Doctoral Thesis

Plant protection agents in developing country agriculture empirical evidence and methodological aspects of productivity and user safety

Author(s):
Angehren, Beda

Publication Date:
1996

Permanent Link:
https://doi.org/10.3929/ethz-a-001761014

Rights / License:
In Copyright - Non-Commercial Use Permitted
Plant Protection Agents in Developing Country Agriculture

Empirical Evidence and Methodological Aspects of Productivity and User Safety

A dissertation submitted to the

SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZURICH

for the degree of

Doctor of Technical Sciences

presented by

Beda Angehrn
Dipl. Ing.-Agr. ETH
born 14 January 1966
citizen of Muolen SG

accepted on the recommendation of

Prof. Peter Rieder, examiner
Prof. Klaus M. Leisinger, co-examiner
Prof. Uri Regev, co-examiner

1996
To Janet
Preface and acknowledgements

This thesis grew out of a collaboration between the Ciba-Geigy Foundation for Cooperation with Developing Countries and the Department of Agricultural Economics of the Swiss Federal Institute of Technology. Since 1991, the Ciba-Geigy Foundation has been working on the project "Safety and Effectiveness in the Application of Plant Protection Agents in Developing Countries", a so far unique social marketing approach to improve the productivity and safety of plant protection agents (PPA) in developing countries (Ciba-Geigy Foundation for Cooperation with Developing Countries, 1993, 1995, and 1996). Based on qualitative and quantitative assessments of PPA users' knowledge, attitudes and practices related to PPA, information, education and communication programs have been designed and implemented in three pilot areas in India, Mexico and Zimbabwe.

The Department of Agricultural Economics has contributed to the planning, monitoring and evaluation of the project with studies on aspects of PPA safety and effectiveness. We are privileged to present a selection of those studies while the project is still running. We intend to highlight basic economic and some technical features of PPA productivity and safety. The actual extension program of the Ciba-Geigy Foundation is not a topic.
Many people contributed to this thesis and, more importantly, to the project it is based on. Thanks are due to all these persons for their intellectual, moral and financial contributions.

Sincere gratitude goes to Klaus M. Leisinger of the Ciba-Geigy Foundation for Cooperation with Developing Countries, Peter Rieder of the Department of Agricultural Economics and Jean-Paul Serres of Ciba-Geigy Mexicana who are the initiators of this thesis. Together with Uri Regev of the Institute of Economics of the Ben Gurion University in Beer-Sheva, they made up an excellent team of advisors without whose help this thesis would not have been possible.

Sincere appreciation is extended to the members of the Project Steering Committee, the Mexican project staff and their colleagues in India and Zimbabwe, my family and friends for a broad variety of contributions: Jorge Aguirre Morales, Nicole Bays, Hilda Dominguez, Carlos Fernández Ruiz, Jost Frei, Klaus von Grebmer, Hans Häfliger, Ricardo Hernández Camacho, Al Imfeld, Ivo, Janet, Martín Jimenez Franco, Peter Jowah, Bernd Kupferschmied, Octavio Magdaleno Díaz, Meinrad, Irma Muñoz, Paul Nett, Felix Nicolier, Blanca Parra Zebadúa, Hans Pfälzer, Hiru Punwani, N.R. Raja Pandian, Vitórico Rincón Nájera, Rodolfo Rojas Ruiz, Luis Felipe Sanchez Puga, Urban, Heike Utsch, Hema Viswanathan, Bill Vorley and Andreas Weder.
Contents

Preface and acknowledgements ................................................................. iii
Abbreviations ......................................................................................... viii
Kurzfassung ......................................................................................... 1
Summary ................................................................................................. 3
1 Introduction .......................................................................................... 5

PART I: PRODUCTIVITY OF PLANT PROTECTION AGENTS ........ 9

2 Econometric assessment of PPA productivity ........................................ 10
  2.1 Introduction .................................................................................. 11
  2.2 Simultaneity and identification ....................................................... 14
  2.3 Data and variables ........................................................................ 28
  2.4 Form of the production function ..................................................... 36
  2.5 Literature ..................................................................................... 38
  2.6 Conclusions ................................................................................ 48

3 Case Study: Effectiveness of different PPA use strategies .................. 49
  3.1 Introduction .................................................................................. 50
  3.2 Pest control in cotton in Tamil Nadu .............................................. 52
  3.3 Data .............................................................................................. 55
  3.4 Model ........................................................................................... 59
  3.5 Results ........................................................................................ 63
  3.6 Conclusions ................................................................................ 66
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ai</td>
<td>Active ingredient (of pesticides)</td>
</tr>
<tr>
<td>ASE</td>
<td>Asymptotic standard error</td>
</tr>
<tr>
<td>cdf</td>
<td>Cumulative distribution function</td>
</tr>
<tr>
<td>CV</td>
<td>Compensating variation</td>
</tr>
<tr>
<td>CVM</td>
<td>Contingent valuation method</td>
</tr>
<tr>
<td>DC</td>
<td>Developing country</td>
</tr>
<tr>
<td>df</td>
<td>Degrees of freedom</td>
</tr>
<tr>
<td>EV</td>
<td>Equivalent variation</td>
</tr>
<tr>
<td>GLM</td>
<td>General linear model</td>
</tr>
<tr>
<td>IPM</td>
<td>Integrated Pest Management, sometimes referred to as Integrated Pest Control. The FAO definition is: &quot;a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest population at levels below those causing economic injury&quot;. Other definitions explicitly include PPA user safety as objective of IPM (ALEBEEK, 1989).</td>
</tr>
<tr>
<td>IRRI</td>
<td>International Rice Research Institute</td>
</tr>
<tr>
<td>LD&lt;sub&gt;50&lt;/sub&gt;</td>
<td>Lethal dose 50. Measure for acute toxicity. Large values represent low toxicity.</td>
</tr>
<tr>
<td>LRP</td>
<td>Linear-response and plateau (function)</td>
</tr>
<tr>
<td>MVP</td>
<td>Marginal value product</td>
</tr>
<tr>
<td>N$</td>
<td><em>Nuevos Pesos</em>, Mexican currency</td>
</tr>
<tr>
<td>NPV</td>
<td>Net present value</td>
</tr>
<tr>
<td>OLS</td>
<td>Ordinary least squares</td>
</tr>
<tr>
<td>PFM</td>
<td>Production function model (single-equation model consisting of the production function)</td>
</tr>
<tr>
<td>PPA</td>
<td>Plant protection agent, occasionally used in a broader sense than pesticide</td>
</tr>
<tr>
<td>PSM</td>
<td><em>Pflanzenschutzmittel</em>, plant protection agent</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Rs</td>
<td>Indian Rupees</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>SE</td>
<td>Standard error of estimated parameter</td>
</tr>
<tr>
<td>SEM</td>
<td>Simultaneous-equation model</td>
</tr>
<tr>
<td>WTA</td>
<td>Willingness to accept (payment to forego a benefit or suffer a loss)</td>
</tr>
<tr>
<td>WTP</td>
<td>Willingness to pay (to secure a benefit or avoid a loss)</td>
</tr>
</tbody>
</table>
Kurzfassung


werden, doch diese Effizienzsteigerung vermindert nicht notwendigerweise den Pestizideinsatz.


Summary

This thesis is a compilation of case studies on productivity and safety of chemical plant protection agents (PPA) in developing country agriculture. The studies present both empirical evidence and methodological considerations. The objectives are to examine basic economic and some technical features of PPA use and to provide suggestions for the design of projects to promote safe and effective use of PPA. Data and some topics stem from the project "Safety and Effectiveness in the Application of Plant Protection Agents in Developing Countries" that is being implemented by the Ciba-Geigy Foundation for Cooperation with Developing Countries in India, Mexico and Zimbabwe.

