6841 F Value = 18.717

Independent Variable	Parameter Estimate	Standard Deviation	P-Value	VIF
Intercept	810.90	16337.78	.9605	0.00
ln(ACRES)	68.19	4704.21	.9885	98.07
IPM_{Low}	-1932.77	20642.97	.9256	139.16
IPM_{Mid}	-52594	17784.01	.0041	134.72
IPM_{Low} * ln(ACRES)	604.81	6914.73	.9305	115.36
IPM_{Mid} * ln(ACRES)	16153	4928.55	.0016	194.48
Fresh	-1214.43	16871.86	.9428	87.38
Fresh * ln(ACRES)	407.65	5173.24	.9374	150.05
Fresh * IPM_{Low}	916.70	21485.32	.9661	121.26
Fresh * IPM_{Mid}	47941	18430.45	.0111	145.40
Fresh * IPM_{Low} * ln(ACRES)	-13.31	7407.19	.9986	109.94
Fresh * IPM_{Mid} * ln(ACRES)	-13795	5418.86	.0129	191.88

The best solution to the collinearity problem is to collect more data. Unfortunately, that is not feasible. Alternative "solutions" are dropping a variable(s), adjusting the DOI cutoffs to redistribute observations among the IPM adoption levels, and/or dropping observations and reestimating the models. All of these alternatives are dubious.[5] Another approach is to disaggregate the IPM dummy variables and define separate variables for each individual pest management practice. Unfortunately, because there are so many pest management practices and so few observations for the processed market, problems with degrees of freedom quickly arise.

The fresh market, however, appears to have sufficient observations to include the individual pest management practices as intercept dummy variables. While there is no reason to believe these practices are not affecting the slope of the pesticide use curve as well as the intercept, significant parameter estimates for the intercepts should give some indication of the general performance of the practice with respect to total pesticide use. The fresh market model is represented by Equation 5.6.

Of the twelve pest management practices represented in Equation 5.6, nine are expected to have a negative effect on pesticide use. The other three practices, scouting for insects and disease, scouting for weeds, and the use of pheromone traps, do not have a hypothesized effect on pesticide use. These three practices are used to monitor pests to ensure the timely and judicious application of pesticides. They do not serve as substitutes for pesticides. Therefore, in any given year, depending on pest population pressure, a producer who monitors pest populations may apply more, less, or the same amount of pesticides as a producer who does not. Over time, monitoring techniques should reduce the amount of pesticides

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[5] A model was run in which the IPM slope dummies were dropped from equation 5.2. In that model, none of the parameters for the IPM intercept dummies were significantly different than zero. A second model was run in which the IPM intercept dummies were removed from equation 5.2. In that model, none of the parameters for the IPM slope dummies were significantly different than zero.

A third model was run in which producers with DOI scores greater than .25 were considered IPM adopters, and those with DOI scores less than or equal to .25 were considered non-adopters. In that model, the slope and intercept parameter estimates for the non-IPM variables were not significantly different than zero, and the estimates for IPM adopters did not behave in the hypothesized direction. There was also considerable evidence of collinearity.

applied to a crop. Unfortunately, time series data are not presently available for the ERS apple producers. Therefore, no hypotheses concerning the parameters of the monitoring variables are developed here.

$$\begin{aligned} TotalUse = {} & \alpha_0 + \beta_0 * \ln(ACRES) \\ & + \alpha_1 * SCOUTIN + \alpha_2 * SCOUTWE + \alpha_3 * BENE + \alpha_4 * TRAP \\ & + \alpha_5 * PHER + \alpha_6 * LOC + \alpha_7 * REDU + \alpha_8 * VAR \\ & + \alpha_9 * PRUNE + \alpha_{10} * TILL + \alpha_{11} * IRRI + \alpha_{12} * DEBRI \end{aligned} \tag{5.6}$$

Where SCOUTIN = Scouting for insects and disease[6]

SCOUTWE = Scouting for weeds

BENE = Use of beneficial insects

TRAP = Use of trap crops

PHER = Use of pheromone traps

LOC = Selecting location of other crops to combat pests

REDU = Use of reduced application rates

VAR = Planting apple varieties resistant to disease

PRUNE = Pruning canopy of apple orchard to combat pests

TILL = Tilling or mowing orchard to control pests

IRRI = Use of irrigation techniques to combat pests

DEBRI = Removal of debris from orchards to combat pests

Inequalities 5.7 represent the hypothesized direction of the parameter estimates for the nine "non-monitoring" practices.

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[6] Scouting for insects and disease are not considered separately because every producer who reportedly scouted their 1991 apple orchards for insects also scouted them for diseases, and vice-versa.

$$H_0:\ \alpha_3<0,\ \alpha_4<0,\ \alpha_6<0,\ \alpha_7<0,\ \alpha_8<0,\ \alpha_9<0,\ \alpha_{10}<0,\ \alpha_{11}<0,\ \alpha_{12}<0 \tag{5.7}$$

The results of Model 5.6, presented in Table 5.8, offer some insight as to why the IPM variables of Equation 5.2 did not perform in the hypothesized direction. Of the twelve pest management practices, three have parameter estimates with p-values less than 0.10: (1) Beneficial Insects; (2) Trap Crops; and (3) Pheromone Traps. The results indicate that producers employing beneficial insects, trap crops, and/or pheromone traps, use more total pesticides than producers who do not employ those practices. For reasons discussed above, the positive pheromone parameter is not particularly surprising. Even the positive trap crop parameter can be explained by arguing that the pest for which the trap crops were planted did not occur, in 1991, at population levels that warranted pesticide applications. As a result, producers employing trap crops in an effort to preempt the development of a pest problem, sprayed at the beginning of the season for a pest that did not need to be controlled. The trap croppers, then, were the ones who made an extra application. The positive parameter for the beneficial insect variable, however, is more puzzling.

Beneficial insects are employed as direct substitutes for pesticides, especially insecticides. In Virginia, the beneficial insects typically employed by apple producers are predators that prey on other insects. Why a producer who releases beneficial insects would apply more pesticides than a producer who does not is unclear. The following are some possible explanations: (1) producers employing beneficial insects may have used more total pesticides, but less insecticides; (2) producers employing beneficial insects may have used more total pesticides and more total insecticides, but, to avoid killing the beneficial insects, they used less of the pesticides that pose a high risk to arthropods; (3) the orchards into which beneficial insects were released in 1991 had significantly more acute pest pressure than other Virginia orchards; (4) the beneficial insects employed by Virginia apple producers in 1991 did not effectively

Table 5.8 Total Pesticide Use versus Individual Practices for Fresh Market Producers

Descriptive Statistics:	R^2 = .7482	Adj. R^2 = .6897	F Value = 12.799
Independent Variable	Parameter Estimate	Standard Deviation	P-Value
Intercept	-5342.05	1550.80	.0011
ln(ACRES)	1756.32	286.23	.0001
SCOUT FOR INSECTS	-456.05	1907.95	.8120
SCOUT FOR WEEDS	1666.18	2594.94	.5234
BENEFICIAL INSECTS	6532.33	2035.94	.0022
TRAP CROPS	6096.50	3307.01	.0705
PHEROMONE TRAPS	2991.53	1391.55	.0359
LOCATION OF OTHER CROPS	1136.23	1691.68	.5046
REDUCED APPLICATION RATES	-246.18	856.23	.7748
RESISTANT VARIETIES	-1233.34	1340.48	.3615
PRUNING CANOPY	-113.63	932.68	.9035
TILLING OR MOWING	1025.56	1251.73	.4161
IRRIGATION TO CONTROL PESTS	26.41	4306.66	.9951
DEBRIS REMOVAL	1697.95	1209.91	.1660

control the pests they were intended to combat; or (5) the beneficial insect question in the ERS survey was not clear enough in distinguishing between what does and does not constitutethe use of beneficial insects -- i.e., due to misunderstanding, producers that did not have a legitimate beneficial insect program responded positively when asked if they used beneficial insects.

The first explanation is pursued in the appendix using Equations A5.1 and A5.2. The results are presented in Table A5.11. In short, the results fail to support the hypothesis that producers using beneficial insects applied fewer insecticides than other producers. In fact, the beneficial insect parameter in the total insecticide use model is significantly positive. The second explanation is pursued in the following Use_{ij} models.

While the Total Use models were unable to evaluate the hypotheses of inequality 5.3, the relationship between total pesticide use and IPM is not the primary focus of this study. Rather, the concern here is with the ability of IPM programs to reduce the risks pesticides pose to the environment and human health. The general model used to examine this risk relationship is expressed by Equation 5.8[7].

$$\begin{aligned} Use_{ij} &= \alpha_0 + \alpha_1 * IPM_{Low} + \alpha_2 * IPM_{Mid} \\ &+ \beta_0 * \ln(ACRES) + \beta_1 * IPM_{Low} * \ln(ACRES) \\ &+ \beta_2 * IPM_{Mid} * \ln(ACRES) \end{aligned} \tag{5.8}$$

The farmer characteristic and pest severity variables are not included in Equation 5.8 for the same reasons they were not included in the Total Use models. Likewise, there are no high-IPM variables.

Inevitably, the model depicted in Equation 5.8 will suffer from collinearity, as did model 5.2. Yet, by following the same strategy laid out above -- disaggregating the IPM variables into the individual

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[7] Recall that there are twenty-four Use_{ij} models, one for each of three risk levels, j, across the eight environmental categories, i. Use_{ij} is the total pounds of active ingredients that pose risk level j to environmental category i, applied to the producer's acreage of bearing apple trees. As with the Total Use model, Bt is not included in Use_{ij}.

pest management practices -- the models may offer some insight into how the individual practices perform with respect to the use of each classification of pesticide.

As with the Total Use models, it is important to first establish whether or not the market for which producers are growing is likely to affect the growers' use of a given classification of pesticide. Unlike the Total Use model, however, there is presently no empirical evidence upon which to base hypotheses concerning the relevance of market variables in the Use_{ij} models. The results of the previous models do, however, suggest some reasonable hypotheses.

Most of the empirical evidence regarding the relationship between total pesticide use and the market for which apples are grown shows that fresh market producers tend to apply more pesticides than producers growing for the processed market. Furthermore, differences in fungicide use are largely responsible for the difference in total pesticide use[8]. In light of this, one may infer that market variables should be relevant to the Use_{ij} models in which the major apple fungicides are represented.

Sulfur and Ziram are the most widely used fungicides in Virginia apple production. Referring to appendix Table A5.1, one can see that in fourteen of the twenty-four environmental/risk classifications at least one of these chemicals is represented. The fourteen classifications are: (1) low risk to groundwater, (2) moderate risk to surface water, (3) low risk to surface water, (4) high risk to acute human health, (5) low risk to acute human health, (6) high risk to chronic human health, (7) low risk to chronic human health, (8) moderate risk to aquatic species, (9) low risk to aquatic species, (10) moderate risk to avian species, (11) low risk to avian species, (12) low risk to mammals, (13) high risk to arthropods, and (14) moderate risk to arthropods. For each of these fourteen Use_{ij} models, then, the relevant hypothesis concerning the market dummy variables is that they will behave in the same direction as in the Total Use model -- i.e., the intercept dummy will have a positive parameter and the slope dummy will have a negative parameter. For the remaining ten Use_{ij} models, the parameters on the market dummy variables

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[8] Results of equations A5.1, A5.3, and A5.4 of the appendix concur that the primary source of the divergence in total pesticide use between fresh and processed market producers is a difference in the total amount of fungicides applied.

are hypothesized to be zero. The hypotheses for the fourteen ziram and sulfur models are formalized in Table 5.8. The results of those models are also presented in Table 5.8. The hypotheses and results for the ten remaining models are formalized and presented in Table 5.9. Equation 5.9 represents the general model used to test all of the hypotheses.

$$Use_{ij} = \alpha_0 + \alpha_1 * Fresh + \beta_0 * \ln(ACRES) + \beta_1 * Fresh * \ln(ACRES) \tag{5.9}$$

As Table 5.8 indicates, the null hypotheses were sustained in all fourteen sulfur-ziram Use_{ij} models. However, as Table 5.9 shows, the null hypotheses were rejected in five of the ten non-sulfur, non-ziram models. Based on these results, one can conclude that the market variables are relevant to nineteen of the twenty-four Use_{ij} models. For the nineteen models in which the market variables matter, the model is run using only the seventy fresh market sample producers as observations. For the five models in which the market variables are not significant, the models are run using all ninety-two sample producers as observations. Equation 5.10 represents the model used to examine the relationship between the twelve individual pest management practices and the use of the twenty-four classifications of pesticides.

$$\begin{aligned} Use_{ij} = {} & \alpha_0 + \beta_0 * \ln(ACRES) \\ & + \alpha_1 * SCOUTIN + \alpha_2 * SCOUTWE + \alpha_3 * BENE + \alpha_4 * TRAP \\ & + \alpha_5 * PHER + \alpha_6 * LOC + \alpha_7 * REDU + \alpha_8 * DEBRI \\ & + \alpha_9 * PRUNE + \alpha_{10} * IRRI + \alpha_{11} * TILL + \alpha_{12} * VAR \end{aligned} \tag{5.10}$$

Although all twenty-four of the Use_{ij} models were run, in the interest of space, the only results reported here are for the models in which the parameter estimate for at least one pest management practice is significantly different than zero. Furthermore, only the significant parameters are reported in Table 5.10.

In the model examining the effect of the pest management practices on the use of pesticides that pose a high risk to arthropods, three pest management practices, including the beneficial insect variable, have parameter estimates significantly greater than zero. This result undermines the second explanation for why the beneficial insect variable had a positive parameter in the Total Use model. In other words, there is no indication that producers employing beneficial insects are using less of the pesticides that pose a high risk to arthropods than producers who do not employ beneficial insects. In fact, the results show the exact opposite -- producers employing beneficial insects applied more of the pesticides that pose a high risk to arthropods than producers who did not employ beneficial insects.

Unfortunately, data constraints preclude inquiry into the third explanation as to why the beneficial insect variable has a positive parameter in the Total Use (Equation 5.2) and Total Insecticide Use (Equation A5.2) models. That is, due to the insufficient number of observations with complete pest severity data, one cannot determine if the producers employing beneficial insects used more total pesticides and more total insecticides in response to greater pest pressure in their orchards.

While the pest pressure explanation cannot be ruled out, the above analysis suggests that the ERS may want to take a critical look at both how the beneficial insect question is incorporated into future pesticide use surveys, and the degree of detail the surveys should pursue. For example, in 1991 there was not an established beneficial insect program for use on apples in Virginia (Pfeifer, 1994; Yoder, 1994). Yet, seven of the ninety-two sample producers reported using beneficial insects to control pests. Exactly what beneficials those seven producers were releasing into their apple orchards is unclear. If the survey were to ask what beneficials were released by the farmer, potential misunderstanding regarding the "conditions of employment" of beneficial insects would likely be alleviated, *and* data would be available for the analysis of particular beneficial insect programs as well as the overall performance of beneficials.