The first part deals with production analysis. Starting with a generic production and behavioral model, we examine the implications of common problems such as missing data, underidentification, formal specification, etc., and review literature on PPA productivity. Results suggest that production function estimations in the context of PPA have often been inappropriate. Suggested solutions comprise the use of on-farm research data, the examination of the role of transaction costs for identification, and the estimation of identified transformations of the model that describes the technology. Some of the theoretical findings are applied in a case study of PPA productivity in cotton in Southern India. While both responsive and preventive PPA use strategies are found to be productive, the former allows of considerable savings. We then analyze the relationship between PPA effectiveness and demand. Human capital, defined as specific skills related to plant protection, increases the effectiveness of PPA, but the effect of this increase on input demand may have either sign, depending on the current levels of human capital and pest damage abatement.
The second part considers adverse health effects of PPA. We are interested in only one of several groups of the population that are potentially exposed to PPA, i.e. the group of PPA users (farmers, spraymen). The empirical studies are almost exclusively concerned with acute health effects. After an introduction to the topic, four case studies are presented. Exposure patterns are examined in a maize growing area in Southern Mexico. Exposure occurs predominantly during mixing and loading, i.e., before the actual spraying operation starts. Accidental spills of the diluted or concentrated pesticide are responsible for a major share of exposure. The links between variables affecting exposure and the incidence of acute adverse health effects are investigated for small-scale cotton farmers in Zimbabwe. Results suggest that protective gear is not a panacea to health risks from PPA and that safe use programs should emphasize hygiene and the maintenance of sprayers and clothing. In a third study, the distribution of health risks within the populations of farmers and spraymen is examined for Indian cotton farmers and spraymen, and for cotton farmers in Zimbabwe. Health risks are most heterogeneous among the Indian farmers, suggesting that identifying relatively unsafe users and targeting extension efforts at them might be worthwhile. However, we cannot infer on the possibilities for doing so.

We then value adverse health effects of operator exposure to PPA. Contingent valuation and indirect valuation methods are used but yield inconsistent health cost estimates. A number of tests conducted suggest that the contingent valuation overestimates health costs in the case of farmers but not in the case of spraymen. A consolidation of the health cost estimates shows that an upper limit of these costs is 20 percent of the PPA value, a figure which is below the profits derived from PPA. The operators’ readiness to adopt protective gear is judged generally low, partly because costs of acute health effects and the protective effect of the gear are not overwhelming, partly because the use of protective gear itself entails a cost composed of discomfort, write-off, and maintenance.
1 Introduction

Plant protection agents\(^1\) (PPA) used in agriculture have conflicting effects. They reduce crop losses due to pests and thereby increase the incomes of farmers and food supply. On the other hand, most synthetic PPA are toxic to humans and non-target organisms in the environment. This may cause adverse health effects on PPA users and other groups of the population, environmental pollution, destruction of beneficial organisms, pest resistance, etc. Recently, adverse health impacts due to PPA have attracted increasing attention from agricultural economists\(^2\). Pingali (1995) even arrives at the conclusion that "the negative human health impact of pesticides is large and overwhels their impact on the paddy ecosystem and the environment". Our focus is on these health effects and the productive effects of PPA against which health effects should be evaluated.

PPA may thus imply a marginal trade-off between income and health. This thesis tries to answer three basic questions that arise: (1) Does the trade-off take place? (2) If it takes place, at what rate does it do so? (3) Could this rate be improved?

For illustration consider Figure 1. The horizontal axis represents the use of toxic PPA which produces a net benefit in the form of revenue or income. Marginal income \( MY \) decreases with the use of PPA in the relevant range.

---

\(^1\)We understand "plant protection agents" quite narrowly as agrochemicals used to manage pests unless otherwise stated.

PPA may also cause adverse health effects to the user which entail health costs. Marginal health costs MHC might increase with the use of PPA as depicted.

**Figure 1:** Marginal income and adverse health effects of PPA use

Does a trade-off between income and health take place? The slopes of the curves MY and MHC imply that increasing use of PPA is associated with decreasing marginal revenue benefits and increasing marginal health costs. (The form of these curves will have to be examined as well.) Thus, there is a usage level \( x_1 \) where marginal income benefits equal marginal health costs. The marginal health costs of increasing the usage beyond this level exceed the marginal revenue benefits. Reducing usage below \( x_1 \) entails more income loss than health gains. Therefore, a trade-off takes place if farmers adopt this kind of reasoning. This seems plausible but is not self-evident because farmers might not be aware of health effects of PPA (Waibel, 1994). Other authors have at least implicitly argued that farmers do not take expected profits into account when choosing PPA use levels (Antle and Pingali, 1994 and 1995) or that PPA do not increase incomes (Rola and Pingali, 1993a). Therefore, in an attempt to answer the question we will compile evidence regarding PPA users' awareness of adverse health effects and the productivity of PPA.
At what rate is health traded-off against income? In other words, how much is the reduction in health from the use of PPA and how much is the loss in income from adverse health effects? Figure 1 shows that at \( x_1 \), marginal income equals marginal health costs. Hence, examining the rate of the trade-off boils down to estimating profits and health costs of PPA use.

Could the rate of the trade-off be improved? How could PPA be used more effectively? How could health be improved by giving up less income than implied by the current rate of the trade-off? To answer these questions, the technical relationships underlying the curves of Figure 1 have to be examined. This allows the identification of possibilities for shifting the curves and improving the rate of the trade-off. To actually shift the curves, the intervention of some agent, namely a policy-maker, may be required. However, we do not discuss policy-making. Rather, we focus on the analysis of the present situation in the study areas, the identification of inefficiencies and, as far as health is concerned, their mitigation by means of education and extension programs.

The thesis consists of two parts. The first concerns PPA productivity, the second health. Part I comprises Chapters 2 to 4. In Chapter 2, we outline the methodology of assessing PPA productivity. The chapter is complemented with a short literature review. In Chapter 3, we investigate the effectiveness of different strategies of using PPA with the object of illustrating some methodological issues and economic aspects of PPA use. We consider Chapter 3 self-explanatory with the exception of the model specification that draws heavily on arguments developed in Chapter 2. In Chapter 4, we examine systematically how shifts in the productivity of PPA (due to increased human capital) affect input use levels. Jointly, Chapters 3 and 4 answer the questions whether PPA are used productively and whether and how PPA productivity could be increased.

Part II comprises Chapters 5 to 10. Chapter 5 gives an introduction to the topic of adverse health effects of PPA. It is followed by three case studies in which we examine technical aspects of the factors leading to adverse health effects from PPA and try to identify prospects of preventive behavior. To do so, purely technical considerations are insufficient. Therefore, we define the rapport between the PPA users' perceptions, awareness and knowledge of, and attitudes toward health risks. However, it should be recognized that those aspects are not the main topic here. (The interested reader is referred to UTSCH, 1991). Chapter 6 presents a case study of PPA exposure patterns.
Chapter 7 analyses the preventive effects of a number of PPA use practices. The results are used to predict health risk reductions that could be achieved by adoption of preventive practices. Chapter 8 explores the need to focus education efforts on subgroups or segments of PPA users by examination of the distribution of health risks in different populations. Chapters 5 to 8 should help to answer the question whether and how the adverse health effects of occupational exposure to PPA could be reduced and to design education programs. They also present empirical data on the magnitude of health problems due to PPA. The chapters 5 to 8 complement each other mutually and should therefore be taken as a whole. Chapter 9 attempts answering the remaining questions, i.e., whether a trade-off between health and income takes place and at what rate. Therefore, we summarize evidence about the farmers' awareness of adverse health effects from PPA and value those effects, i.e., express them in monetary units. In the final chapter, results are evaluated with regard to the questions raised above.

There are a number of issues that affect the benefit-cost ratio of PPA but are not addressed here. Firstly, we abstain from considering the externalities of PPA use such as groundwater pollution or PPA residues on food. Secondly, we treat market prices as exogenous and reflecting true values. We do not consider market distortions caused by subsidies or taxes on PPA or agricultural produce, which, by the way, have been drastically reduced in all three countries of interest in recent years. Third, all studies refer to single years, that is, we refrain from considering the interseasonal effects of PPA. Fourth, in deriving conclusions for extension we do not explicitly consider the costs of extension efforts.
PART I:

PRODUCTIVITY OF PLANT PROTECTION AGENTS
Agricultural production analysis has left much to be desired (Junankar, 1989), namely with respect to the estimation of PPA productivity and demand (Chambers and Lichtenberg, 1994). It has long been recognized that production and factor allocation are simultaneous which means that the identification of the estimation model must be carefully assessed. The lack of price variations in cross-section data implies that production functions are underidentified unless restrictions on the covariance of the output and input error terms are introduced. Pest pressure and managerial skills affect production and input allocation but are commonly omitted from the model as a result of lack of data. This is grave due to the simultaneity between productive and allocative relationships. Profit or cost function approaches to production analysis consider simultaneity but set the marginal value products of the inputs equal to marginal factor costs. This makes them structurally inept to estimate marginal value products in the economic range. In rare cases, simultaneous-equation systems have been estimated that allow for imperfect information (Pingali and Carlson, 1986; Antle and Pingali, 1994). Further concerns relate to the specifications of the production and derived input demand functions (Lichtenberg and Zilberman, 1986; Chambers and Lichtenberg, 1994) and aggregation of PPA variables (Antle, 1988; Junankar, 1989). A discussion of methodological problems and a literature review suggest that many econometric estimates of PPA productivity have been inappropriate. We suggest that identified models may be obtained by transformation of the structural equations. Case studies on single crops in limited areas should increasingly use on-farm research data, thus improving data availability and reducing simultaneous-equation bias by control of some variables.
2.1 Introduction

PPA productivity estimates are needed for many purposes such as the formulation of PPA use recommendations or regulation of PPA use and availability. They should be based on real-life economic data (Zilberman and Castillo, 1994) and therefore econometrical methods apply. Those are, in theory, appropriate to quantify the effects of alternative policies at an aggregate level. They contrast in that respect with other productivity assessment methodologies such as field trials, crop loss models, and methods that use data from on-farm research which were developed for different purposes.

By "field trials" we understand experiments conducted to compare the effectiveness of different pest control treatments or pest management strategies. The results may be in physical units (e.g. percent pest damage controlled) or economic measures (e.g. partial budgeting). The researcher controls effects that are not under investigation and creates a variation in variables of interest. This simplifies the statistical analysis and makes the results reliable—for situations that are comparable to the experimental setting. Actual field conditions may deviate considerably from those settings. Field trials may thus give a notion of the potential effectiveness of different treatments but are inherently unsuitable to quantify real-life productivity.

Crop loss models aim at a quantification of the biological relationships and dynamics underlying crop management. Typical applications are the estimation of economic threshold or injury levels of pest populations that justify control actions (Zadoks, 1987) and the development of pest population sampling and monitoring methods (Walker, 1987). Like field trials, the models apply only to the environmental circumstances in which the initial study was carried out (Gaunt, 1987). This limits the scope for extrapolations. Pest control methods used in the study of crop losses may also differ significantly from the farmers' practices.

Results of field trials and crop loss models can be used for economic simulation models designed, for example, to predict the farmers' responses to policies (see e.g. Reichelderfer and Bender, 1979; Harper and Zilberman, 1989; Regev et al, 1990; Lichtenberg et al, 1993). Results from econometric studies and historical data may enter such models in a calibration process to check the forecasting ability with historical data. This improves the scope for extrapolation to the real economy.
On-farm research was born out of the perception that experimental findings are not necessarily pertinent to real-life farming systems. Farming systems research has been suggested to identify research needs for the design of recommendations (CIMMYT, 1988b). The idea of on-farm research is to conduct experiments within the socio-economic environment of the farm, thus ensuring that variables not under examination reflect real-life conditions. Only a few variables are examined at a time (CIMMYT, 1988a). This reduces the complexity of the economic analysis.

Figure 2 gives an overview of these methodologies, positioned on a grid of properties.

**Figure 2:** Synopsis of methods to assess PPA productivity

The horizontal axis depicts increasing suitability for modeling economic behavior (from left to right). The vertical axis represents the degree of statistical and mathematical complexity of the model (from the bottom to the top).

Ideally, a model is both simple and realistic, a combination which is hard to find (lower right corner of Figure 2). Econometric models and on-farm research are on the right side of the grid because they incorporate empirical economic information. Due to the possibility of controlling some variables, on-farm research is conceptually simpler than econometrics. However, unlike econometric models, on-farm research does not give any aggregate es-
estimates. We conclude that econometrics is the core discipline to estimate PPA productivity. Its scope and limitations are discussed subsequently.

Figure 3 lists a number of desirable properties of econometric models: theoretical plausibility, explanatory ability, accuracy of the parameter estimates, forecasting ability, and simplicity (KOUTSOYIANNIS, 1977).

**Figure 3:** Desirable properties and critical features of econometric models including PPA variables

The features displayed at the corners of the figure affect these properties and appear particularly relevant to models involving PPA. Those are (i) the simultaneity of allocative and productive relationships (CHAMBERS and LICHTENBERG, 1994), (ii) the kind and aggregation of PPA variables (e.g. HARPER and ZILBERMAN, 1992), and (iii) the form of the production function (LICHTENBERG and ZILBERMAN, 1986; CHAMBERS and LICHTENBERG, 1994). These features compete for manageable degrees of complexity of the model. The corner stones "simultaneity", "data and variables", and "functional form" are discussed in Sections 2.2 to 2.4. Section 2.5 is a review of econometrical literature with emphasis on the marginal value product of PPA. Conclusions are offered in Section 2.6.
2.2 Simultaneity and identification

Econometric and experimental assessments of PPA productivity differ in that the first uses data from real-life production, i.e. "economic data". The input levels are chosen by a decision unit (farmer) who reacts to variables that affect production. For instance, the farmer may adjust fertilizer levels to the nutrient content of the soil. Therefore, the usage levels of different inputs depend on each other and on exogenous variables that affect production. Input allocation and production are simultaneous. In experiments, on the other hand, input levels are usually fixed in advance by the researcher and, hence, exogenous. There is a one-way relationship between input and output levels that can be estimated with a single-equation production model.

The fact that real-life input allocation is a function of the same variables as production is most important and deserves a few comments. Besides variables such as weather or nutrient contents of the soil, the decision unit takes *indicators of actual production* into account. For example, the farmer may fertilize in relation to the observed vitality of the crop or control pests in relation to observed pest damage. Over a season many cycles of observations, decisions, actions of the farmer, and biological reactions of the crop take place. That is, the farmer applies a sequential decision rule (Antle and Pingali, 1995). This does not imply that farmers use sophisticated measuring tools and formal simulation models to predict crop responses. The reader will certainly agree that a farmer who sprays PPA when he observes that there are pests takes the presence of pests into account in the spraying decision, even though he does not count the pest population. We emphasize this because we feel that too often it has been argued that sequential decision rules are not followed and that therefore input allocation is roughly exogenous to production. Several studies highlight that farmers generally have an admirable capacity for predicting yields (Bessler, 1980; Grisley and Kellog, 1983). In absence of formalized decision rules, farmers must be assumed to have some internalized "crop production model". It is only natural that they adjust input usage to what they think the effect will be. Of course, the accuracy of the prediction depends on factors such as experience, complexity of the available techniques, the variability of the environment, the possibilities of observing the factors that affect production, etc. For instance, it may simply be impossible to detect certain fungi infestations
by an eyeball survey before considerable damage occurs. However, in general, input allocation is affected by expected output.