Section 5.7 Concluding Remarks on the Apple Analysis

The preceding analysis of 1991 Virginia apple production attempted to isolate the effect of IPM adoption on the use of twenty-four classifications of pesticides. Unfortunately, severe collinearity was detected in the IPM-pesticide use models. To overcome the collinearity problem, the IPM variables were disaggregated and the relationships between the individual pest management practices and pesticide use were examined.

Three practices -- trap crops, pheromone traps, and beneficial insects -- were found to significantly increase the amount of pesticides applied to apple orchards. The counter-intuitive signs of the trap crop and pheromone trap variables were explained verbally, while further analysis was used to examine a set of hypotheses concerning the positive beneficial insect coefficient. The analysis refuted two of the hypotheses: (1) producers using beneficial insects used less insecticide than other producers; and (2) producers using beneficial insects used less of the pesticides that pose a high risk to arthropods than other producers. In fact, the analysis showed that producers using beneficial insects used significantly more insecticide and significantly more of the pesticides that pose a high risk to arthropods than other producers.

Data constraints prevented examination of the other three hypotheses, but several recommendations regarding the design of future ERS chemical use surveys emerged from the analysis. It is suggested the ERS consider ammending the surveys in the following ways: (1) collect the farmer characteristic variables (education level of primary operator, percentage of farm owner's income derived from the study crop) whose absence is hypothesized to introduce an omitted variables bias into the pesticide use models; (2) include a series of general pest severity questions to be asked of all respondents -- for example, the question "Overall, how would you rate the severity of insect infestation in your apple orchards last year?" could be asked and repeated for fungi and weeds; and (3) ask farmers who claim to employ beneficial insects to identify the beneficials they release into their orchards.

Table 5.8 Hypotheses and Results for Fourteen Sulfur, Ziram Use$_{ij}$ versus Market Models

Null Hypotheses: H_0: $\alpha_1 > 0$ H_0: $\beta_1 < 0$

Dependent Variable	Parameter Estimate	Standard Deviation	P-Value	Conclusions
Groundwater	α_1 = 26962	5065.12	.0001	Fail to reject H_0
Low Risk	β_1 = -8561.80	1311.01	.0001	Fail to reject H_0
Surface Water	α_1 = 3723.67	768.25	.0001	Fail to reject H_0
Moderate Risk	β_1 = -1157.37	198.85	.0001	Fail to reject H_0
Surface Water	α_1 = 24375	4476.64	.0001	Fail to reject H_0
Low Risk	β_1 = -7829.22	1158.69	.0001	Fail to reject H_0
Acute Human Health	α_1 = 6063.91	1287.78	.0001	Fail to reject H_0
High Risk	β_1 = -1810.88	333.32	.0001	Fail to reject H_0
Acute Human Health	α_1 = 22162	4244.05	.0001	Fail to reject H_0
Low Risk	β_1 = -7193.15	1098.49	.0001	Fail to reject H_0
Chronic Human Health	α_1 = 2645.68	834.43	.0021	Fail to reject H_0
High Risk	β_1 = -709.10	215.98	.0015	Fail to reject H_0
Chronic Human Health	α_1 = 24616	4464.44	.0001	Fail to reject H_0
Low Risk	β_1 = -8326.62	1155.53	.0001	Fail to reject H_0
Aquatic Species	α_1 = 3939.52	689.38	.0001	Fail to reject H_0
Moderate Risk	β_1 = -1241.63	178.43	.0001	Fail to reject H_0
Aquatic Species	α_1 = 22692	4311.31	.0001	Fail to reject H_0
Low Risk	β_1 = -7284.80	1115.90	.0001	Fail to reject H_0
Avian Species	α_1 = 4089.65	838.46	.0001	Fail to reject H_0
Moderate Risk	β_1 = -1293.63	217.02	.0001	Fail to reject H_0
Avian Species	α_1 = 24022	4537.64	.0001	Fail to reject H_0
Low Risk	β_1 = -7636.56	1174.48	.0001	Fail to reject H_0
Mammalian Species	α_1 = 24774	4736.09	.0001	Fail to reject H_0
Low Risk	β_1 = -7899.73	1225.84	.0001	Fail to reject H_0
Arthropods	α_1 = 24290	4499.81	.0001	Fail to Reject H_0
High Risk	β_1 = -7892.28	1164.69	.0001	Fail to Reject H_0
Arthropods	α_1 = 3894.32	745.03	.0001	Fail to reject H_0
Moderate Risk	β_1 = -1240.31	192.84	.0001	Fail to reject H_0

Table 5.9 Hypotheses and Results for Ten Non-Sulfur, Non-ziram Use_{ij} versus Market Models

Null Hypotheses: $H_0: \alpha_1 = 0$ $H_0: \beta_1 = 0$

Dependent Variable	Parameter Estimate	Standard Deviation	P-Value	Conclusions
Groundwater	$\alpha_1 = 1299.24$	253.88	.0001	Reject H_0
High Risk	$\beta_1 = -419.93$	65.71	.0001	Reject H_0
Groundwater	$\alpha_1 = 35.98$	65.64	.5850	Fail to reject H_0
Moderate Risk	$\beta_1 = -7.66$	16.99	.6532	Fail to reject H_0
Surface Water	$\alpha_1 = 198.79$	294.23	.5010	Fail to reject H_0
High Risk	$\beta_1 = -2.80$	76.15	.9708	Fail to reject H_0
Acute Human Health	$\alpha_1 = 70.93$	160.16	.6590	Fail to reject H_0
Moderate Risk	$\beta_1 = 14.65$	41.45	.7246	Fail to reject H_0
Chronic Human Health	$\alpha_1 = 1038.42$	1683.04	.5388	Fail to reject H_0
Moderate Risk	$\beta_1 = 45.53$	435.62	.9170	Fail to reject H_0
Aquatic Species	$\alpha_1 = 1665.07$	457.77	.0002	Reject H_0
High Risk	$\beta_1 = -462.96$	118.48	.0005	Reject H_0
Avian Species	$\alpha_1 = 185.08$	58.58	.0002	Reject H_0
High Risk	$\beta_1 = -59.19$	15.16	.0022	Reject H_0
Mammalian Species	$\alpha_1 = 561.14$	161.25	.0002	Reject H_0
High Risk	$\beta_1 = -164.13$	41.74	.0008	Reject H_0
Mammalian Species	$\alpha_1 = 2962.06$	508.30	.0001	Reject H_0
Moderate Risk	$\beta_1 = -925.53$	131.56	.0001	Reject H_0
Arthropods	$\alpha_1 = 112.44$	724.28	.8770	Fail to Reject H_0
Low Risk	$\beta_1 = 143.20$	187.47	.4470	Fail to Reject H_0

Table 5.10 Significant Results for Use_{ij} versus Pest Management Practices Models

Dependent Variable	Significant Practices (p-value < .10)	Parameter Estimate	Standard Deviation	P-Value
Groundwater High Risk	IRRI	640.85	189.99	.0014
Groundwater Low Risk	BENE	6400.55	1960.62	.0019
	TRAP	6465.71	3184.68	.0471
	PHER	2909.20	1340.08	.0342
Surface Water High Risk	SCOUTWE	-426.37	246.29	.0874
	BENE	748.83	216.19	.0009
	PHER	423.78	143.68	.0042
Surface Water Moderate Risk	IRRI	3839.80	867.75	.0001
Surface Water Low Risk	BENE	5115.91	1678.98	.0035
	TRAP	6738.43	2727.21	.0165
	PHER	2672.31	1147.58	.0235
Acute Human Health Moderate Risk	TRAP	422.66	156.82	.0086
	IRRI	378.64	159.44	.0200
Acute Human Health Low Risk	BENE	5388.56	1607.09	.0014
	TRAP	5392.15	2610.43	.0435
	PHER	2305.91	1098.44	.0403
Chronic Human Health High Risk	BENE	1526.27	816.60	.0668
Chronic Human Health Moderate Risk	BENE	3893.67	1250.62	.0026
	TRAP	2866.53	1602.81	.0776
	PHER	1701.74	831.19	.0440
Chronic Human Health Low Risk	IRRI	1531.68	597.99	.0131
Aquatic Species High Risk	IRRI	1214.65	713.18	.0941
	DEBRI	382.93	200.36	.0611
Aquatic Species Moderate Risk	IRRI	2282.99	627.04	.0006
Aquatic Species Low Risk	BENE	5841.23	1697.54	.0011
	TRAP	5895.93	2757.34	.0369
	PHER	2662.27	1160.26	.0255

Table 5.10 Continued

Dependent Variable	Significant Practices (p-value < .10)	Parameter Estimate	Standard Deviation	P-Value
Avian Species High Risk	BENE	106.51	40.94	.0118
	TRAP	-125.19	66.50	.0650
	LOC	108.48	34.02	.0023
	IRRI	385.47	86.60	.0001
	VAR	45.36	26.95	.0980
Avian Species Moderate Risk	IRRI	2920.42	754.55	.0003
Avian Species Low Risk	BENE	5984.90	1825.70	.0018
	TRAP	6245.91	2965.51	.0397
	PHER	3006.95	1247.86	.0193
Mammalian Species High Risk	TRAP	750.54	194.16	.0003
Mammalian Species Moderate Risk	TRAP	-681.81	288.96	.0218
	PHER	221.67	121.59	.0736
	IRRI	967.94	376.30	.0128
Mammalian Species Low Risk	BENE	6284.67	1850.76	.0013
	TRAP	6027.78	3006.22	.0501
Arthropods High Risk	BENE	4918.48	1666.62	.0046
	TRAP	4676.42	2707.12	.0896
	PHER	2357.72	1139.13	.0431
Arthropods Moderate Risk	TRAP	-996.16	456.85	.0334
	IRRI	3558.38	594.94	.0001
Arthropods Low Risk	BENE	1021.76	596.81	.0909

Section 5.8 IPM and Virginia Peanut Production

Due to their high market value and vulnerability to disease, and weed and insect pests, peanuts are grown under intensive managment in Virginia. To date, effective substitutes for pesticides are not available for use in Virginia peanut production. As a result, pesticides, especially fungicides and herbicides, play a fundamental role in peanut management strategies. While research efforts aimed at developing substitutes for pesticides have yet to bear fruit, there has been considerable success in reducing fungicide use through a disease forecasting system.

In 1979, the early leaf spot advisory system (ELSA) came on line. Developed through a cooperative effort between Virginia Polytechnic Institute and State University, the National Aeronautics and Space Administration, and the United States Department of Agriculture, ELSA is designed to identify environmental conditions that are favorable to early leaf spot infection. Prior to ELSA the "conventional" method for combating early leaf spot in Virginia peanut production was to apply chlorothalonil to peanut fields at fourteen day intervals. By accurately predicting periods of early leaf spot infection, the ELSA forecasts and fungicide application recommendations have allowed farmers to apply chlorothalonil in a more judicious manner.

In a four-year study (1987 through 1990) evaluating ELSA, P.M. Phipps found that farmers following ELSA recommendations made, on average, thirty-three percent fewer applications of chlorothalonil than farmers using the fourteen-day spray regime. Furthermore, yields from the ELSA farms were not significantly different than yields from the fourteen-day spray farms; nor was there a significant difference in the value of those yields.

Maintaining the value of yields while reducing the number of applications of chlorothalonil is of obvious financial benefit to growers. From a producer's perspective, ELSA is a success. The degree of grower acceptance of ELSA is also impressive -- by 1990, ninety-four percent of Virginia's peanut producers were applying foliar fungicides (e.g., chlorothalonil) based on ELSA recommendations (Phipps, 1993).

The benefits of ELSA are not restricted to peanut producers. Society also benefits through the reduction in the amount of chlorothalonil introduced into the environment[9]. Essentially, by reducing the amount of chlorothanil applied to peanuts in Virginia, ELSA has reduced certain pesticidal risks to human health and the environment. The reduction of these risks has implications for the external costs of peanut production. The remainder of this chapter focuses on estimating the 1992 savings in external costs attributable to ELSA.

Section 5.9 Virginia Peanut Production in 1992

In 1992, 93,720 acres of peanuts were harvested in Virginia (Census of Agriculture). Nearly all of those acres were located in eight counties in the southeastern part of the state. The eight counties and their respective acreage of harvested peanuts are listed in Table 5.11. These eight counties constitute the study area for the external cost analysis of the ELSA program. Figure 5.2 shows the location of the study area in the state.

Section 5.10 Other Crops Grown in the Peanut Study Area

Corn (for both grain and silage), sorghum, winter wheat, barley, oats, rye, cotton, tobacco, soybeans, alfalfa hay, other hay, and watermelon were also grown in the study area in 1992 (COA). The total harvested acreage in the study area reported for each crop in the Census of Agriculture is listed in

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[9] It is assumed that the recommended application rate under ELSA is the same as the application rate used in the fourteen-day calendar spray program. Therefore, a thirty-three percent reduction in the number of applications is equivalent to a thirty-three percent reduction in the total pounds of chlorothalonil applied to a farm's peanut acres.

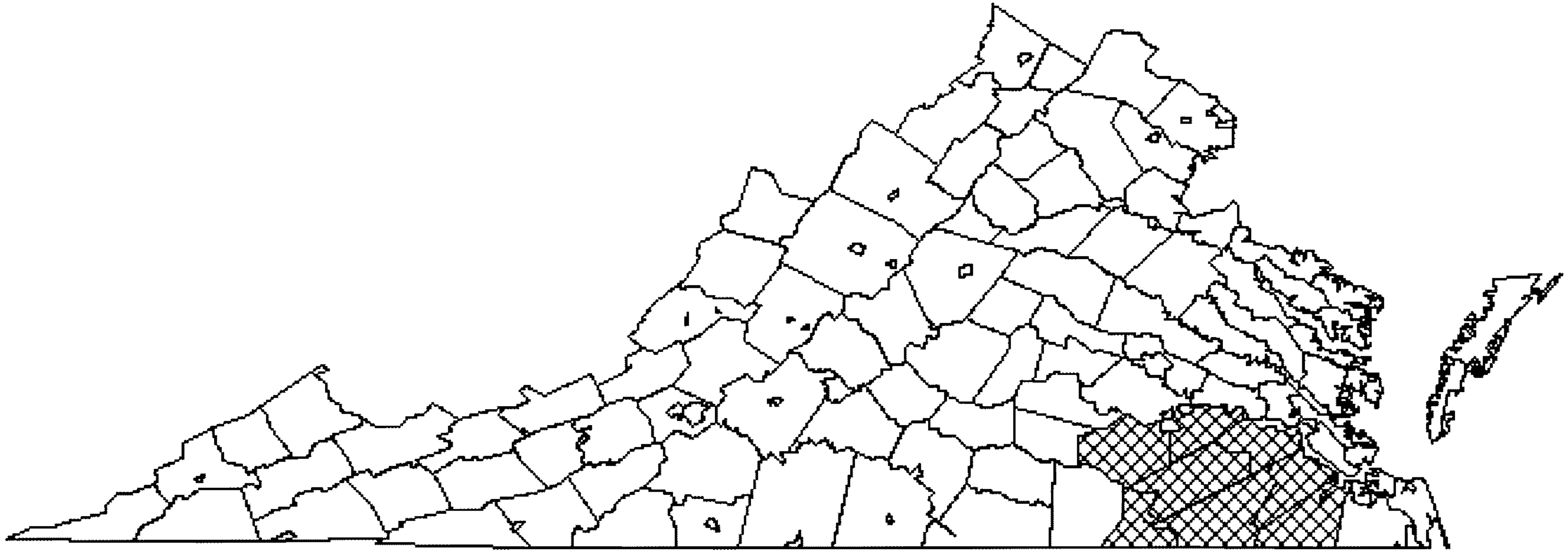

Figure 5.2 Peanut Study Area

Table 5.12[10]. Within the context of this paper, "other hay" refers to all of the following: small grain hay, other tame hay, wild hay, haylage and grass silage, red clover seed, and other field and grass seed.

Section 5.11 Pesticides Applied Within the Study Area in 1992

The pesticides applied to peanuts and the other crops grown in the peanut study area are identified and assigned relative risk levels in Tables A5.6 through A5.19 of the appendix. Most of the information regarding the specific pesticides used on crops in the peanut study area comes from Pesticide Use in Virginia Crop Production published by the National Center for Food and Agricultural Policy (NCFAP). Because pesticide use for cotton and rye production in Virginia is not included in NCFAP's Virginia report, the pesticides reported for cotton and rye production in North Carolina are used as proxies.

Section 5.12 Estimating 1992 Reductions in External Costs Attributable to ELSA

The strategy for estimating reductions in external costs attributable to ELSA is to compare the amount of each pesticide class actually applied to the peanut study area in 1992, i.e., $\text{Use}_{ij\ \text{w/ELSA}}$, to the amount that would have been applied had ELSA never been developed, i.e., $\text{Use}_{ij,\ \text{w/o ELSA}}$. The willingness-to-pay (WTP) estimates from the contingent valuation survey (CVS) of Chapter Four are then used to estimate the social value of the reduction in pesticide use.

Because it has the most accurate pesticide use data 1992 was chosen as the study year. Four fundamental assumptions must be made to reconcile the 1994 CVS estimates and the 1990 ELSA evaluation with the 1992 pesticide use data. These assumptions are as follows: (1) society's willingness-to-pay to avoid pesticide risks in 1992 is equivalent to the 1994 WTP estimates expressed in 1992 dollars; (2) in 1992, peanut producers following ELSA recommendations applied thirty-three percent fewer pounds of

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[10] If the acreage of a crop in a county is reported as "D" in the Census of Agriculture then the harvested acreage of that crop in that county is considered to be zero.

chlorothalonil than producers using a fourteen-day spray schedule; (3) in 1992, ninety-four percent of peanut producers applied chlorothalonil according to ELSA recommendations, while six percent applied chlorothalonil on a fourteen-day spray schedule; and (4) the only difference in pesticide use between the ELSA and fourteen-day producers was in the amount of chlorothalonil applied.

The last assumption allows us to ignore all of the Use_{ij} active ingredient classifications that are not relevant to chlorothalonil. In other words, because the amount of all pesticides, except chlorothalonil, applied by ELSA and fourteen-day producers is assumed to be the same, the savings in external costs attributable to ELSA come exclusively from reductions in the use of chlorothalonil. Referring to appendix Table A5.6, the eight Use_{ij} classifications relevant to chlorothalonil are: (1) low risk to groundwater, (2) high risk to surface water, (3) high risk to aquatic species, (4) high risk to acute human health, (5) moderate risk to chronic human health, (6) low risk to avian species, (7) low risk to mammalian species, and (8) low risk to non-target arthropods.

As Equation 3.1 indicates, Use_{ij} is comprised of two elements, the total amount of active ingredient class ij applied to all crops in the study area other than the study crop (Σ Use_{ija}), and the total amount of active ingredient class ij applied to the study crop (Use_{ij*}). The calculation of Use_{ija} is represented by Equation 5.11[11]

$$Use_{ija} = \sum_{p=1}^{m} (Acres_a * Treat_{ap} * Rate_{ap}) \tag{5.11}$$

Where m = number of active ingredients of class ij applied to crop a

$Acres_a$ = number of acres of crop a harvested in the study area

$Treat_{ap}$ = proportion of study area acres of crop a treated with active ingredient p

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[11] Figures for $Treat_{ap}$ and $Rate_{ap}$ are taken from NCFAP's pesticide use reports.

$Rate_{ap}$ = pounds of active ingredient p applied per acre per year to crop a

Similarly, $Use_{ij*,\ w/ELSA}$, the amount of active ingredient class ij actually applied to peanuts in the study area in 1992, is calculated by Equation 5.12. The total amount of active ingredient class ij applied to the entire study area in 1992, namely, $Use_{ij,\ w/ELSA}$, is the sum over all crops except peanuts of Use_{ija}, plus $Use_{ij*,\ w/ELSA}$. This calculation is represented by Equation 5.13.

$$Use_{ij*,w/ELSA} = \sum_{p=1}^{m} (Acres_{*} * Treat_{*p} * Rate_{*p}) \tag{5.12}$$

Where m = number of active ingredients of class ij applied to peanuts

$Acres_{*}$ = number of harvested acres of peanuts in the study area

$Treat_{*p}$ = proportion of study area peanut acres treated with active ingredient p

$Rate_{*p}$ = pounds of active ingredient p applied per acre per year to peanuts

$$Use_{ij,w/ELSA} = \sum_{a=1}^{n-1} (Use_{ija}) + Use_{ij*,w/ELSA} \tag{5.13}$$

Where n = number of crops grown in the study area

To calculate the amount of active ingredient class ij that would have been applied to the study area if ELSA had not been established, $Use_{ij,\ w/o\ ELSA}$, Equation 5.13 must be modified. The first element remains the same, but the second element must be changed to the amount of active ingredient class ij that would have been applied to peanuts in the absence of ELSA, namely $\text{Use}_{ij*,\ \text{w/o ELSA}}$.

By assuming both that producers following ELSA recommendations applied thirty-three percent less chlorothalonil in 1992 than producers using a calendar spray schedule, *and* that ninety-four percent of Virginia's peanut producers used ELSA while six percent used calendar sprays, a system of equations may be developed and solved for the amount of chlorothalonil that would have been applied in the absence of ELSA. The system of equations is represented by Equations 5.14a and 5.14b.

$$X = 1.5 * Y \tag{5.14a}$$

$$Z = Acres_{*} * (.94 * Y + .06 * X) \tag{5.14b}$$

Where X = pounds of chlorothalonil applied per acre per year to farms using a fourteen-day spray schedule

Y = pounds of chlorothalonil applied per acre per year to farms following ELSA recommendations

Acres_{*} = number of peanut acres harvested in the study area in 1992

Z = total pounds of chlorothalonil applied to peanuts in the study area in 1992[12]

Equation 5.15 is used to estimate $\text{Use}_{ij,\ \text{w/o ELSA}}$. The estimates of $\text{Use}_{ij,\ \text{w/ELSA}}$ and $\text{Use}_{ij,\ \text{w/o ELSA}}$ for the relevant active ingredient classes are presented in Table 5.13.

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[12] Z was estimated in the following manner: 0.99048 of Virginia's total harvested peanut acres in 1992 were grown in the study area (COA); 215,927 pounds of chlorothalonil were applied to peanuts in Virginia in 1992 (NCFAP): the total pounds of chlorothalonil applied to peanuts in the study area in 1992 was, therefore, assumed to be $Z = (0.99048)*(215{,}927) = 213{,}871.375$ lbs.

The values of X and Y that follow from Z are: $X = 3.3553$ lbs/acre; $Y = 2.2368$ lbs/acre. The total amount of chlorothalonil that would have been applied to peanuts in the the study area in the absence of ELSA is, then, $X * \text{Acres}_{*} = 311{,}463$ lbs.

$$Use_{ij,w/oELSA} = \sum_{a=1}^{n-1} (Use_{ija}) + \sum_{p=1}^{m-1} (Use_{ij*p}) + X * Acres_{*} \quad (5.15)$$

Where n = number of crops grown in the study area

p = number of active ingredients of class ij other than chlorothalonil applied o peanuts in the study area

X * Acres. = total pounds of chlorothalonil that would have been applied to the study area in the absence of ELSA

The savings in the external costs inflicted on each of the risk-environmental categories is represented by Equation 5.16. The total savings in external costs attributable to the ELSA program is simply the sum of the savings for each of the eight relevant ij categories. The results of these calculations are presented in Table 5.14.

$$Savings_{ij} = WTP_{ij} * POP * Realized_{ij} \quad (5.16)$$

The total savings in external costs are estimated to be approximately $844,000 per year. In other words, each of the nearly 60,000 households in the peanut study area would have been willing to pay an extra $14.00 per year in groceries to realize the reduction in pesticide use that ELSA provides.

Table 5.11 Virginia's Eight Major Peanut Producing Counties in 1992

County	Harvested Peanut Acres
Dinwiddie	2,535
Greensville	8,196
Isle of Wight	14,867
Prince George	3,089
Southampton	30,927
Surry	7,186
Sussex	11,619
Suffolk (IC)	14,409
Total	92,828

Table 5.12 1992 Harvested Acreage of Other Crops in the Peanut Study Area

Crop	Harvested Acreage
Corn	90,960
Sorghum	5,368
Winter Wheat	41,146
Barley	2,638
Oats	675
Rye	1,551
Cotton	17,814
Tobacco	2,211
Soybeans	108,355
Alfalfa Hay	892
Other Hay	8,140
Watermelon	999

Table 5.13 Estimates of $\text{Use}_{ij,\ w/ELSA}$ and $\text{Use}_{ij,\ w/o\ ELSA}$

Active Ingredient Class	$\text{Use}_{ij,\ w/ELSA}$	$\text{Use}_{ij,\ w/o\ ELSA}$	% Reduction in Use_{ij} due to ELSA
Low Risk to Groundwater	746,710 lbs.	844,302 lbs.	11.56 %
High Risk to Surface Water	1,937,263 lbs.	2,034,855 lbs.	4.80 %
High Risk to Aquatic Species	1,856,759 lbs.	1,954,351 lbs.	4.99 %
High Risk to Acute Human Health	1,744,810 lbs.	1,842,402 lbs.	5.30 %
Moderate Risk to Chronic Human Health	2,268,005 lbs.	2,365,596 lbs.	4.13 %
Low Risk to Avian Species	2,240,733 lbs.	2,338,324 lbs.	4.17 %
Low Risk to Mammalian Species	965,198 lbs	1,062,789 lbs.	9.18 %
Low Risk to Non-target Arthropods	2,325,027 lbs.	2,422,618 lbs.	4.03 %

Table 5.14 Estimates of 1992 External Cost Savings Due to the ELSA Program[13]

Active Ingredient Class	Savings in External Costs
Low Risk to Groundwater	$ 141,662
High Risk to Surface Water	139,148
High Risk to Aquatic Species	143,670
High Risk to Acute Human Health	149,452
Moderate Risk to Chronic Human Health	85,440
Low Risk to Avian Species	44,782
Low Risk to Mammalian Species	99,795
Low Risk to Non-Target Arthropod Species	39,827
Total Savings	$ 843,779

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[13] There were 58,527 households in the peanut study area in 1990 (Census of Housing, 1990). It was assumed that there were 58,527 households in 1992 as well.

The numbers in Table 5.16 are yearly willingness-to-pay experssed in 1992 dollars. The monthly WTP_{ij} estimates from the contingent valuation survey were adjusted to 1992 dollars using the CPI deflator (137.9/147). They were then converted to yearly WTP estimates by multiplying by twelve.

Chapter VI: Conclusion

Section 6.1 Introduction

The study described in the preceding chapters undertakes the formidable task of developing and applying a methodology capable of estimating the savings in the external costs of pesticide use induced by the adoption of integrated pest management programs. The major accomplishments resulting from application of the methodology to Virginia apple and peanut IPM programs are presented in the following section. The results have implications for the formulation of pesticide and IPM related policies as well. Section 6.3 discusses the major policy implications emanating from the study.

Section 6.2 Major Accomplishments of the Thesis

The primary accomplishment of the thesis is the conceptualization and formalization of a methodology capable of estimating changes in the external costs of pesticide use attributable to the adoption of integrated pest management programs. The actual application of the methodology to the two IPM programs in Chapter V generated a new strategy for defining IPM adoption, a new test for identifying payment vehicle bias in contingent valuation surveys, estimates of society's willingness to pay to avoid pesticide risks, and the assignment of relative risk levels to more than 130 pesticidal active ingredients.

The DOI Adoption Algorithm. When assigning a level of IPM adoption to a producer, the early IPM literature focussed on scouting. In contrast, the Degree of Integration (DOI) adoption algorithm developed in Section 3.7 recognizes alternative pest management practices (biological agents, cultural practices, etc.) in addition to scouting. The Massachusetts adoption criteria described in Section 2.5 also recognize alternative practices. There are, however, some fundamental differences between the DOI algorithm and the Massachusetts criteria.

The DOI identifies four levels of IPM adoption (High, Medium, Low, and Non-IPM) as opposed to the two levels (IPM and Non-IPM) identified by the Massachusetts criteria. From an evaluative perspective, four levels of adoption seems more appropriate, particularly for crops with a multitude of alternative practices available.

By weighing equally all alternative practices available for controlling a pest type, the DOI is not as program specific as the Massachusetts criteria. On the surface, a more generalized set of criteria may not appear as appealing as a program specific one, but the lack of specificity has some distinct advantages. The general nature of the DOI formula allows it to readily incorporate new practices and be easily adjusted when old practices become obsolete. In other words, the DOI algorithm remains fundamentally consistent as an IPM program evolves. The Massachusetts criteria, on the other hand, must determine how to adjust the weights given to the various practices when other practices are introduced and old practices are no longer relevant. In addition, the DOI algorithm is flexible enough to be applied to any crop in any location, whereas the Massachusetts criteria would require an individual point system be developed for each crop in each location. Finally, the DOI has resolved the issues of complementary and substitute practices mentioned in Section 2.5. These issues have yet to be addressed by the Massachusetts criteria.

The ORR Test for Payment Vehicle Bias. The contingent valuation survey described in Chapter IV employed two payment vehicles to elicit society's willingness to pay to avoid pesticide risks to the environment and human health. As discussed in Section 2.4, payment vehicle bias is one of the potential biases to which CVSs are subject. Because the two vehicles used in the CVS for this study employed different payment intervals, the traditional test for payment vehicle bias (a test on the means) did not seem appropriate. Rather than rely on a test of the means, a new test -- the overt rejection rate (ORR) test -- was developed and used. Although the ORR was developed to test for bias when the payment interval of the two vehicles differs, its applicability is not restricted to such situations.