These considerations imply that productive and allocative relationships underlying economic data are inherently simultaneous. The simultaneity is obvious in dynamic models that account for interactions of input use, crop responses, and pest and predator populations. However, it persists in variables aggregated over time. This simultaneity has a number of implications for the model formulation and the prospects of obtaining unbiased and reliable estimates. In particular, it implies that production function estimation is subject to simultaneous-equation bias when variables that affect both production and input allocation are omitted from the model. However, omission of certain variables of this type is the rule rather than the exception in production analysis. For example, data on pest pressure or managerial skills are not normally available and therefore their influence is commonly omitted.

2.2.1 Simultaneous-equation system

Consider the production function $q = f(x,z,\gamma)$ that describes the physical relationship between a single output or crop yield $q$, two inputs $x$ and $z$, and a non-choice variable $\gamma$. Examples for inputs are PPA, fertilizer, irrigation water, seeds, etc. Examples for $\gamma$ are managerial skills and environmental factors such as rainfall, soil quality, temperature, solar radiation, initial population levels of pests, predators and parasites, pest and predator migration, etc.

The input demand equations are derived from the production function and some behavioral rule such as profit maximization. With exogenous prices $p$, $w$ and $s$ for $q$, $x$ and $z$, respectively, profits are $\Pi = pq - wx - sz$. Under the assumption of perfect information and provided that second order conditions are fulfilled, the first order conditions for profit maximization, $pf'(x,z,\gamma) = w$

---

A comment on the notation: Here, both Greek and Latin letters may denote variables and parameters (and functions). That is so because the identification problems to be discussed arise partly because the distinction between parameters and variables is not obvious. Environmental growth conditions, for example, may be omitted when they do not vary much. They would then simply be accounted for in the parameters of $f(\cdot)$. When they do vary, however, they are best treated as variables. Bold small letters denote vectors and bold capital letters denote matrices.
and \( p_f(x, z, \gamma) = s \) describe allocative behavior. (Subscripts denote partial derivatives.) If closed forms \( x = d_1(\cdot) \) and \( z = d_2(\cdot) \) of the first order conditions exist, the following system of simultaneous equations holds.

\[
\begin{align*}
q &= f(x, z, \gamma) \\
x &= d_1(p, w, z, \gamma) \\
z &= d_2(p, s, x, \gamma)
\end{align*}
\]

The equations \( d_1(\cdot) \) and \( d_2(\cdot) \) are derived from the profit function \( \Pi(\cdot) \) which in turn is derived from the production function. Hence, they contain a subset of the parameters and variables of \( f(\cdot) \). Moreover, they contain variables that appear in the profit but not in the production function, namely prices. In the following we refer to variables that appear in both the production function and the demand equations as "non-price factors", represented by \( \gamma \). Variables that appear in the demand equations but not in the production function will be called "price factors", represented by \( p, s \) and \( w \).

A set of reduced form equations is obtained as follows. Let \( \pi(p, w, s, \gamma) = \max_{q, x, z} \Pi(\cdot) \) be the indirect profit function dual to the production possibilities (technology) implied by the production function. If a unique solution to the profit maximization problem exists, it can be recaptured by differentiation of the profit function via the Hotelling-Shepard lemma (Chambers and Lichtenberg, 1994).

\[
\begin{align*}
q(p, w, s, \gamma) &= \pi_p(p, w, s, \gamma) \\
x(p, w, s, \gamma) &= -\pi_w(p, w, s, \gamma) \\
z(p, w, s, \gamma) &= -\pi_s(p, w, s, \gamma)
\end{align*}
\]

Such systems can be used to examine the technology. Typical applications are the estimation of input demand elasticities, rates of substitution, and the examination of homotheticity and economies of scale (e.g. Lopez, 1980; Walo, 1994).

By combining the production function of (1) and the input allocation equations of (2) we obtain the recursive or triangular system.
\begin{equation}
q = f(x, z, \gamma)
\end{equation}

\begin{equation}
x = -\pi_n(p, w, s, \gamma).
\end{equation}

\begin{equation}
z = -\pi_i(p, w, s, \gamma)
\end{equation}

Models (1) to (3) are mathematically equivalent.

Occasionally, attempts have been made to test the duality theorem in general and profit maximizing or cost minimizing behavior in particular. For example, RAY and BHADRA (1993) find that Indian farmers do not generally minimize costs and that their failure to do so is not explained by risk aversion. Their test is basically a comparison of the cost efficiencies across farmers. It runs as follows. When there are farmers in the sample who produce more than others at equal costs (and with comparable amounts of quasi fixed factors), or farmers who produce the same output quantity at lower costs, the hypothesis of cost-minimization is rejected. This approach requires that all factors affecting production are included in the comparison. However, this seems quite impossible. As the authors note: "one must recognize that the actual output data are influenced by random factors like weather and may also include measurement errors". Of course, rejecting the method used by RAY and BHADRA is no proof that farmers minimize costs. However, in absence of alternative behavioral rules, cost-minimization seems to be a reasonable working hypothesis, even more so because RAY and BHADRA find farmers to be technically quite efficient and point out that "it is difficult to explain why a farmer would be generally technically efficient but fail to select the cost-minimizing input bundle." Others like LOPEZ (1980) or WALO (1994) find agricultural production well described by the duality theorem. JUNANKAR (1989) criticizes the profit function approach (among other reasons) because markets in developing countries are far from perfect. We find that the appropriate solution in such situations is to include marginal transaction costs in the demand equations rather than to ignore behavior.

2.2.2 Identification

For the discussion of identification, it seems worthwhile to reproduce the typical textbook illustration thereof and extend it to production and input choice. Figure 4 depicts three sets of data on a traded quantity \( Q \) of some good with price \( P \).
Figure 4: Identification of supply and demand

a: demand identified  b: supply identified  c: neither supply nor demand identified

The demand and the supply functions are simultaneous relationships between the price and the quantity. The dots represent observations on $P$ and $Q$. In panel a, the supply at a given price varies considerably (represented by $S_1$ to $S_5$), while the demand is relatively stable ($D$ and $D'$). The data identifies the demand function. In panel b, the supply is relatively stable while the demand varies widely—the supply function is identified. In panel c, both demand and supply show considerable variability. The data identifies neither function unless it includes information about factors that shift only the demand and others that shift only the supply, and provided that these shift factors explain an adequate share of the demand and supply variances.

Figure 5 shows the analogous case of production and input allocation. The production function describes how input $x$ affects output $q$. The demand function describes how the anticipated output, which is somehow related to $q$, affects input allocation.
Non-price factors may induce considerable shifts in the production function \( f \), such as depicted in panels b and c. A single input demand curve \( d \) is a set of points on the production functions that satisfy the behavioral rule when non-price shift factors vary. Under the assumption of profit maximization, the slope of the production function equals the input output price ratio in these points. Therefore, the input demands are shifted by price factors. The input demand is fairly stable when prices show little variance (panel b) but varies considerably when prices change adequately (panels a and c). In analogy to Figure 4, data on \( q \) and \( x \) identifies the production function when prices vary but non-price factors are fairly stable (panel a). The demand equation is identified when production varies widely but prices do not (panel b). In panel c, neither the production nor the demand function are identified unless the "shift factors" are known.

**Rules of identification**

Formal rules for identification include the order and the rank conditions. The order condition requires that the model is complete and that each equation is identified (KOUTSOYIANNIS, 1977). For an individual equation to be identified, the other equations in the model must show sufficient variability. This is sometimes stated more formally as follows. The total number of variables (endogenous and exogenous) excluded from an equation must be equal to or greater than the number of endogenous variables in the model less one (KOUTSOYIANNIS, 1977). The order condition is only a necessary condition.
for identification. Sufficiency is ensured by the rank condition which is fulfilled when it is possible to recover the parameters of the structural model from the reduced form parameters.

The models (1) to (3) are complete in the sense of containing one equation for each endogenous variable. Moreover, each equation is identified. Their parameters can be estimated with simultaneous-equation methods.

Recursive systems

More general conditions for identification consider restrictions on the covariance matrix of the error terms. These may be operative for identification, for example in the case of recursive systems (Greene, 1993).

Recursive systems are a special case of simultaneous-equation systems. Their equations can be ordered such that the right hand side of the first equation contains only predetermined variables, the right hand side of the second equation contains only predetermined variables and the first endogenous variable, etc.

Consider the model (3), complemented with error terms u and \( v_i \), and normalized in prices. (Interpret \( w \) and \( s \) as price ratios.)

\[
q = f(x, z, y) + u \\
(4) \\
x = -\pi_w(w, s, y) + v_1. \\
z = -\pi_s(w, s, y) + v_2
\]

This model is recursive. If \( u \) and \( v_i \) are independent, each equation may be estimated with single-equation techniques (Judge et al., 1988, p. 616). A correlation between \( u \) and \( v_i \), on the other hand, causes a correlation between the inputs and \( u \) that biases the estimates obtained with single-equation techniques applied to the production function. (The single-equation estimates of the demand functions remain unbiased.)

Thus, there are two basic possibilities of estimating the system (4) or single equations thereof. One may apply simultaneous-equation methods to the full model. These methods do not require restrictions on the covariance matrix of the error terms. Alternatively, one may estimate the single equations. This
yields unbiased estimates for the demand functions and—if $u$ and $v_i$ are independent—for the production function.

Identification prospects with different data sets

Identification problems arise when certain variables do not show any variation in the area and/or time period of interest. Cross-section data, for instance, does not normally show price variations. The input demand is then basically a function of non-price factors, i.e., variables that appear in the production function. Hence, there are no variables absent from the production function that appear in the demand equation. The production function is underidentified. Identification should thus be evaluated in the specific model that applies to a given data set rather than in the general model ((1) to (3)).

In the following, we discuss identification under different situations of data variability and availability. We focus on identification of the full simultaneous-equation system (SEM) and the identification of the single-equation model consisting of the production function (PFM).

Data may be available on both price and non-price variables ($w, s, y$), non-price variables only ($y$), price variables only ($w, s$), or neither price nor non-price variables (in addition to data on inputs and outputs). Similarly, the input variances might be known to be dominated by both price and non-price factors, price factors only, or non-price factors only. The case where neither prices nor non-price factors can be assumed to have important allocative effects is unrealistic with economic data, because there must be some reason for the input variance. Therefore, this case is not discussed any further.

Sources of the input variance are plotted against data availability in Table 1. The columns from left to right represent decreasing numbers of exogenous variables with effects on input allocation. Decreasing data availability is given in the rows, from top to bottom. Each cell contains the respective "true" model with missing variables canceled.

The meaning of the columns is the following: The left column represents cases where both price and non-price factors vary and can, or must be assumed to affect input allocation. Thus, for a case to fall into this category, variations are required in market prices or marginal costs of using a certain input. The middle column represents cases where prices do not vary in the area and time period of consideration. This is a common case in cross-section studies. The right column represents cases where price factors domi-
nate the input variance. Non-price factors do either not vary or do not appear in the first derivative of the production function with respect to the control variables. Since pest pressure, managerial skills, and environmental conditions generally vary and must be assumed to affect input allocation, these cases are somewhat unrealistic.

The meaning of the rows is as follows. The top row represents full data availability, denoted by the letters $w$, $s$, and $\gamma$. For a case to fall into this row it is not sufficient that the data contains some prices and some non-price factors. Rather, it must contain all relevant prices and non-price factors. The second to the fourth rows represent limited data availability.
Table 1: Identification with different allocative relationships and data

<table>
<thead>
<tr>
<th>Data</th>
<th>Exogenous variables that cause the input variation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$w, s, \gamma$</td>
</tr>
<tr>
<td>------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>$w$</td>
<td>i) $q = f(x, z, \gamma) + u$</td>
</tr>
<tr>
<td></td>
<td>$x = -\pi_w(w, s, \gamma) + v_1$</td>
</tr>
<tr>
<td></td>
<td>$z = -\pi_s(w, s, \gamma) + v_2$</td>
</tr>
<tr>
<td></td>
<td>✓ SEM identified</td>
</tr>
<tr>
<td></td>
<td>✓ PFM identified</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>$s$</td>
<td>iv) $q = f(x, z, \gamma) + u$</td>
</tr>
<tr>
<td></td>
<td>$x = -\pi_w(w, s, \gamma) + v_1$</td>
</tr>
<tr>
<td></td>
<td>$z = -\pi_s(w, s, \gamma) + v_2$</td>
</tr>
<tr>
<td></td>
<td>✓ PFM identified</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td>vii) $q = f(x, z, \gamma) + u$</td>
</tr>
<tr>
<td></td>
<td>$x = -\pi_w(w, s, \gamma) + v_1$</td>
</tr>
<tr>
<td></td>
<td>$z = -\pi_s(w, s, \gamma) + v_2$</td>
</tr>
<tr>
<td></td>
<td>✓ SEM identified</td>
</tr>
<tr>
<td></td>
<td>× PFM underidentified</td>
</tr>
</tbody>
</table>

Notes: "w" denotes non-availability of data on $w$. Data on $x$, $z$ and $q$ is assumed available in all cases. "✓" and "×" denote viable and biased models, respectively. SEM = simultaneous-equation model. PFM = Model consisting of the production function, only. $u$, $v_1$ and $v_2$ are error terms.

The demand equations are identified (or trivial) in all cases with exception of (ii), (iv) and (v) where identification of the system of demand equations depends on restrictions that do not appear in the above notation. (For example, if $\gamma$ is a vector, some of its elements might not appear in one or the other behavioral equation.)

Case (i) is the mathematically most general case of a full-sized simultaneous-equation system with complete data availability. Price factors are contained in the behavioral equations but not in the production function. The
output, $q$, is contained in the production function but not in the behavioral equations. Hence, the system fulfills the order condition. Applying single equation methods to the behavioral equations or simultaneous-equation methods to the full system yields unbiased estimates. Simultaneous-equation methods do not require independence of $u$ and $v_i$. Therefore, the full system is identified also in case (vii) where $\gamma$ is omitted for lack of data and causes a correlation between $u$ and $v_i$.

In case (i) the production function may be estimated with single-equation methods if $u$ and $v_i$ are independent. Note, however, that missing non-price variables would cause a correlation between $u$ and $v_i$ (case (vii)). A production model estimated with single equation techniques should thus contain all relevant non-price factors in order to ensure that $u$ and $v_i$ and, hence, $u$ and the inputs are independent.

If prices vary but are not available and therefore omitted from the demand equations (case (iv)), the variation in prices affects $v_i$ and mitigates a potential correlation between $u$ and $v_i$. However, it does not eliminate such a correlation. Therefore, the analyst who estimates the PFM should make sure that there are no missing variables which cause such a correlation.