The issue of payment vehicle bias comes as no surprise to Kenneth Arrow who argues that the vehicle should matter to respondents. While this is an intuitively appealing argument, it does not dismiss the issue of payment vehicle bias for two reasons: (1) policy makers may have a variety of options available and may be interested not only in the mean willingness to pay associated with each vehicle, but also in which vehicle the population will most readily accept; and (2) when evaluating non-use values, analysts are interested in willingness to pay estimates that are divorced from policy instruments. If a CVS is pretested with several payment vehicles, the ORR can help identify the vehicle to which the population is least averse. This information may assist policy makers in the selection of a policy instrument, and help analysts design surveys capable of generating more reliable estimates of non-use values.

The CVS Willingness to Pay Estimates. The methodology developed in Chapter III was designed not only for this study, but for possible use in the evaluation of IPM programs across the country. One of the drawbacks of the methodology is its extensive data requirements. Fortunately, a lot of the data generated by this study can be used when employing the methodology to evaluate other IPM programs.

In Chapter IV, the results of the contingent valuation survey are presented and analyzed. The analysis shows that there is no divergence in the willingness to pay estimates across individual states. Therefore, the estimates reported in Table 4.6 (reproduced here as Table 6.1) may be used in the evaluation of any IPM program anywhere in the country. The availability of these data substantially eases the data collection requirements of analysts employing this methodology in the future.

The Assignment of Risk Levels. As part of this study, more than 130 pesticidal active ingredients were assigned relative risk levels in accordance with the criteria developed in Chapter III. Table A6.1 of the Appendix to Chapter VI presents these chemicals and their risk levels. As with the willingness to pay estimates, the availability of these data facilitates future studies of this kind by considerably reducing the amount of time and effort spent on data collection. In addition, the risk assignments may be used by farmers to guide their selection of pesticides.

Table 6.1 Estimated Willingness to Pay per Household in Increased Monthly Grocery Expenses to Avoid High, Moderate, and Low Pesticide Risks to Eight Environmental and Human Health Categories

Environmental Category	High Risk			Moderate Risk			Low Risk		
	Mean ($/Mo)	Std Dev	N	Mean ($/Mo)	Std Dev	N	Mean ($/Mo)	Std Dev	N
Acute Human Health	4.28	4.68	397	2.89	3.44	392	1.74	2.75	388
Chronic Human Health	4.59	4.85	397	3.14	3.68	392	1.89	2.87	388
Ground Water	4.56	4.75	397	3.08	3.62	392	1.86	2.91	388
Surface Water	4.40	4.62	397	2.93	3.43	392	1.76	2.79	388
Aquatic Species	4.37	4.64	397	2.88	3.42	392	1.75	2.84	388
Avian Species	4.15	4.48	397	2.72	3.23	392	1.63	2.67	388
Mammals	4.13	4.46	397	2.71	3.25	392	1.65	2.69	388
Arthropods	3.76	4.33	397	2.49	3.11	392	1.50	2.54	388

Section 6.3 Policy Implications

There are several policy implications that emanate from this study. First, the analysis of the apple IPM program leads to a number of suggestions regarding the design of future ERS chemical use surveys. Second, recommendations regarding future funding of the ELSA peanut program, and the desirability of replicating that program in other parts of the country, can be made based on the analysis of ELSA in Chapter V. Third, the discussion about the lack of and need for a single set of criteria for assigning levels of IPM adoption to producers implies that the USDA should consider embracing and promoting a single method for defining adoption. And fourth, the ordinal preferences revealed by the CVS survey suggest a means for prioritizing pesticide risk mitigation efforts.

The Design of Future ERS Chemical Use Surveys for Apples. The analysis of the Virginia apple IPM program suggests the ERS should include in future chemical use surveys inquiry into the highest education level attained by the farm manager, and the percentage of household income the generated by the crop in question. The ERS should also consider asking a series of general pest severity questions. Perhaps the question, "Overall, how would you rate the severity of insect infestation in your apple orchards last year?" would suffice. The question could then be repeated for fungi and weed infestation levels. A continuous zero-to-ten scale could be used to record the responses. The inclusion of the education, percentage of income, and general pest severity variables in the pesticide use models will likely improve the models' predictive ability.

The ERS should also consider including a direct question regarding what beneficial insects a producer releases in their orchards. Asking such a question is likely to alleviate possible confusion about the "conditions of employment" of beneficial insects discussed in section 5.6.

Finally, the ERS should not abandon the chemical usage surveys. Time series data will be helpful in evaluating the performance of all of the alternative pest management practices, particularly scouting.

The ELSA Program for Peanuts. The analysis of Chapter V estimated the 1992 savings in external costs attributable to the ELSA program at approximately $840,000. In light of these savings, and in recognition of the fact that reductions in external costs are only one component of the potential social benefits of the ELSA program, the continuation of the ELSA program in the Virginia area is strongly recommended. In addition, federal, state and local agricultural and environmental agencies may want to replicate the ELSA program in other regions, and possibly develop similar forecasting systems for other crops.

Promoting a Single Method for Defining IPM Adoption. The fact that the agricultural community has yet to embrace a single set of criteria for assigning levels of IPM adoption is understandable. IPM programs are a conglomeration of pest management practices designed to combat the particular pests that afflict a crop in a specific geographical location. Because pest complexes vary across crops and locations, IPM programs vary as well. Nonetheless, that the lack of a common set of criteria is understandable does not diminish the desirability of establishing one. A common set of adoption criteria would facilitate not only the aggregation of results of IPM program evaluations, but would also facilitate the evaluations themselves. Presently, an analyst interested in evaluating an IPM program must first decide how, and the degree to which to differentiate between producers with respect to IPM adoption. A common set of adoption criteria would alleviate the need for this preliminary step.

Osteen, Bradley, and Moffit define IPM as the integration of biological, cultural, and chemical control for "optimal" pest management. The term optimal is, undoubtedly, a source of potential confusion and contention. From an environmentalist's perspective, optimal control may mean that which has the least environmental repercussions; from a producer's perspective, optimal control may mean that which generates the greatest profits; from a consumer's perspective, optimal control may mean that which results in the lowest food prices. In light of the benefits of a common set of adoption criteria, it is suggested that the USDA decide what the USDA means by integrated pest management. Once that is done, the USDA should embrace and promote a single method for defining IPM adoption. The DOI and the Massachusetts criteria are two candidates that should be considered. Were the Massachusetts criteria to be chosen, I strongly urge that the issues concerning complementary and substitute practices, the assignment of points to practices, the evolution of the IPM program, and the number of levels of IPM to identify first be addressed. (These issues are discussed in detail in Section 2.5.)

Ordinal Preferences Revealed for Pesticide Risk Mitigation. One of the most interesting results to come out of this study is the revelation of the social ordinal preferences for avoiding pesticide risks. Table 4.10 presents these results. Not only are these results fundamental to the application of the methodology of Chapter III, but they may also be used to prioritize policies and regulations aimed at mitigating the risks pesticides pose to the environment and human health.

Section 6.4 Concluding Remarks

Integrated pest management was conceived as a means of easing producers' reliance on chemical pesticides while maintaining agricultural production and preserving profitability. Many IPM programs have attained these goals. It is premature, however, to infer that reductions in pesticide use imply environmental/social benefits. A thorough analysis of the social benefits of reduced pesticide use must examine the toxicity, mobility, and persistence characteristics of the pesticides being used. If farmers reduce the total pounds of pesticidal active ingredient applied to their acreage but simultaneously substitute highly toxic, highly mobile, persistent chemicals for relatively benign ones, it is difficult to argue that society is better off. The methodology developed in Chapter III recognizes this subtlety.

The results of the contingent valuation survey administered for this study show that society values the non-target resources that are adversely affected by pesticide use. Employing the CVS estimates in the analysis of the ELSA peanut program illustrates the magnitude of environmental benefits that IPM programs can generate.

In these times of budget deficits, integrated pest management programs will be subject to the same scrutiny as other publicly funded activities. The future of public funding for IPM research and extension relies on the ability to demonstrate the net social benefits of IPM. This thesis represents a significant step in the development of an analytical framework in which to evaluate the total costs and benefits of integrated pest management programs.

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Appendix to Chapter IV

The Contingent Valuation Survey

Introduction

For more than fifty years, chemical pesticides have been an important part of farming in the United States. These chemicals have allowed farmers to control insects and other pests while producing high quantities of food at relatively low prices. Although many of these pesticides kill destructive pests, they can also harm humans and other life forms. When we apply chemical pesticides to crops, we risk damage to the surrounding environment. Some examples of unintended damage pesticides may cause can be found on the back cover of the survey.

The challenge to agricultural researchers is to reduce or eliminate the risk of damage to the environment, while keeping harvests plentiful and farming profitable. Unfortunately, the search for safer ways to control pests is not free. State and federal government agencies often must pay the cost of developing ways to control pests without pesticides, and the costs of educating farmers how to use them. In addition, safer ways of farming may result in higher food prices. For this reason, it is important to estimate how much the public is willing to pay to avoid risks from pesticides to humans and the environment before public funds are spent for that purpose. This survey is designed to help obtain such an estimate.

Questionnaire

1. Approximately how much do you (or your family)

spend on groceries IN A MONTH? $______ per month

For the purposes of this survey, HIGH risks from pesticide use are defined to occur when:

the pesticide is <u>somewhat</u> or <u>very</u> likely to cause a <u>high</u> level of damage to the environment

OR

the pesticide is <u>very</u> likely to cause a <u>moderate</u> level of damage to the environment

2. How much **more** would you (your family) be willing to spend

on groceries EACH MONTH to avoid HIGH risks to the

environment and human health from pesticide use? $______ per month

Questions 2 and 3 are separate questions. The answers to these questions will not be added together.

3. How much **more** would you (your family) be willing to pay in

federal income tax to support efforts aimed at finding ways

to avoid HIGH risks to the environment and human health

from pesticide use? $______ per year

4. Please indicate how important you believe it is to avoid a HIGH risk from pesticides in each of the following categories. Circle the appropriate number between 0 and 6, where 0 means avoiding a high risk in that category is not important and 6 means avoiding a high risk in that category is very important.

Environemntal Category at Risk	Importance (0-6)						
	Not Important					Very Important	
a. short-term human health effects (yourself and others)	0	1	2	3	4	5	6
b. long-term human health effects (yourself and others)	0	1	2	3	4	5	6
c. groundwater (wells and aquifers)	0	1	2	3	4	5	6
d. surface water (such as rivers, lakes, streams)	0	1	2	3	4	5	6
e. aquatic species (such as fish, shell fish, plants)	0	1	2	3	4	5	6
f. birds (such as ducks, eagles, sparrows)	0	1	2	3	4	5	6
g. mammals (such as deer, raccoons, bears, dogs)	0	1	2	3	4	5	6
h. insects (such as honey bees, beetles)	0	1	2	3	4	5	6

For the purposes of this survey, MODERATE risks from pesticide use are defined to occur when:

the pesticide is <u>somewhat</u> likely to cause a <u>moderate</u> level of damage to the environment

OR

the pesticide is <u>somewhat</u> or <u>very</u> likely to cause a <u>low</u> level of damage to the environment

5. How much **more** would you (your family) be willing to spend
on groceries EACH MONTH to avoid MODERATE risks to the
environment and human health from pesticide use? $______ per month

Questions 5 and 6 are separate questions. The answers to these questions will not be added together.

6. How much **more** would you (your family) be willing to pay in
federal income tax to support efforts aimed at finding ways
to avoid MODERATE risks to the environment and human health
from pesticide use? $______ per year

7. Please indicate how important you believe it is to avoid a MODERATE risk from pesticides in each of the following categories. Circle the appropriate number between 0 and 6, where 0 means avoiding a moderate risk in that category is not important and 6 means avoiding a moderate risk in that category is very important.

Environemntal Category at Risk	Importance (0-6)						
	Not Important						Very Important
a. short-term human health effects (yourself and others)	0	1	2	3	4	5	6
b. long-term human health effects (yourself and others)	0	1	2	3	4	5	6
c. groundwater (wells and aquifers)	0	1	2	3	4	5	6
d. surface water (such as rivers, lakes, streams)	0	1	2	3	4	5	6
e. aquatic species (such as fish, shell fish, plants)	0	1	2	3	4	5	6
f. birds (such as ducks, eagles, sparrows)	0	1	2	3	4	5	6
g. mammals (such as deer, raccoons, bears, dogs)	0	1	2	3	4	5	6
h. insects (such as honey bees, beetles)	0	1	2	3	4	5	6

For the purposes of this survey, LOW risks from pesticide use are defined to occur when:

the pesticide is <u>somewhat</u> likely to cause a <u>low</u> level of damage to the environment

OR

the pesticide is <u>not very</u> likely to cause a <u>low</u> or <u>moderate</u> level of damage to the environment

8. How much **more** would you (your family) be willing to spend on groceries EACH MONTH to avoid LOW risks to the environment and human health from pesticide use? $______ per month

Questions 8 and 9 are separate questions. The answers to these questions will not be added together.

9. How much **more** would you (your family) be willing to pay in federal income tax to support efforts aimed at finding ways to avoid LOW risks to the environment and human health from pesticide use? $______ per year

10. Please indicate how important you believe it is to avoid a LOW risk from pesticides in each of the following categories. Circle the appropriate number between 0 and 6, where 0 means avoiding a low risk in that category is not important and 6 means avoiding a low risk in that category is very important.

Environemntal Category at Risk	Importance (0-6)						
	Not Important						Very Important
a. short-term human health effects (yourself and others)	0	1	2	3	4	5	6
b. long-term human health effects (yourself and others)	0	1	2	3	4	5	6
c. groundwater (wells and aquifers)	0	1	2	3	4	5	6
d. surface water (such as rivers, lakes, streams)	0	1	2	3	4	5	6
e. aquatic species (such as fish, shell fish, plants)	0	1	2	3	4	5	6
f. birds (such as ducks, eagles, sparrows)	0	1	2	3	4	5	6
g. mammals (such as deer, raccoons, bears, dogs)	0	1	2	3	4	5	6
h. insects (such as honey bees, beetles)	0	1	2	3	4	5	6

Please answer the following questions by marking the appropriate space. Please keep in mind that all your responses are strictly confidential.

11. What is your gender?	___ MALE ___ FEMALE
12. What year were you born?	19___
13. Which of the following best describes your total household income before taxes in 1993?	___ less than $10,000 ___ $10,000 to $24,999 ___ $25,000 to $49,999 ___ $50,000 to $74,999 ___ $75,000 to $99,999 ___ $100,000 to $150,000 ___ more than $150,000
14. How many people live in your household?	___
15. Which of the following best describes where you live?	___ a rural area ___ an urban area

Chemical Pesticides can affect five broad environmental and human health categories. Below is a list of these categories and some examples of the harmful effects pesticides may cause each category.