The right column (cases (iii), (vi), (ix) and (xii)) shows that production function estimation is justified when price factors dominate the input variance while the allocative effects of non-price factors are negligible. The non-sample information that prices dominate the input variance allows to assume that the error terms are independent. Data on price factors is not required for production function estimation but allows the estimation of the full system when available. As mentioned, these cases are unlikely.

The middle column (cases (ii), (v), (viii), (xi)) is characterized by the absence of price factors. The full system is underidentified because price factors are absent from the demand equations and do not ensure adequate variability of the inputs at given levels of $\gamma$. The assumption that $u$ and $v_i$ are independent cannot be defended if some non-price factors are missing (cases (viii) and (xi)). Moreover, even when the production function contains all relevant non-price factors (cases (ii) and (v)), the lack of price variations raises the question what actually causes the variance of $v_i$. Independence of $u$ and $v_i$ is not ensured. Hence, the PFM is underidentified.

In cases (viii), (x) and (xi), the demand equations are trivial. The full system is not identified due to lack of data. The omission of non-price factors from
the production function causes a correlation between the inputs and \( u \) and, hence, a bias.

In conclusion, estimation of the production function with single-equation methods is justified if one of the following conditions is fulfilled:

1. Price factors vary and no non-price factors are missing ((i) and (iv)).

2. Price factors vary and non-price factors have no effect on input demand (right column).

3. Price factors do not vary, no non-price factors are missing and there is some reason to assume that input demand (at fixed non-price factors) varies independently of \( u \) despite the lack of variation in prices.

Cross-section data satisfies neither the first nor the second condition. The third condition is difficult to satisfy because common data sets do not include information about pest pressure and managerial skills (and often lack data about some, if not most, other environmental variables).

### 2.2.3 Prospects of alternative models

In some cases, the investigator is interested in only one equation of the system (the production function, for example) and attempts to estimate its parameters without complete knowledge of the model. Identification cannot be established by the application of the above formal rules. It may then be ensured by a priori information about "shift factors" that affect some functions but not others. For instance, if one could assume the production function fairly stable and input usage to vary adequately, one could proceed with production function estimation. If one can assume that other factors dominate the input and output variances, other models might be identified.

For illustration, consider the specification 

\[ q = \alpha [1 - \delta \exp(-\lambda x)] \]

where \( \alpha, \delta \) and \( \lambda \) correspond to the variable \( y \) in the generic model. \( x \) are PPA. \( \alpha \) is potential crop yield, i.e. the output produced when \( \delta = 0 \). \( \delta \) is the potential pest damage expressed as a proportion of \( \alpha \), \( \delta \in [0, 1] \). \( \delta \) is a function of (assumedly exogenous) initial pest pressure and pest migration which in turn depend on environmental conditions and other exogenous factors. \( \lambda \) is an effectiveness parameter that depends on the farmer's skills in using PPA. The function is concave and nondecreasing in \( x \) for positive \( \lambda, \delta \) and \( x \). It is
an example of a production function having the form of a cumulative distribution function in the damage control agent $x$ (cf. Section 2.4). The input demand equation is obtained by solving the first order condition for profit maximization. It is

$$x = -1/\lambda \cdot \ln[w/(p\alpha\delta\lambda)].$$

This function happens to be the reduced-form equation for $x$. Substitution in the production function yields the reduced-form equation for $q$,

$$q = \alpha - w/(p\lambda),$$

which indicates how output varies as profit maximizing input levels are chosen in relation to the exogenous variables. The two reduced-form equations describe how any variation in the exogenous variables shifts $x$ and $q$. Figure 6 shows how inputs and outputs vary simultaneously as single exogenous variables are varied. The figure is obtained by numerical simulation.
Figure 6: Spurious input-output correlations

Starting from an arbitrarily chosen point M, a variation in \( \alpha \) returns values of \( x \) and \( q \) that form curve A. Respective variations in \( w/p \), \( \lambda \), and \( \delta \) generate curves B, C, and D. Economic data that happens to show a large variance in one exogenous variable but only small variations in the others is scattered around the respective curve. Field data that happens to show large variances in several of the exogenous variables is scattered around a mixture of the curves. The data may thus show a spurious correlation between \( q \) and \( x \), depending on the variances of the exogenous variables.

Attempts to estimate the production model \( q = f(x) + u \) yield parameters that are impossible to interpret. The parameter estimates may be related to the model in question (curve B) or to another model or to a mixture of models (KOUTSOYIANNIS, 1977). In particular, the first derivative of the estimated function is not normally an estimate of the marginal input productivity.

However, knowledge of the factors that shift \( q \) and \( x \) may allow to find identified transformations of the model. Assume, for example, that \( \alpha \) is known to vary widely while the other exogenous factors are relatively stable. Substitution for \( \alpha \) yields
\[ q = \frac{w}{(p\lambda \delta) \cdot (\exp(\lambda x) - \delta)} \]

or

\[ x = \frac{1}{\lambda} \cdot \ln\left(\frac{pq\lambda \delta}{w + \delta}\right). \]

These equations fulfill the order condition because one knows that \( \alpha \)—which is absent from the equations—dominates the variances of \( q \) and \( x \). Alternatively, when \( \lambda \) or \( \delta \) were known to dominate the input variances, it might be possible to find estimation models by elimination of \( \delta \) or \( \lambda \). Since the order condition is only necessary for identification, transformed models do not normally allow recovery of all parameters.

The suitability of a transformation depends on the type of a priori knowledge, the purpose of the estimation, i.e. the parameters of interest and the specifications of the structural equations. The latter signifies that what one actually does is to make use of non-linearity restrictions imposed on the specification of the structural equations.

Models derived from restrictions imposed on the structural equations draw heavily on the assumption about the behavioral rule (e.g. profit maximization), a priori information about the effects of the eliminated variable(s) and the functional form of the structural equations. This may be quite restrictive but appears preferable to production function estimation devoid of any considerations of input choice and identification.

Of course, the prospects of finding identified models improves when data is collected specifically for the purpose of production analysis rather than taken from secondary sources. Combinations of surveys and experimental methods might also prove useful. On-farm research, for example, allows control of some variables while leaving others reflecting actual field conditions. The controlled variables may be useful for the identification of econometric models. Thus, on-farm research data may be more suitable than economic survey data in some instances. An example for the use of such data is given in Chapter 4.

### 2.3 Data and variables

The above discussion showed that the prospects of finding identified models depends on data availability and variability. In the context of plant protec-
tion, (initial) pest pressure and managerial skills are critical because data on these variables is often lacking. Moreover, cross-section data is often devoid of price variations. These three types of variables are outlined shortly below, followed by a discussion of problems associated with PPA variables.

2.3.1 Pest pressure

PPA productivity depends crucially on the potential pest damage to yields, defined as the difference or ratio between yields in absence of pests and yields in presence of pests but absence of the control agents of interest. The potential damage is a function of pest pressure. As indicated above, farmers must be assumed to take pest pressure into account. Farmers do not have perfect information on the pest populations, their dynamics and effects on yield. However, it is equally certain that they are not completely ignorant about the pest histories of their fields and the effects of environmental conditions on pest pressure. Detailed evidence for this truism is given, for example, by Pingali and Carlson (1986). Many pests are easy to observe, e.g. weeds or some insect pests. Small-scale farmers are likely to spend much time in their fields. They may thus observe pest pressure at very low marginal costs. Large scale farmers might spend less time in the fields, but can realize considerable economies of scale in monitoring pests. Therefore, farmers must be assumed to have a notion of the presence and pressure of pests and potential damage. The subjective estimates may lack precision4, but, as long as they approximate the true values, potential pest damage appears in the input demand equations.

The argument that farmers follow fixed schedules of preventive sprayrounds is sometimes brought forward to justify omission of potential damage from the allocative equations. It has been argued that observation of pest pressure

---

4It should also be recognized that the hypothesis that farmers have a notion of pest pressure or potential damage cannot be tested by comparing experimental findings to the farmers' answers to abstract questions such as "how much percent of the yield do you think would be lost if you did not use PPA". Utsch (1991) asked Sri Lanka rice farmers to express in percents their estimate of the yield damage that would occur if they did not use a specific brand. Most farmers gave percentages between 80 and 100 percent. This seems unreasonably high given that there are typically many substitutes to a specific PPA brand. We suspect that farmers have difficulties in expressing their experience in percent figures or that they interpreted the question as referring to not using PPA at all or percent loss in revenue rather than yields.
is difficult, for example in the case of diseases or soil insect pests whose first symptoms appear well after infestation. There is a basic inconsistency in this argument: When schedules are truly fixed, there is no variance in the input quantities, rendering production function estimation unfeasible. When PPA usage varies, on the other hand, spraying is not according to fixed schedules, contradicting the initial argument.

2.3.2 Managerial skills

Managerial and technical skills of the farmer affect PPA effectiveness in many ways, e.g. through the accuracy of pest identification, selection of suitable PPA brands, dosage, timing of applications (with respect to the pest population age structure, weather conditions, and the hour of the day), coverage of weeds, seed, soil or crop, and the use and effectiveness of non-chemical control methods. Management of these factors requires skills that cannot be presumed constant over farmers. Hence, the variance in yields or profits is partly explained by the variance in skills. Moreover, farmers must be assumed at least partly conscious of their individual capacities and/or past successes and failures in crop protection which implies that skills appear also in the demand functions.

2.3.3 Price factors

Price factors include market prices and other variables that appear in the demand equations but not in the production function. Cross-section data does not usually contain price variations, simply because market prices—which are the most obvious prices that can be used—tend to be fairly stable in a single time period. Cross-section data from a limited agroecological and geographical region is likely to refer to a single PPA market with small to negligible regional price variations.

Price factors include more than just market prices. In developing countries, transaction costs tend to make up an important share of the total costs of PPA. They may also show considerable variation, due to differences in the access to credits or infrastructure, for example (GANDHI, 1996). Observations in the three project areas suggest the existence of considerable variations in the marginal PPA application costs. In Zimbabwe, for instance, the distance between the water source used for the preparation of the spray mixture and the field is 600 meters on average, with a standard deviation of 800 meters. The time needed to haul the water for three to four hours of
spraying with a manual knapsack sprayer is around 100 minutes with a large standard deviation. These comments suggest that marginal transaction costs may be operative for identification. The prospects of identifying simultaneous-equation systems with such variables in cross-section data would be an interesting research topic.

2.3.4 PPA variables

PPA are a heterogeneous production factor. They include different formulations of different active ingredients that are applied at different rates and with different techniques. The number of active ingredients used on a single crop may exceed a dozen even in a small area such as the Indian project area where eight major and a large number of minor active ingredients are used on cotton. The number of brands is a multiple of the number of active ingredients. However, only a limited number of PPA variables can be successfully included in an econometrical model. Hence, aggregation of brands is inevitable.

Separability

Consider the production function

\[ q = f(x,z), \]

where \( x \) is a vector of physical quantities of homogenous PPA such as individual PPA brands and \( z \) is a vector of other inputs. Assume there is a single pest that is controlled by \( x \). The elements \( x_i \) of \( x \) differ in effectiveness. Intuitively, one might consider rewriting the production function as

\[ q = F(X(x),z). \]

where \( X(x) \) is a function that captures the productive effects of \( x \). Indeed, \( X(x) \) is a micro-production function and may be interpreted as damaging capacity of the pest (or joint effect of \( x \) and pests). However, it does not have to be interpretable as some biological or physical variable. Rather, it is sufficient to ensure that \( X(x) \) captures the effects of \( x \) on production. It can be shown that (5) is valid if \( f(x,z) \) is weakly separable, that is, if the technical
rate of substitution between the pest control inputs is independent of $z$ (Chambers, 1988). That is

$$
\frac{\partial f_{x_i}}{\partial z_k} f_{x_j} = 0, \forall i, j, k.
$$

By combining (5) and (6) one obtains

$$
\frac{\partial X_{x_i}}{\partial z_k} X_{x_j} = 0, \forall i, j, k.
$$

That is, the relative effectiveness of different PPA brands must be the same at all levels of $z$.

The extension to several pests or several micro-production functions, $X^k$, $k = 1 \ldots m$, is straightforward. For example, when there are weeds, insect pests and diseases, it might be appropriate to partition $x$ into subvectors $x^k$ of herbicides ($k = 1$), insecticides ($k = 2$) and fungicides ($k = 3$) and define $X^k(x^k)$, $k = 1, 2, 3$. Separability implies then that the technical rate of substitution between brands of type $k$ must be independent of the usage levels of the other types of PPA.

Separability seems reasonable, at first sight, for the case of a single pest in a single crop. However, it is easy to imagine a number of situations where (7) is violated:

- Two PPA $x_i$ and $x_j$ might control the same pest but differ in other features such as the effectiveness under varying environmental conditions. An example are residual herbicides and desiccants. Both require favorable weed growth conditions to work properly, namely sufficient humidity and temperature. However, desiccants need these conditions immediately upon application, while residual herbicides may still work when applied to a dry or cold soil some time before humidity or temperature increases. Hence, the relative effectiveness of the two is a function of environmental conditions and therefore related to $z$, violating the condition for weak separability.
When there are different pests, $X(x)$ may be interpreted as damaging capacity of the joint pest infestations. Generally, the elements of $x$ control different pests to different degrees. The technical rate of substitution depends then on the relative population sizes of the different pests. The elements of $z$ (environmental conditions, sowing density, soil preparation, fertilization, etc.) affect both absolute and relative pest infestation levels, causing non-separability. This example applies also to a single pest that is resistant to $x_i$ but not to $x_j$. The frequency of resistance in the pest population typically depends on $z$, letting $z$ affect the technical rate of substitution between $x_i$ and $x_j$.

Finally, consider the case of different pests that are controlled by different PPA. For example, let $X^1(x^1)$ and $X^2(x^2)$ be the damaging capacities of weeds and insect pests, controlled by herbicides and insecticides, respectively. When the production function is weakly separable, we may write $q = F(X^1(x^1), X^2(x^2), z)$. Way and Cammell (1985) give a number of examples for fungicides that act on insects, nematodes or mites, and insecticides and herbicides that act on pathogens. The effects may be direct on the physiology of the exposed species or indirect on the habitat of the non-target species. Predators of the insect pest or the insect pest itself may, for example, develop on weeds and migrate to the crop, or vice-versa, be attracted by the weed. Insecticides typically differ in their impacts on predators, so that the technical rate of substitution between insecticides depends on herbicide usage. (The example is inspired by Mocis latipens that develops on weeds, cf. Section 4.4).

In conclusion, separability between different types of PPA and between PPA and other inputs or environmental factors appears to be the exception rather than the rule. However, aggregation cannot be avoided, as mentioned.

**Aggregation**

The preferable specification of the micro-production function or aggregation procedure depends on the scope of the study. For economic analysis the aggregated PPA value often appears as the "natural choice". For a study of the productivity of a certain compound, the mass of that compound and the masses of other PPA might constitute suitable variables. Plant protection costs include labor and machinery costs as well as PPA acquisition costs. This may also create aggregation problems. Aggregation by mass, cost, he-
donic prices, application rates, and number of applications (sprayrounds) and the problem of labor are outlined subsequently.