Environmental & Human Health Categories	Examples of Harmful Effects
acute or short-term human health effects	convulsions, temporary paralysis, unconsciousness
chronic or long-term human health effects	depression, muscle weakness, cancer
contamination of groundwater	contaminated sources of drinking water
contamination of surface water	damage to the following: human recreational and economic activities; the natural beauty of rivers, lakes, ponds, and streams; and the plants and animals living in and around the surface water
effects of plants and animals (not pests)	limit the ability of birds, insects, mammals, fish, and plants to survive and/or reproduce

Table A4.1 Survey Population and Response by State

State	# Sent	Undeliverable	# Returned	Usable Responses	Useable Response Rate (%)
AL	50	9	7	7	17.1
AK	3	0	1	1	33.3
AZ	33	8	8	7	28.0
AR	29	4	5	5	20.0
CA	171	26	26	25	17.2
CO	38	2	8	7	19.4
CT	41	2	5	5	12.8
DE	8	2	0	0	0.0
DC	7	4	2	2	66.7
FL	162	23	25	21	15.1
GA	73	11	6	6	9.7
HI	10	3	2	2	28.6
ID	13	1	2	2	16.7
IL	118	8	21	19	17.3
IN	68	4	10	9	14.1
IA	38	1	6	5	13.5
KS	34	5	6	5	17.2
KY	42	4	3	3	7.9
LA	46	7	2	2	5.1
ME	19	7	3	3	25.0
MD	51	4	9	8	17.0
MA	77	9	5	5	7.4
MI	98	6	21	19	20.7
MN	61	4	9	8	14.0
MS	27	4	4	3	13.0
MO	62	4	8	8	13.8

Table A4.1 Continued

State	# Sent	Undeliverable	# Returned	Useable Responses	Useable Response Rate (%)
MT	11	1	2	1	10.0
NE	22	1	2	1	4.8
NV	8	3	2	2	40.0
NH	17	7	2	1	10.0
NJ	81	4	9	8	10.4
NM	15	6	3	3	33.3
NY	207	22	24	21	11.4
NC	80	17	10	8	12.7
ND	9	2	1	1	14.3
OH	123	7	19	17	14.7
OK	38	7	4	4	12.9
OR	28	2	5	5	19.2
PA	148	10	23	20	14.5
RI	12	1	2	2	18.2
SC	38	5	5	5	15.2
SD	10	1	1	1	11.1
TN	60	5	4	3	5.5
TX	172	25	30	28	19.1
UT	16	0	6	6	37.5
VT	10	2	3	2	25.0
VA	371	79	44	37	12.7
WA	53	5	6	4	8.3
WV	21	5	3	3	18.8
WI	66	5	15	15	24.6
WY	5	0	1	1	20.0
Uknown			24	18	
TOTALS	3000	384	454	404	15.4

Table A4.2 WTP Estimates to Avoid Pesticide Risks to Acute Human Health for Comparison States

STATE	Risk Level								
	High			Moderate			Low		
	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Virginia	5.33		36	3.97		36	2.52		35
Pennsylvania	4.74		20	3.30		20	2.07		20
New York	5.53		20	3.90		19	2.45		21
Florida	4.91		21	2.82		21	1.29		21
Ohio	4.05		17	2.35		16	1.46		17
Michigan	5.11		19	2.90		19	1.27		18
Wisconsin	3.72		15	3.36		13	2.48		12
Illinois	3.19		18	2.18		19	1.56		19
Texas	3.42		27	2.66		26	1.43		27
California	3.94		25	2.38		25	1.38		24
Unknown	1.81		17	1.34		18	0.91		18

Table A4.3 WTP Estimates to Avoid Pesticide Risks to Chronic Human Health for Comparison States

	Risk Level								
	High			Moderate			Low		
STATE	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Virginia	5.81		36	4.26		36	2.63		35
Pennsylvania	4.79		20	3.47		21	2.29		20
New York	5.98		20	4.07		19	2.55		21
Florida	5.06		21	3.39		21	1.48		21
Ohio	3.71		17	2.32		16	1.47		17
Michigan	5.37		19	3.02		19	1.27		18
Wisconsin	3.52		15	3.30		13	2.48		12
Illinois	3.43		18	2.39		19	1.83		19
Texas	3.36		27	2.73		26	1.68		27
California	4.62		25	2.86		25	1.59		24
Unknown	2.30		17	1.65		18	1.07		18

Table A4.4 WTP Estimates to Avoid Pesticide Risks to Ground Water for Comparison States

	Risk Level								
	High			Moderate			Low		
STATE	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Virginia	5.51		36	4.16		36	2.61		35
Pennsylvania	5.03		20	3.35		20	2.28		20
New York	5.87		20	3.96		19	2.45		21
Florida	4.94		21	3.32		21	1.90		21
Ohio	3.52		17	2.23		16	1.46		17
Michigan	5.39		19	3.11		19	1.33		18
Wisconsin	3.78		15	3.30		13	2.40		12
Illinois	3.64		18	2.46		19	1.86		19
Texas	3.51		27	2.80		26	1.73		27
California	4.49		25	2.75		25	1.55		24
Unknown	2.14		17	1.48		18	0.95		18

Table A4.5 WTP Estimates to Avoid Pesticide Risks to Surface Water for Comparison States

	Risk Level								
	High			Moderate			Low		
STATE	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Virginia	5.30		36	3.71		36	2.27		35
Pennsylvania	4.56		20	3.28		20	2.25		20
New York	5.75		20	3.86		19	2.38		21
Florida	4.90		21	2.94		21	1.87		21
Ohio	3.52		17	2.15		16	1.43		17
Michigan	5.40		19	2.91		19	1.29		18
Wisconsin	3.64		15	3.30		13	2.40		12
Illinois	3.40		18	2.29		19	1.70		19
Texas	3.30		27	2.61		26	1.46		27
California	4.21		25	2.52		25	1.48		24
Unknown	2.17		17	1.46		18	0.83		18

Table A4.6 WTP Estimates to Avoid Pesticide Risks to Aquatic Species for Comparison States

STATE	Risk Level								
	High			Moderate			Low		
	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Virginia	5.50		36	3.83		36	2.49		35
Pennsylvania	4.79		20	3.29		20	2.08		20
New York	5.41		20	3.78		19	2.46		21
Florida	4.83		21	2.94		21	1.86		21
Ohio	3.34		19	1.79		16	1.39		17
Michigan	5.44		19	2.99		19	1.28		18
Wisconsin	3.48		15	3.25		13	2.40		12
Illinois	3.36		18	2.29		19	1.68		19
Texas	3.26		27	2.59		26	1.34		27
California	4.43		25	2.65		25	1.43		24
Unknown	2.12		17	1.35		18	0.89		18

Table A4.7 WTP Estimates to Avoid Pesticide Risks to Mammalian Species for Comparison States

STATE	Risk Level								
	High			Moderate			Low		
	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Virginia	4.81		36	3.44		36	2.19		35
Pennsylvania	4.97		20	3.04		20	2.03		20
New York	4.99		20	3.40		19	2.29		21
Florida	4.84		21	2.96		21	1.90		21
Ohio	3.12		17	1.69		16	1.24		17
Michigan	4.72		19	2.88		19	1.12		18
Wisconsin	3.39		15	3.16		13	2.08		12
Illinois	3.77		18	2.25		19	1.69		19
Texas	2.63		27	2.11		26	1.04		27
California	4.34		25	2.60		25	1.40		24
Unknown	2.12		17	1.52		18	1.08		18

Table A4.8 WTP Estimates to Avoid Pesticide Risks to Avian Species for Comparison States

	Risk Level								
	High			Moderate			Low		
STATE	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Virginia	4.82		36	3.44		36	2.16		35
Pennsylvania	5.07		20	3.19		20	2.03		20
New York	4.99		20	3.40		19	2.29		21
Florida	4.82		21	2.95		21	1.89		21
Ohio	3.21		17	1.69		16	1.25		17
Michigan	4.87		19	2.88		19	1.11		18
Wisconsin	3.40		15	3.22		13	2.08		12
Illinois	3.74		18	2.25		19	1.69		19
Texas	2.70		27	2.11		26	1.04		27
California	4.38		25	2.61		25	1.36		24
Unknown	2.13		17	1.54		18	0.98		18

Table A4.9 WTP Estimates to Avoid Pesticide Risks to Arthropods for Comparison States

STATE	Risk Level								
	High			Moderate			Low		
	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Virginia	4.58		36	3.30		36	2.06		35
Pennsylvania	3.65		20	2.39		20	1.47		20
New York	4.46		20	3.02		19	2.21		21
Florida	4.04		21	2.25		21	1.06		21
Ohio	2.94		17	1.59		16	1.19		17
Michigan	4.18		19	2.51		19	1.05		18
Wisconsin	3.27		15	2.71		13	2.00		12
Illinois	3.14		18	2.15		19	1.52		19
Texas	2.34		27	1.89		26	0.96		27
California	3.99		25	2.47		25	1.40		24
Unknown	1.98		17	1.33		18	0.84		18

Appendix to Chapter V

Superscripts in Tables A5.1, and A5.6 through A5.19 denote the following sources (complete references of these sources appear in the bibliography):

a = list of chemicals applied to Virginia apples comes from the USDA Fruit and Nut Chemical Usage Survey data
b = list of chemicals applied to these crops come from Phillips and Shabman (1991)
e = list of chemicals applied to these crops come from Gianessi and Anderson (1995)

Toxicicity, persistence and mobility data were obtained from:

1 = Becker et. al. (1989), unless otherwise noted
2 = EXTOXNET, unless otherwise noted
3 = Higley and Wintersteen (1992)
4 = Smith (1993)
5 = K_{OC} and soil half life (Wauchope et. al., 1992), Groundwater Ubiquity Score equation and risk delineation (Gustafson, 1989)
6 = USEPA Office of Drinking Water
7 = USEPA Office of Pesticides and Toxic Substances
9 = The Pesticide Manual (1987)
10 = Agrochemical Handbook
11 = Briggs (1992)
12 = Kovach et. al. (1992)
24 = 24 hr. LC50
48 = 48 hr. LC50
epa = USEPA does not require data
S = Susan Jennings, personal communication
Red = USEPA Office of Pesticide Programs Reregistration Eligibility Document for the specific chemical
Y = Keith Yoder, personal communication
DG = data gap

Table A5.1 Relative Risk Levels for Apple Pesticides

VA APPLE[a] PESTICIDE	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2,4-D	MID[5]	HIGH[5]	HIGH	HIGH[2]	MID	MID	MID	HIGH
Abamectin	LOW[2]	LOW[2]	MID	HIGH[2]	LOW	LOW	HIGH	HIGH
Azinophos-methyl	LOW	HIGH	HIGH	HIGH	MID	MID	HIGH	HIGH
Bacillus thur (Bt)	LOW[2]	LOW[2]	LOW	LOW[2]	MID	LOW	LOW	MID
Benomyl	HIGH	HIGH	HIGH	MID	HIGH	LOW	LOW[7]	HIGH
Calcium polysulfide	LOW[7]	LOW[7]	MID[DG]	LOW	LOW[7]	MID[DG]	MID[DG]	MID[DG]
Captan	LOW	LOW	LOW	HIGH	HIGH	LOW	LOW[7]	LOW
Carbaryl	LOW	MID	MID[9]	MID	LOW	MID	LOW	HIGH
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Chlorpyrifos	LOW	HIGH	HIGH[9]	MID	MID	MID	HIGH	HIGH
Copper Hydroxide	LOW[12]	MID[12]	MID[12]	LOW[12]	LOW[12]	MID[12]	MID[DG]	MID[DG]
Copper Sulfate	LOW[2]	LOW[2]	MID	HIGH	LOW[epa]	LOW	HIGH	HIGH
Copper Oxychl. Sul.	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]
Diazinon	MID	MID	HIGH	MID[2]	HIGH	HIGH	MID	HIGH
Dicofol	LOW	HIGH	HIGH	MID	LOW	LOW	MID	LOW
Dimethoate	MID	LOW	LOW	MID	MID	HIGH	HIGH	HIGH
Dinocap	LOW	MID	LOW	LOW	HIGH	HIGH	MID	LOW
Diuron	MID[5]	HIGH[5]	MID	MID[2]	MID	LOW	LOW	LOW
Dodine	LOW[5]	MID[5]	HIGH[7]	HIGH	MID	LOW[7]	LOW	LOW
Endosulfan	LOW	HIGH	HIGH	HIGH	MID	MID	HIGH	LOW
Esfenvalerate	LOW	HIGH	HIGH[3]	MID	LOW	LOW	MID	HIGH
Ethion	LOW[5]	MID[5]	HIGH	HIGH[2]	HIGH	HIGH	HIGH	LOW
Ethyl parathion	LOW[5]	MID[5]	HIGH[3]	HIGH[3]	MID[3]	HIGH[3]	HIGH[3]	MID[3]
Fenarimol	HIGH	HIGH	HIGH[7]	MID	HIGH[11]	LOW[7]	MID[9]	LOW[7]

Table A5.1 Continued

VA APPLE PESTICIDES	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non-target[2]
Ferbam	MID[5]	MID[5]	LOW[12]	LOW[11]	MID[11]	MID[DG]	LOW[9]	MID[12]
Formetanate hydro	HIGH	LOW	LOW[7]	HIGH	MID[DG]	HIGH[4]	HIGH[4]	MID[7]
Glyphosate	LOW	HIGH	MID	HIGH	LOW	LOW	LOW[4]	MID
Malathion	LOW	LOW	LOW	MID	HIGH	MID	LOW	HIGH[10]
Mancozeb	LOW	HIGH	HIGH	LOW	HIGH	LOW	LOW[10]	HIGH[12]
Metalaxyl	HIGH	LOW	LOW	MID	LOW	LOW	LOW	LOW
Methidathion	LOW[5]	MID[5]	HIGH	HIGH	MID	HIGH	HIGH[11]	HIGH
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID
Methoxychlor	LOW[5]	MID[5]	HIGH	LOW	MID	LOW[3]	LOW	HIGH[3]
Methyl parathion	LOW[5]	LOW[5]	MID	HIGH	MID	LOW	MID	HIGH
Metiram	LOW	HIGH	LOW	LOW	HIGH	LOW	LOW	LOW
Myclobutanil	MID[DG]	MID[DG]	MID[DG]	HIGH	LOW[S]	MID[DG]	LOW[9]	MID[DG]
Napthalene aceticacid	MID[5]	MID[5]	MID[DG]	MID[DG]	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Norflurazon	LOW[5]	MID[5]	LOW[9]	LOW[S]	LOW[S]	LOW[9]	LOW[9]	LOW[12]
Oryzalin	LOW	MID	MID	LOW	MID	LOW	LOW	LOW
Oxamyl	LOW	LOW	LOW	HIGH	LOW	LOW[4]	LOW[4]	MID
Oxythioquinox	LOW[5]	MID[5]	HIGH[12]	MID[DG]	MID[DG]	HIGH[12]	LOW[9]	LOW[9]
Paraquat	LOW	HIGH	MID[9]	HIGH	HIGH	MID[6]	HIGH[6]	LOW
Permethrin	LOW	HIGH	HIGH[9]	MID	MID	LOW	MID	HIGH
Petroleum distillate	LOW[12]	LOW[12]	LOW[12]	LOW	MID[12]	LOW[12]	LOW[9]	HIGH[Y]
Phosmet	LOW	MID	HIGH[3]	MID	MID[3]	LOW[3]	MID[3]	MID[3]
Phosphamidon	HIGH[5]	LOW[5]	MID[7]	HIGH	MID[7]	HIGH[4]	HIGH[4]	HIGH[4]
Propargite	LOW[5]	HIGH[5]	HIGH[9]	HIGH	MID[3]	LOW[3]	MID[9]	LOW[3]
Simazine	HIGH	MID	MID	LOW[2]	MID	LOW	LOW	LOW

Table A5.1 Continued

VA APPLE PESTICIDES	groud-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non-target[2]
Streptomycin	LOW[12]	LOW[12]	MID[DG]	MID[DG]	LOW[12]	MID[DG]	MID[DG]	MID[DG]
Sulfur	LOW[7]	LOW[7]	LOW[11]	LOW	LOW[7]	LOW[11]	LOW[11]	HIGH[12]
Terbacil	HIGH[5]	HIGH[5]	LOW	LOW[2]	LOW	LOW	LOW	LOW
Thiophanate Methyl	LOW	MID	HIGH[7]	LOW	LOW[4]	LOW[4]	LOW[4]	HIGH[11]
Thiram	LOW[5]	LOW[5]	MID[7]	LOW	HIGH	LOW[4]	LOW[4]	LOW[7]
Triadimefon	MID	MID	MID	MID	MID	LOW	MID	LOW[10]
Trichlorfon	HIGH	LOW	LOW[48]	HIGH	HIGH	HIGH	MID	HIGH
Vinclozolin	LOW[12]	LOW[12]	LOW[12]	MID[12]	LOW[12]	LOW[11]	LOW[9]	LOW[9]
Ziram	LOW[13]	MID[DG]	MID	HIGH[2]	HIGH	MID[4]	LOW[4]	LOW[11]

$$\mathit{TotalInsecticideUse} = \alpha_0 + \beta_0 * \ln(\mathit{ACRES}) + \alpha_1 * \mathit{Fresh} + \beta_1 * \mathit{Fresh} * \ln(\mathit{ACRES}) \tag{A5.1}$$

Table A5.? Results from Equation A5.2 Total Insecticide Use versus Fresh/Processed Market

Descriptive Statistics:	R^2 = .4784	Adjusted R^2 = .4606	F Value = 26.899
Independent Variable	**Estimate**	**Std. Dev.**	**P-Value**
Intercept	-4924.50	1554.05	.0021
ln(Bearing Acres)	1928.70	384.29	.0001
Fresh	2391.94	1685.22	.1593
Fresh * ln(Bearing Acres)	-405.70	436.19	.3549

$$\begin{aligned} \mathit{TotalInsecticideUse} = \alpha_0 &+ \beta_0 * \ln(\mathit{ACRES}) + \alpha_1 * \mathit{SCOUTIN} \\ &+ \alpha_2 * \mathit{BENE} + \alpha_3 * \mathit{TRAP} + \alpha_4 * \mathit{PHER} \\ &+ \alpha_5 * \mathit{LOC} + \alpha_6 * \mathit{REDU} + \alpha_7 * \mathit{PRUNE} \\ &+ \alpha_8 * \mathit{IRRI} + \alpha_9 * \mathit{TILL} + \alpha_{10} * \mathit{VAR} \end{aligned} \tag{A5.2}$$

Table A5.3 Total Insecticide Use versus Individual Insect Practices for All Apple Producers

Descriptive Statistics:	R^2 = .6630	Adj. R^2 = .6166	F Value = 14.305
Independent Variable	Parameter Estimate	Standard Deviation	P-Value
Intercept	-2752.83	851.08	.0018
ln(ACRES)	1013.79	184.26	.0001
SCOUT FOR INSECTS	-407.32	710.23	.5679
BENEFICIAL INSECTS	4690.25	1120.47	.0001
TRAP CROPS	2557.07	1503.69	.0929
PHEROMONE TRAPS	2000.45	778.87	.0121
LOCATION OF OTHER CROPS	1047.06	1228.87	.3967
REDUCED APPLICATION RATES	30.22	513.87	.9533
IRRIGATION PRACTICES	1405.37	1519.73	.3579
PRUNING CANOPY	53.86	615.59	.9305
MOWING/TILLAGE PRACTICES	842.12	801.60	.2966
RESISTANT VARIETIES	-588.34	840.71	.4861

$$TotalHerbicideUse = \alpha_0 + \beta_0 * \ln(ACRES) + \alpha_1 * Fresh + \beta_1 * Fresh * \ln(ACRES) \quad \text{(A5.3)}$$

Table A5.? Results from Equation A5.4, Total Herbicide Use versus Fresh/Processed Market

Descriptive Statistics:	R^2 = .0261	Adjusted R^2 = -.0063	F Value = 0.806

Independent Variable	Estimate	Std. Dev.	P-Value
Intercept	2.61	16.04	.8710
ln(Bearing Acres)	2.04	4.01	.6117
Fresh	-3.07	17.40	.8605
Fresh * ln(Bearing Acres)	1.03	4.55	.8221

$$TotalFungicideUse = \alpha_0 + \beta_0 * \ln(ACRES) + \alpha_1 * Fresh + \beta_1 * Fresh * \ln(ACRES) \quad \text{(A5.5)}$$

Table A5.? Results from Equation A5.5, Total Fungicide Use versus Fresh/Processed Market

Descriptive Statistics:	R^2 = .5217	Adjusted R^2 = .5054	F Value = 31.991
Independent Variable	**Estimate**	**Std. Dev.**	**P-Value**
Intercept	-27373	4332.35	.0001
ln(Bearing Acres)	9484.14	1071.33	.0001
Fresh	25892	4698.01	.0001
Fresh * ln(Bearing Acres)	-8581.61	1215.99	.0001

Table A5.6 Relative Risk Levels for Virginia Peanut Pesticides

VA PEANUT PESTICIDES[e]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2, 4-DB	MID[5]	HIGH[5]	MID	LOW	LOW	LOW	LOW	LOW
Acephate	LOW	LOW	LOW[9]	LOW	LOW[3]	MID[4]	MID[4]	HIGH[4]
Acifluorfen	MID	MID	LOW	HIGH	MID	MID	LOW[6]	LOW
Alachlor	MID	MID	MID	MID	HIGH	LOW	MID[7]	LOW
Aldicarb	HIGH[5]	HIGH[5]	MID	HIGH[2]	LOW	HIGH	HIGH	LOW
Benefin	LOW	HIGH	HIGH[9]	MID	MID[DG]	LOW[9]	LOW[9]	LOW[11]
Bentazon	HIGH	MID	LOW	MID	MID	LOW	MID	LOW
Carbaryl	LOW	MID	MID[9]	MID	LOW	MID	LOW	HIGH
Carboxin	LOW	MID	HIGH	LOW	LOW	LOW	LOW	LOW
Chlorothalonil	LOW	HIGH	HIGH	HIGH	MID	LOW	LOW	LOW
Chlorpyrifos	LOW	HIGH	HIGH[9]	MID	MID	MID	HIGH	HIGH
Copper Hydroxide	LOW[12]	MID[12]	MID[12]	LOW[12]	LOW[12]	MID[12]	MID[DG]	MID[DG]
Disulfoton	LOW	MID	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH[4]
Esfenvalerate	LOW	HIGH	HIGH[3]	MID	LOW	LOW	MID	HIGH
Ethalfluralin	LOW	HIGH	HIGH[9]	MID	HIGH[11]	MID[9]	LOW[9]	LOW[12]
Ethoprop	HIGH	MID	HIGH[3]	HIGH	MID[3]	HIGH[4]	HIGH[4]	HIGH[3]
Fenoxaprop	LOW	HIGH	MID[DG]	MID	MID[DG]	MID[DG]	LOW[9]	MID[DG]
Fonofos	MID	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	HIGH
Imazethapyr	HIGH[5]	HIGH[5]	LOW[9]	LOW	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Iprodione	LOW	MID	MID	LOW	MID	LOW	LOW	LOW
Malathion	LOW	LOW	LOW	MID	HIGH	MID	LOW	HIGH[10]
Metam Sodium (Metham)	MID[5]	HIGH[5]	HIGH[10, 48]	HIGH[5]	HIGH[11]	LOW[4]	MID[4]	LOW[10]
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID
Metolachlor	MID	MID	MID	LOW	MID	LOW	LOW	LOW[9]
Paraquat	LOW	HIGH	MID[9]	HIGH	HIGH	MID[6]	HIGH[6]	LOW

Table A5.6 Continued

VA PEANUT PESTICIDE	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non-target[2]
PCNB	LOW	HIGH	HIGH	MID	MID	MID	LOW	LOW[10]
Pendimethalin	LOW	HIGH	HIGH	MID	MID[7]	LOW[7]	LOW[7]	LOW
Phorate	LOW	HIGH	HIGH[9]	HIGH	LOW	HIGH	HIGH	MID[11]
Propargite	LOW[5]	HIGH[5]	HIGH[9]	HIGH	MID[3]	LOW[3]	MID[9]	LOW[3]
Pyridate	MID[DG]	MID[DG]	LOW[9]	LOW[S]	MID[DG]	LOW[9]	LOW[9]	LOW[9]
Sethoxydim	LOW[5]	LOW[5]	LOW	MID	LOW	LOW	LOW	LOW
Sulfur	LOW[7]	LOW[7]	LOW[11]	LOW	LOW[7]	LOW[11]	LOW[11]	HIGH[12]
Thiophanate Methyl	LOW	MID	HIGH[7]	LOW	LOW[4]	LOW[4]	LOW[4]	HIGH[11]
Vernolate	LOW[5]	LOW[5]	LOW[11]	LOW	MID[DG]	LOW[4]	LOW[4]	MID[11]

Table A5.7 Relative Risk Levels for Virginia Tobacco

VA TOBACCO PESTICIDE[e]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
Acephate	LOW	LOW	LOW[9]	LOW	LOW[3]	MID[4]	MID[4]	HIGH[4]
Aldicarb	HIGH[5]	HIGH[5]	MID	HIGH[2]	LOW	HIGH	HIGH	LOW
Benefin	LOW	HIGH	HIGH[9]	MID	MID[DG]	LOW[9]	LOW[9]	LOW[11]
Chloropicrin	LOW[S]	LOW[S]	LOW[S]	HIGH[S]	LOW[S]	LOW[S]	LOW[S]	LOW[S]
Chlorpyrifos	LOW	HIGH	HIGH[9]	MID	MID	MID	HIGH	HIGH
Diphenamid	MID[5]	HIGH[5]	MID[10]	MID[DG]	MID[DG]	MID[DG]	LOW[9]	LOW[10]
Ethoprop	HIGH	MID	HIGH[3]	HIGH	MID[3]	HIGH[4]	HIGH[4]	HIGH[3]
Fenamiphos	HIGH[5]	HIGH[5]	HIGH	HIGH[2]	LOW	HIGH	HIGH	LOW
Isopropalin	LOW[5]	MID[5]	HIGH[9]	LOW[S]	HIGH[S]	LOW[9]	LOW[9]	MID[DG]
Maleic Hydrazide	HIGH[5]	HIGH[5]	LOW[9]	LOW[Red]	LOW[Red]	LOW[9]	LOW[9]	LOW[Red]
Metalaxyl	HIGH	LOW	LOW	MID	LOW	LOW	LOW	LOW
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID
Methyl Bromide	HIGH[5]	HIGH[5]	LOW	HIGH[2]	HIGH	HIGH	HIGH	HIGH
Napropamide	MID[5]	HIGH[5]	MID	LOW[2]	MID	LOW	LOW	LOW[12]
Pebulate	LOW[5]	MID[5]	MID[9]	LOW[S]	MID[S]	LOW[4]	LOW[4]	MID[DG]
Pendimethalin	LOW	HIGH	HIGH	MID	MID[7]	LOW[7]	LOW[7]	LOW

Table A5.8 Relative Risk Levels for Virginia Corn Pesticides

VA CORN PESTICIDE[e]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2,4-D	MID[5]	HIGH[5]	HIGH	HIGH[2]	MID	MID	MID	HIGH
Alachlor	MID	MID	MID	MID	HIGH	LOW	MID[7]	LOW
Atrazine	HIGH	MID	MID[9]	MID	MID	LOW	LOW	LOW
Butylate	MID	MID	MID	LOW	HIGH	LOW	LOW	LOW
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Chlorpyrifos	LOW	HIGH	HIGH[9]	MID	MID	MID	HIGH	HIGH
Cyanazine	MID	MID	LOW	MID	HIGH	MID	MID	LOW[11]
Dicamba	HIGH	LOW	LOW	MID[2]	MID	LOW	LOW	LOW
Glyphosate	LOW	HIGH	MID	HIGH	LOW	LOW	LOW[4]	MID
Metolachlor	MID	MID	MID	LOW	MID	LOW	LOW	LOW[9]
Paraquat	LOW	HIGH	MID[9]	HIGH	HIGH	MID[6]	HIGH[6]	LOW
Pendimethalin	LOW	HIGH	HIGH	MID	MID[7]	LOW[7]	LOW[7]	LOW
Permethrin	LOW	HIGH	HIGH[9]	MID	MID	LOW	MID	HIGH
Simazine	HIGH	MID	MID	LOW[2]	MID	LOW	LOW	LOW
Terbufos	LOW	MID	HIGH	HIGH	LOW	HIGH	HIGH	LOW

Table A5.9 Relative Risk Levels for Virginia Alfalfa Hay Pesticides

ALFALFA HAY PESTICIDE[b]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Chlorpyrifos	LOW	HIGH	HIGH[9]	MID	MID	MID	HIGH	HIGH

Table A5.10 Relative Risk Levels for Virginia Sorghum Pesticides

VA SORGHUM PESTICIDE[b]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
Alachlor	MID	MID	MID	MID	HIGH	LOW	MID[7]	LOW
Atrazine	HIGH	MID	MID[9]	MID	MID	LOW	LOW	LOW
Carbaryl	LOW	MID	MID[9]	MID	LOW	MID	LOW	HIGH
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Chlorpyrifos	LOW	HIGH	HIGH[9]	MID	MID	MID	HIGH	HIGH
Diazinon	MID	MID	HIGH	MID[2]	HIGH	HIGH	MID	HIGH
EPTC	MID	MID	LOW	MID[2]	LOW	LOW	LOW	LOW
Ethoprop	HIGH	MID	HIGH[3]	HIGH	MID[3]	HIGH[4]	HIGH[4]	HIGH[3]
Fonofos	MID	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	HIGH
Malathion	LOW	LOW	LOW	MID	HIGH	MID	LOW	HIGH[10]
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID
Metolachlor	MID	MID	MID	LOW	MID	LOW	LOW	LOW[9]
Permethrin	LOW	HIGH	HIGH[9]	MID	MID	LOW	MID	HIGH
Simazine	HIGH	MID	MID	LOW[2]	MID	LOW	LOW	LOW
Terbufos	LOW	MID	HIGH	HIGH	LOW	HIGH	HIGH	LOW
Trichlorfon	HIGH	LOW	LOW[48]	HIGH	HIGH	HIGH	MID	HIGH

Table A5.11 Relative Risk Levels for Virginia Soybean Pesticides

VA SOYBEAN PESTICIDE[c]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2,4-D	MID[5]	HIGH[5]	HIGH	HIGH[2]	MID	MID	MID	HIGH
2,4-DB	MID[5]	HIGH[5]	MID	LOW	LOW	LOW	LOW	LOW
Aciflourfen	MID	MID	LOW	HIGH	MID	MID	LOW[6]	LOW
Alachlor	MID	MID	MID	MID	HIGH	LOW	MID[7]	LOW
Bentazon	HIGH	MID	LOW	MID	MID	LOW	MID	LOW
Chlorimuron	HIGH[5]	MID[5]	MID[7]	LOW	LOW[7]	LOW[7]	LOW[7]	MID
Clomazone	MID	MID	HIGH	LOW	LOW	LOW	LOW	MID[DG]
Fluazifop-P-Butyl	LOW	HIGH	HIGH[9]	HIGH	MID	LOW	LOW	LOW
Glyphosate	LOW	HIGH	MID	HIGH	LOW	LOW	LOW[4]	MID
Imazaquin	HIGH[5]	HIGH[5]	LOW[9]	LOW	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Imazethapyr	HIGH[5]	HIGH[5]	LOW[9]	LOW	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Linuron	MID	MID	LOW	LOW	MID	MID	LOW[7]	LOW
Metolachlor	MID	MID	MID	LOW	MID	LOW	LOW	LOW[9]
Paraquat	LOW	HIGH	MID[9]	HIGH	HIGH	MID[6]	HIGH[6]	LOW
Pendimethalin	LOW	HIGH	HIGH	MID	MID[7]	LOW[7]	LOW[7]	LOW
Trifluralin	LOW	HIGH	HIGH[9]	MID	MID	LOW	LOW	LOW[10]

Table A5.12 Relative Risk Levels for Virginia Other Hay Pesticides

OTHER HAY PESTICIDES[b]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
Metribuzin	HIGH	MID	LOW	LOW	LOW	MID	MID	LOW
Paraquat	LOW	HIGH	MID[9]	HIGH	HIGH	MID[6]	HIGH[6]	LOW
Sethoxydim	LOW[5]	LOW[5]	LOW	MID	LOW	LOW	LOW	LOW
Simazine	HIGH	MID	MID	LOW[2]	MID	LOW	LOW	LOW
Terbacil	HIGH[5]	HIGH[5]	LOW	LOW[2]	LOW	LOW	LOW	LOW

Table A5.13 Relative Risk Levels for Virginia Watermelon Pesticides

VA Watermelon PESTICIDE[e]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
Benomyl	HIGH	HIGH	HIGH	MID	HIGH	LOW	LOW[7]	HIGH
Bensulide	MID[5]	MID[5]	HIGH	LOW[2]	MID	MID	MID	HIGH
Carbaryl	LOW	MID	MID[9]	MID	LOW	MID	LOW	HIGH
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Chlorothalonil	LOW	HIGH	HIGH	HIGH	MID	LOW	LOW	LOW
Dicofol	LOW	HIGH	HIGH	MID	LOW	LOW	MID	LOW
Dimethoate	MID	LOW	LOW	MID	MID	HIGH	HIGH	HIGH
Endosulfan	LOW	HIGH	HIGH	HIGH	MID	MID	HIGH	LOW
Esfenvalerate	LOW	HIGH	HIGH[3]	MID	LOW	LOW	MID	HIGH
Ethalfluralin	LOW	HIGH	MID[9]	MID	HIGH[11]	MID[9]	LOW[9]	LOW[12]
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID
Naptalam	HIGH[5]	HIGH[5]	LOW[9]	MID	MID[DG]	MID[DG]	LOW[9]	LOW[10]
Triadimefon	MID	MID	MID	MID	MID	LOW	MID	LOW[10]

Table A5.14 Relative Risk Levels for Virginia Cotton Pesticides

VA COTTON PESTICIDES[e]	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
Acephate	LOW	LOW	LOW[9]	LOW	LOW[3]	MID[4]	MID[4]	HIGH[4]
Aldicarb	HIGH[5]	HIGH[5]	MID	HIGH[2]	LOW	HIGH	HIGH	LOW
Bifenthrin	LOW[5]	MID[5]	HIGH[9]	MID[S]	MID[11]	LOW[9]	MID[9]	MID[DG]
Cyanazine	MID	MID	LOW	MID	HIGH	MID	MID	LOW[11]
Cyfluthrin	LOW[5]	MID[5]	HIGH[9]	MID[S]	MID[DG]	MID[9]	MID[9]	MID[DG]
Cypermethrin	LOW[5]	MID[5]	HIGH	HIGH[2]	MID	LOW	MID	HIGH
Dicofol	LOW	HIGH	HIGH	MID	LOW	LOW	MID	LOW
Dicrotophos	MID[5]	HIGH[5]	LOW[9,24]	HIGH[S]	MID[11]	HIGH[4]	HIGH[4]	HIGH[4]
Dimethipin	HIGH[5]	HIGH[5]	MID[9]	LOW[S]	MID[DG]	MID[DG]	LOW[9]	MID[DG]
Dimethoate	MID	LOW	LOW	MID	MID	HIGH	HIGH	HIGH
Disulfoton	LOW	MID	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH[4]
DSMA = MSMA	LOW[5]	HIGH[5]	LOW[9,48]	LOW[S]	MID[DG]	MID[DG]	LOW[9]	MID[DG]
Esfenvalerate	LOW	HIGH	HIGH[3]	MID	LOW	LOW	MID	HIGH
Ethephon	LOW[5]	MID[5]	LOW[9]	MID[S]	HIGH[S]	LOW[4]	LOW[4]	LOW[S]
Ethoprop	HIGH	MID	HIGH[3]	HIGH	MID[3]	HIGH[4]	HIGH[4]	HIGH[3]
Etridiazole	MID[5]	HIGH[5]	MID[10,24]	MID[S]	MID[DG]	LOW[11]	LOW[9]	LOW[10]
Fenamiphos	HIGH[5]	HIGH[5]	HIGH	HIGH[2]	LOW	HIGH	HIGH	LOW
Fluazifop	LOW	HIGH	HIGH[9]	MID[DG]	MID[DG]	LOW[9]	LOW[9]	LOW[9]
Fluometuron	HIGH[5]	HIGH[5]	LOW	MID[2]	HIGH	LOW	LOW	LOW
Glyphosate	LOW	HIGH	MID	HIGH	LOW	LOW	LOW[4]	MID
Lambda-cyhalothrin	LOW[5]	MID[5]	HIGH[9]	MID[S]	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Mepiquat Chloride	LOW[5]	HIGH[5]	LOW[9]	MID[S]	MID[DG]	LOW[9]	LOW[9]	LOW[9]
Metalaxyl	HIGH	LOW	LOW	MID	LOW	LOW	LOW	LOW
Methazole	LOW[5]	LOW[5]	LOW[9]	MID[S]	MID[DG]	MID[DG]	LOW[9]	HIGH[10]
Metolachlor	MID	MID	MID	LOW	MID	LOW	LOW	LOW[9]

Metribuzin	HIGH	MID	LOW	LOW	LOW	MID	MID	LOW
MSMA = DSMA[5]	LOW[5]	HIGH[5]	LOW[9,48]	LOW[S]	MID[DG]	MID[DG]	LOW[9]	MID[DG]
Norflurazon	LOW[5]	MID[5]	LOW[9]	LOW[S]	LOW[7]	LOW[9]	LOW[9]	LOW[12]
Oxyflurofen	LOW	HIGH	HIGH	MID[2]	HIGH	LOW	LOW	HIGH[9]
Paraquat	LOW	HIGH	MID[9]	HIGH	HIGH	MID[6]	HIGH[6]	LOW
PCNB	LOW	HIGH	HIGH	MID	MID	MID	LOW	LOW[10]
Pendimethalin	LOW	HIGH	HIGH	MID	MID[7]	LOW[7]	LOW[7]	LOW
Phorate	LOW	HIGH	HIGH[9]	HIGH	LOW	HIGH	HIGH	MID[11]
Profenofos	LOW[5]	LOW[5]	MID[9]	HIGH[S]	MID[DG]	HIGH[4]	MID[4]	HIGH[4]
Thidiazuron	MID[5]	MID[5]	LOW[9]	LOW[S]	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Thiodicarb	LOW	MID	HIGH[7]	MID	LOW[7]	LOW[7]	MID[7]	MID[DG]
Tralomethrin	LOW[5]	MID[5]	HIGH[9]	MID[S]	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Tribufos	LOW[5]	LOW[5]	MID[DG]	MID[S]	MID[DG]	MID[DG]	MID[DG]	MID[DG]
Trifluralin	LOW	HIGH	HIGH[9]	MID	MID	LOW	LOW	LOW[10]

Table A5.15 Relative Risk Levels for Virginia Barley Pesticides

VA BARLEY PESTICIDE[e]	groundwater[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2, 4-D	MID[5]	HIGH[5]	HIGH	HIGH[2]	MID	MID	MID	HIGH
Bromoxynil	LOW	MID	HIGH	MID	MID	HIGH	MID	LOW
Carbaryl	LOW	MID	MID[9]	MID	LOW	MID	LOW	HIGH
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Dicamba	HIGH	LOW	LOW	MID[2]	MID	LOW	LOW	LOW
Diclofop	LOW	MID	HIGH[9]	HIGH	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Dimethoate	MID	LOW	LOW	MID	MID	HIGH	HIGH	HIGH
Disulfoton	LOW	MID	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH[4]
MCPA	MID[DG]	MID[DG]	LOW[10]	MID[DG]	MID[DG]	MID[DG]	LOW[10]	LOW[10]
Malathion	LOW	LOW	LOW	MID	HIGH	MID	LOW	HIGH[10]
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID
Paraquat	LOW	HIGH	MID[9]	HIGH	HIGH	MID[6]	HIGH[6]	LOW
Thifensulfuron	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]

Table A5.16 Relative Risk Levels for Virginia Oat Pesticides

VA OAT[e] PESTICIDE	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2, 4-D	MID[5]	HIGH[5]	HIGH	HIGH[2]	MID	MID	MID	HIGH
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Dicamba	HIGH	LOW	LOW	MID[2]	MID	LOW	LOW	LOW
MCPA	MID[DG]	MID[DG]	LOW[10]	MID[DG]	MID[DG]	MID[DG]	LOW[10]	LOW[DG]
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID

Table A5.17 Relative Risk Levels for Virginia Rye Pesticides

VA RYE[e] PESTICIDES	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2, 4-D	MID[5]	HIGH[5]	HIGH	HIGH[2]	MID	MID	MID	HIGH

Table A5.18 Relative Risk Levels for Virginia Wheat Pesticides

VA WHEAT[e] PESTICIDE	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2, 4-D	MID[5]	HIGH[5]	HIGH	HIGH[2]	MID	MID	MID	HIGH
Carbaryl	LOW	MID	MID[9]	MID	LOW	MID	LOW	HIGH
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Dicamba	HIGH	LOW	LOW	MID[2]	MID	LOW	LOW	LOW
Dimethoate	MID	LOW	LOW	MID	MID	HIGH	HIGH	HIGH
Disulfoton	LOW	MID	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH[4]
Mancozeb	LOW	HIGH	HIGH	LOW	HIGH	LOW	LOW[10]	HIGH[12]
MCPA	MID[DG]	MID[DG]	LOW[10]	MID[DG]	MID[DG]	MID[DG]	LOW[10]	LOW[10]
Malathion	LOW	LOW	LOW	MID	HIGH	MID	LOW	HIGH[10]
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID
Propiconazole	MID	MID	LOW[10]	MID	MID[DG]	MID[DG]	LOW[10]	LOW[10]
Thifensulfuron	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]
Triadimefon	MID	MID	MID	MID	MID	LOW	MID	LOW[10]
Tribenuron	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]	MID[DG]

Table A5.19 Relative Risk Levels for Virginia Small Grains Pesticides

SMALL GRAINS[b] PESTICIDE	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2, 4-DB	MID[5]	HIGH[5]	MID	LOW	LOW	LOW	LOW	LOW
Bromoxynil	LOW	MID	HIGH	MID	MID	HIGH	MID	LOW
Carbaryl	LOW	MID	MID[9]	MID	LOW	MID	LOW	HIGH
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Dicamba	HIGH	LOW	LOW	MID[2]	MID	LOW	LOW	LOW
Diclofop	LOW	MID	HIGH[9]	HIGH	MID[DG]	LOW[9]	LOW[9]	MID[DG]
Dimethoate	MID	LOW	LOW	MID	MID	HIGH	HIGH	HIGH
Disulfoton	LOW	MID	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH[4]
Malathion	LOW	LOW	LOW	MID	HIGH	MID	LOW	HIGH[10]
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID

APPENDIX TO CHAPTER VI

Superscripts in Table A6.1 denote the following sources (complete references of these sources appear in the bibliography):

1 = Becker et. al. (1989), unless otherwise noted
2 = EXTOXNET, unless otherwise noted
3 = Higley and Wintersteen (1992)
4 = Smith (1993)
5 = K_{OC} and soil half life (Wauchope et. al., 1992), Groundwater Ubiquity Score equation and risk delineation (Gustafson, 1989)
6 = USEPA Office of Drinking Water
7 = USEPA Office of Pesticides and Toxic Substances
8 = Manual of Freshwater...
9 = The Pesticide Manual (1987)
10 = Agrochemical Handbook (
11 = Briggs (1992)
12 = Kovach et. al. (1992)
epa = USEPA does not require data
S = Susan Jennings, personal communication
Y = Keith Yoder, personal communication
Red = USEPA Office of Pesticide Programs Reregistration Eligibility Document

Empty cells denote data gaps.

Table A6.1 Relative Risk Levels for Pesticides

PESTICIDE	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non targets[2]
2,4-D	MID[5]	HIGH[5]	HIGH	HIGH[2]	MID	MID	MID	HIGH
2,4-DB	MID[5]	HIGH[5]	MID	LOW	LOW	LOW	LOW	LOW
Abamectin	LOW[2]	LOW[2]	MID	HIGH[2]	LOW	LOW	HIGH	HIGH
Acephate	LOW	LOW	LOW[9]	LOW	LOW[3]	MID[4]	MID[4]	HIGH[4]
Acifluorfen	MID	MID	LOW	HIGH	MID	MID	LOW[6]	LOW
Alachlor	MID	MID	MID	MID	HIGH	LOW	MID[7]	LOW
Aldicarb	HIGH[5]	HIGH[5]	MID	HIGH[2]	LOW	HIGH	HIGH	LOW
Atrazine	HIGH	MID	MID[9]	MID	MID	LOW	LOW	LOW
Azinophos-methyl	LOW	HIGH	HIGH	HIGH	MID	MID	HIGH	HIGH
Bacillus thur (Bt)	LOW[2]	LOW[2]	LOW	LOW[2]	MID	LOW	LOW	MID
Benefin	LOW	HIGH	HIGH[9]	MID		LOW[9]	LOW[9]	LOW[11]
Benomyl	HIGH	HIGH	HIGH	MID	HIGH	LOW	LOW[7]	HIGH
Bensulide	MID[5]	MID[5]	HIGH	LOW[2]	MID	MID	MID	HIGH
Bentazon	HIGH	MID	LOW	MID	MID	LOW	MID	LOW
Bifenthrin	LOW[5]	MID[5]	HIGH[9]	MID[S]	MID[11]	LOW[9]	MID[9]	
Bromoxynil	LOW	MID	HIGH	MID	MID	HIGH	MID	LOW
Butylate	MID	MID	MID	LOW	HIGH	LOW	LOW	LOW
Calcium polysulfide	LOW[7]	LOW[7]	MID[DG]	LOW	LOW[7]	MID[DG]	MID[DG]	MID[DG]
Captan	LOW	LOW	LOW	HIGH	HIGH	LOW	LOW[7]	LOW
Carbaryl	LOW	MID	MID[9]	MID	LOW	MID	LOW	HIGH
Carbofuran	HIGH	LOW	MID	HIGH	LOW	HIGH	HIGH	HIGH
Carboxin	LOW	MID	HIGH	LOW	LOW	LOW	LOW	LOW
Chloramben			LOW	MID[2]	HIGH	LOW	LOW	
Chlorimuron	HIGH[5]	MID[5]	MID[7]	LOW	LOW[7]	LOW[7]	LOW[7]	MID
Chlorimuron ethyl	HIGH[7]	LOW[7]	MID[7]	LOW[7]	LOW[7]	LOW[7]	LOW[7]	HIGH[7]

Table A6.1 Continued

PESTICIDES	ground-water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non-target[2]
Chloropicrin	LOW[S]	LOW[S]	LOW[S]	HIGH[S]	LOW[S]	LOW[S]	LOW[S]	LOW[S]
Chlorothalonil	LOW	HIGH	HIGH	HIGH	MID	LOW	LOW	LOW
Chlorpyrifos	LOW	HIGH	HIGH[9]	MID	MID	MID	HIGH	HIGH
Clomazone	MID	MID	HIGH	LOW	LOW	LOW	LOW	
Copper Sulfate	LOW[2]	LOW[2]	MID	HIGH	LOW[epa]	LOW	HIGH	HIGH
Cyanazine	MID	MID	LOW	MID	HIGH	MID	MID	LOW[11]
Cyfluthrin	LOW[5]	MID[5]	HIGH[9]	MID[S]		MID[9]	MID[9]	
Cypermethrin	LOW[5]	MID[5]	HIGH	HIGH[2]	MID	LOW	MID	HIGH
Diazinon	MID	MID	HIGH	MID[2]	HIGH	HIGH	MID	HIGH
Dicamba	HIGH	LOW	LOW	MID[2]	MID	LOW	LOW	LOW
Diclofop	LOW	MID	HIGH[9]	HIGH		LOW[9]	LOW[9]	
Dicofol	LOW	HIGH	HIGH	MID	LOW	LOW	MID	LOW
Dicrotophos	MID[5]	HIGH[5]	LOW[9,24]	HIGH[S]	MID[11]	HIGH[4]	HIGH[4]	HIGH[4]
Dimethipin	HIGH[5]	HIGH[5]	MID[9]	LOW[S]			LOW[9]	
Dimethoate	MID	LOW	LOW	MID	MID	HIGH	HIGH	HIGH
Dinocap	LOW	MID	LOW	LOW	HIGH	HIGH	MID	LOW
Diphenamid	MID[5]	HIGH[5]	MID[10]				LOW[9]	LOW[10]
Disulfoton	LOW	MID	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH[4]
Diuron	MID[5]	HIGH[5]	MID	MID[2]	MID	LOW	LOW	LOW
Dodine	LOW[5]	MID[5]	HIGH[7]	HIGH	MID	LOW[7]	LOW	LOW
DSMA = MSMA	LOW[5]	HIGH[5]	LOW[9,48]	LOW[S]			LOW[9]	
Endosulfan	LOW	HIGH	HIGH	HIGH	MID	MID	HIGH	LOW
EPTC	MID	MID	LOW	MID[2]	LOW	LOW	LOW	LOW
Esfenvalerate	LOW	HIGH	HIGH[3]	MID	LOW	LOW	MID	HIGH
Ethalfluralin	LOW	HIGH	HIGH[9]	MID	HIGH[11]	MID[9]	LOW[9]	LOW[12]
Ethephon	LOW[5]	MID[5]	LOW[9]	MID[S]	HIGH[S]	LOW[4]	LOW[4]	LOW[S]

Table A6.1 Continued

PESTICIDE	ground water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non-target[2]
Ethion	LOW[5]	MID[5]	HIGH	HIGH[2]	HIGH	HIGH	HIGH	LOW
Ethoprop	HIGH	MID	HIGH[3]	HIGH	MID[3]	HIGH[4]	HIGH[4]	HIGH[3]
Ethyl parathion	LOW[5]	MID[5]	HIGH[3]	HIGH[3]	MID[3]	HIGH[3]	HIGH[3]	MID[3]
Etridiazole	MID[5]	HIGH[5]	MID[10,24]	MID[S]		LOW[11]	LOW[9]	LOW[10]
Fenamiphos	HIGH[5]	HIGH[5]	HIGH	HIGH[2]	LOW	HIGH	HIGH	LOW
Fenarimol	HIGH	HIGH	HIGH[7]	MID	HIGH[11]	LOW[7]	MID[9]	LOW[7]
Fenoxaprop	LOW	HIGH		MID			LOW[9]	
Ferbam	MID[5]	MID[5]	LOW[12]	LOW[11]	MID[11]		LOW[9]	MID[12]
Fluazifop	LOW	HIGH	HIGH[9]			LOW[9]	LOW[9]	LOW[9]
Fluazifop-P-Butyl	LOW	HIGH	HIGH[9]	HIGH	MID	LOW	LOW	LOW
Fluometuron	HIGH[5]	HIGH[5]	LOW	MID[2]	HIGH	LOW	LOW	LOW
Fonofos	MID	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	HIGH
Formetanate hydro	HIGH	LOW	LOW[7]	HIGH		HIGH[4]	HIGH[4]	MID[7]
Glyphosate	LOW	HIGH	MID	HIGH	LOW	LOW	LOW[4]	MID
Imazaquin	HIGH[5]	HIGH[5]	LOW[9]	LOW		LOW[9]	LOW[9]	
Imazethapyr	HIGH[5]	HIGH[5]	LOW[9]	LOW		LOW[9]	LOW[9]	
Iprodione	LOW	MID	MID	LOW	MID	LOW	LOW	LOW
Isopropalin	LOW[5]	MID[5]	HIGH[9]	LOW[S]	HIGH[S]	LOW[9]	LOW[9]	
Lambda-cyhalothrin	LOW[5]	MID[5]	HIGH[9]	MID[S]		LOW[9]	LOW[9]	
Lindane	HIGH[2]	HIGH	HIGH	MID[2]	LOW	MID	MID	HIGH
Linuron	MID	MID	LOW	LOW	MID	MID	LOW[7]	LOW
Malathion	LOW	LOW	LOW	MID	HIGH	MID	LOW	HIGH[10]
Maleic Hydrazide	HIGH[5]	HIGH[5]	LOW[9]	LOW[Red]	LOW[Red]	LOW[9]	LOW[9]	LOW[Red]
Mancozeb	LOW	HIGH	HIGH	LOW	HIGH	LOW	LOW[10]	HIGH[12]

Table A6.1 Continued

PESTICIDE	ground water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non-target[2]
Mepiquat Chloride	LOW[5]	HIGH[5]	LOW[9]	MID[S]		LOW[9]	LOW[9]	LOW[9]
Metalaxyl	HIGH	LOW	LOW	MID	LOW	LOW	LOW	LOW
Metam Sodium (Metham)	MID[5]	HIGH[5]	HIGH[10, 48]	HIGH[S]	HIGH[11]	LOW[4]	MID[4]	LOW[10]
Methazole	LOW[5]	LOW[5]	LOW[9]	MID[S]			LOW[9]	HIGH[10]
Methidathion	LOW[5]	MID[5]	HIGH	HIGH	MID	HIGH	HIGH[11]	HIGH
Methomyl	HIGH	MID	HIGH	HIGH	LOW	MID	MID	MID
Methoxychlor	LOW[5]	MID[5]	HIGH	LOW	MID	LOW[3]	LOW	HIGH[3]
Methyl Bromide	HIGH[5]	HIGH[5]	LOW	HIGH[2]	HIGH	HIGH	HIGH	HIGH
Methyl parathion	LOW[5]	LOW[5]	MID	HIGH	MID	LOW	MID	HIGH
Metiram	LOW	HIGH	LOW	LOW	HIGH	LOW	LOW	LOW
Metolachlor	MID	MID	MID	LOW	MID	LOW	LOW	LOW[9]
Metribuzin	HIGH	MID	LOW	LOW	LOW	MID	MID	LOW
MSMA = DSMA[5]	LOW[5]	HIGH[5]	LOW[9,48]	LOW[S]			LOW[9]	
Myclobutanil				HIGH	LOW[S]		LOW[9]	
Napropamide	MID[5]	HIGH[5]	MID	LOW[2]	MID	LOW	LOW	LOW[12]
Naptalam	HIGH[5]	HIGH[5]	LOW[9]	MID			LOW[9]	LOW[10]
Napthalene aceticacid	MID[5]	MID[5]				LOW[9]	LOW[9]	
Norflurazon	LOW[5]	MID[5]	LOW[9]	LOW[S]	LOW[S]	LOW[9]	LOW[9]	LOW[12]
Oryzalin	LOW	MID	MID	LOW	MID	LOW	LOW	LOW
Oxyflurofen	LOW	HIGH	HIGH	MID[2]	HIGH	LOW	LOW	HIGH[9]
Oxythioquinox	LOW[5]	MID[5]	HIGH[12]			HIGH[12]	LOW[9]	LOW[9]
Paraquat	LOW	HIGH	MID[9]	HIGH	HIGH	MID[6]	HIGH[6]	LOW
PCNB	LOW	HIGH	HIGH	MID	MID	MID	LOW	LOW[10]

Table A6.1 Continued

PESTICIDE	ground water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non-target[2]
Pebulate	LOW[5]	MID[5]	MID[9]	LOW[7]	MID[7]	LOW[4]	LOW[4]	
Pendimethalin	LOW	HIGH	HIGH	MID	MID[7]	LOW[7]	LOW[7]	LOW
Permethrin	LOW	HIGH	HIGH[9]	MID	MID	LOW	MID	HIGH
Petroleum distillate	LOW[12]	LOW[12]	LOW[12]	LOW	MID[12]	LOW[12]	LOW[9]	HIGH[Y]
Phorate	LOW	HIGH	HIGH[9]	HIGH	LOW	HIGH	HIGH	MID[11]
Phosmet	LOW	MID	HIGH[3]	MID	MID[3]	LOW[3]	MID[3]	MID[3]
Phosphamidon	HIGH[5]	LOW[5]	MID[7]	HIGH	MID[7]	HIGH[4]	HIGH[4]	HIGH[4]
Primisulfuron				LOW[2]	LOW	LOW	LOW	LOW
Profenofos	LOW[5]	LOW[5]	MID[9]	HIGH[S]		HIGH[4]	MID[4]	HIGH[4]
Propargite	LOW[5]	HIGH[5]	HIGH[9]	HIGH	MID[3]	LOW[3]	MID[9]	LOW[3]
Propiconzole	MID	MID	LOW[10]	MID			LOW[10]	LOW[10]
Pyridate			LOW[9]	LOW[S]		LOW[9]	LOW[9]	LOW[9]
Quizalofop ethyl	LOW	HIGH	HIGH[7]	LOW	LOW[7]	LOW[7]	LOW[7]	LOW[7]
Sethoxydim	LOW[5]	LOW[5]	LOW	MID	LOW	LOW	LOW	LOW
Simazine	HIGH	MID	MID	LOW[2]	MID	LOW	LOW	LOW
Streptomycin	LOW[12]	LOW[12]	MID[DG]	MID[DG]	LOW[12]	MID[DG]	MID[DG]	MID[DG]
Sulfur	LOW[7]	LOW[7]	LOW[11]	LOW	LOW[7]	LOW[11]	LOW[11]	HIGH[12]
Terbacil	HIGH[5]	HIGH[5]	LOW	LOW[2]	LOW	LOW	LOW	LOW
Terbufos	LOW	MID	HIGH	HIGH	LOW	HIGH	HIGH	LOW
Thidiazuron	MID[5]	MID[5]	LOW[9]	LOW[S]		LOW[9]	LOW[9]	
Thiodicarb	LOW	MID	HIGH[7]	MID	LOW[7]	LOW[7]	MID[7]	
Thiophanate Methyl	LOW	MID	HIGH[7]	LOW	LOW[4]	LOW[4]	LOW[4]	HIGH[11]
Thiram	LOW[5]	LOW[5]	MID[7]	LOW	HIGH	LOW[4]	LOW[4]	LOW[7]
Tralomethrin	LOW[5]	MID[5]	HIGH[9]	MID[S]		LOW[9]	LOW[9]	
Triadimefon	MID	MID	MID	MID	MID	LOW	MID	LOW[10]

Table A6.1 Continued

PESTICIDE	ground water[1]	surface water[1]	aquatic species[2]	acute human[1]	chronic human[2]	birds[2]	mammal[2]	non-target[2]
Tribufos	LOW[5]	LOW[5]		MID[S]				
Trichlorfon	HIGH	LOW	LOW[48]	HIGH	HIGH	HIGH	MID	HIGH
Trifluralin	LOW	HIGH	HIGH[9]	MID	MID	LOW	LOW	LOW[10]
Vernolate	LOW[5]	LOW[5]	LOW[11]	LOW		LOW[4]	LOW[4]	MID[11]
Vinclozolin	LOW[12]	LOW[12]	LOW[12]	MID[12]	LOW[12]	LOW[11]	LOW[9]	LOW[9]
Ziram	LOW[13]		MID	HIGH[2]	HIGH	MID[4]	LOW[4]	LOW[11]

VITA

Jeffrey Daniel Mullen was born the tenth of December, 1965. After receiving a B.A. in economics from Northwestern University in 1988, Jeff joined the U.S. Peace Corps. He spent two years in Tikobo I, in the Western Region of Ghana, with the family of Joseph Justice Assabieh. It was in Ghana that Jeff realized his fondness for agriculture. Upon his return from Ghana, he worked in Washington D.C. as a program assistant for the Institute for Transportation and Development Policy, a non-profit organization dedicated to promoting low-cost transportation alternatives around the world. Happily married, Jeff's closest friends are his wife, his brother and sisters, and a friend he met in the sixth grade. He is eternally grateful to his loving parents who have instilled in him the courage and confidence needed to achieve one's goals.