**Mass aggregation:** Aggregation by mass corresponds to specifying $X = \Sigma x_i$, where $x_i$ is the mass of the formulation or the active ingredient of brand $i$. Mass aggregation may be appropriate for PPA of similar effectiveness in terms of control effect per mass unit. The masses of different active ingredients needed to achieve a given level of control may differ by large factors (Carlson and Wetzstein, 1993). Therefore, mass aggregation is often inappropriate (Antle and Pingali, 1994). The researcher may be misled and conclude that farmers using low-rate brands were invariably more effective than their colleagues using brands of higher recommended rates.

**Cost aggregation:** Monetary aggregation corresponds to the specification $X(x) = w'x$, where $w$ are the prices of the brands $x$. The specification is correct if prices reflect the relative effectiveness of brands. This is certainly not true for many pairs of PPA, but may hold approximately for subsets of brands used by a single farmer in a single crop, because farmers are likely to limit their choice of PPA to brands with comparable cost-effectiveness ratios.

If $X(x)$ is a suitable aggregation function, i.e. a function that captures the productive effects of $x$, the farmer who minimizes the costs to achieve a given level $X^* = X(\cdot)$ minimizes the Lagrangian expression $L = w'x + \lambda(X(x) - X^*)$. The first order conditions establish $w = \lambda X_x$. Therefore, $\lambda x'X_x = x'w = X$. Hence, weighting brands with prices is equivalent to weighting them with multiples of their respective marginal value products under the assumption of cost minimizing behavior. Cost aggregation seems thus appropriate when cost minimization or profit maximization is assumed anyway.

It may also be argued that agrochemical companies take the relative advantages of their brands into account when fixing the prices. Note, however, that comparative advantages of brands vary across crops. The price of a brand used in crop A may thus reflect the brand's effectiveness in crop B, namely when sales for crop B are relatively important for the company. It is also interesting to observe that prices vary considerably across comparable formulations. The most expensive brand is often the one that was marketed first. The existence of such price premiums hints at potential transaction (information) costs incurred by changing from a familiar to an unfamiliar compound. Where such information costs play a major role the assumption
that a farmer uses different brands at levels where their marginal value products are similar is violated and cost aggregation is harder to defend.

**Hedonic prices:** Occasionally, hedonic prices are used for the aggregation of PPA variables (e.g. **ANTLE** and **PINGALI**, 1994 and 1995). Prices per unit of active ingredient are interpreted as a function of a quality (effectiveness) component and other factors that are not correlated with efficacy. The quality component is a function of application rates. The prices of individual brands are regressed with a heuristic model on the recommended rates of active ingredients and dummies for other product characteristics. Evaluation of the model at recommended rates and fixed values of the dummies yields what can be interpreted as quality factors. These factors are then used to aggregate the brands (**ANTLE**, 1988; **ANTLE** and **PINGALI**, 1994 and 1995).

We find such a procedure valid in theory and most important where extremely heterogeneous PPA are used. In practice, however, choosing the "right" rates is a tedious undertaking. Some labels give ranges of rates and recommendations on how to dose in function of soil conditions, crop size, etc. The researcher may not have sufficient information on those factors and resorts to mean doses which are not necessarily a good approximation to optimal doses in a given area. Labeled dosages may also be a result of negotiations between formulators and regulators rather than effectiveness considerations (**MOFFITT**, 1988). In such a case, the labeled rate poorly reflects the relative effectiveness of a brand. In some cases, the best practice may be to split the dose (of a preemergence herbicide, for example), i.e. to use only half of the recommended dose in a first sprayround, and spraying the other half only if the first turns out insufficient (**MÜLLER-SCHÄRER** and **BAUMANN**, 1993). The labeled dose is then a poor approximation to actual practices and not suitable for use in hedonic price models.

**Aggregation in terms of multiples of recommended rates:** The recommended rate is an approximation to the mass or volume of PPA required to achieve a given level of control. Therefore, masses might be weighted with the inverse of the recommended rate to correct partly for heterogeneity in efficacy per mass unit. The procedure is subject to similar limitations as the hedonic price approach.
Number of sprayrounds: Taking the number of sprayrounds per season as a PPA variable may be justified in situations that are relatively homogenous in brands, dosage, equipment, and types of pests.

2.3.5 Labor

Accounting for labor associated with pest control measures may pose considerable problems. Spray labor can be included in a PPA variable aggregated by costs when it is assessed separately and when the (shadow) wage rate is known. Labor to apply PPA may be approximately proportional to the number of sprayrounds, allowing to model labor costs as a multiple of the latter. Since doses per sprayround vary across brands, labor is certainly not proportional to the physical quantity of active ingredients or the value of PPA. Moreover, a considerable proportion of the labor variance may be due to variations in the type of appliance, the carefulness of the application, etc.

2.4 Form of the production function

Common production functions allow for potentially unbound contributions of inputs to output. This property contradicts biological considerations of crop protection. In a now classical paper, LICHTENBERG and ZILBERMAN (1986) argued that the output effect of a damage control agent cannot be more than complete abatement of potential damage which in turn is limited to total loss. Hence, a production function should have the form of a cumulative distribution function (cdf) in damage control agents such as PPA.

Figure 7 reproduces stylized graphs of the abatement specifications suggested by LICHTENBERG and ZILBERMAN (1986). A Cobb-Douglas and a linear-response and plateau function (LRP) are also depicted.

5Some PPA are not sprayed but, for example, applied as granules to the soil, as dressings to the seed or as "dipping" to the roots of transplanted seedlings. "Sprayround" is understood here as including all these types of PPA applications.
The Cobb-Douglas specification does not have the desired property of not exceeding 1 (complete control) as input levels increase. The exponential, logistic, Weibull and linear-response and plateau functions are cumulative distribution functions. The specific form of the production function in damage control agents has a number of implications for production analysis. First, the production functions are generally nonlinear in parameters which complicates the estimation. Second, missing variables may have relatively severe effects. For instance, large variations in managerial skills may lead to spurious input-output correlations that are negatively sloped as shown in Figure 6 (p. 27). Third, a shift in the production function due to pest resistance to PPA, increased skills, etc., may imply shifts of the average and marginal productivity that are of opposite signs (cf. Chapter 4). Therefore, resistance build-up and other reductions of average PPA productivity do not necessarily imply reductions in marginal productivities and optimal PPA use levels (Lichtenberg and Zilberman, 1986). This implication is quite drastic given that other authors tried to quantify the effect of resistance by ex-
amination of marginal PPA productivities (e.g. Carlson, 1977; Clark and Carlson, 1990).

2.5 Literature

Econometric studies about PPA have clustered round four major themes. One is the marginal value product (MVP) of PPA. As the negative side effects of PPA use became more and more apparent, the belief that PPA were overused became more widespread, which led to a number of attempts to estimate marginal value products. A second major topic is the price elasticity of PPA demand. A third group of studies is concerned with the effect of PPA on production risk, usually defined as the variation of profits or income. Since most farmers are risk-averse (Young, 1979), risk may affect input allocation. A fourth group of studies deals with various technical peculiarities of PPA such as pest tolerance or resistance, PPA carry over effects between seasons, pest population dynamics, environmental and health effects, etc. Literature on the first three of these themes is reviewed in this section.

2.5.1 Marginal value product of PPA

Simultaneous-equation systems such as (1) are commonly established on the joint assumptions of profit maximization and perfect information, partly because data to identify anticipated profit maximization models is often not available. The estimation of marginal value products in the economic range is impossible with models based on those assumptions simply because the input demand functions are obtained by equating the MVP and the marginal factor cost. This may be a reason why models used to estimate the MVP of PPA are commonly production functions. As mentioned, production function models are underidentified when pest pressure and other exogenous variables affecting input allocation are missing.

CARRASCO-TAUBER and MOFFITT (1992) estimate production functions of various cumulative distribution specifications with a data set similar to the one used by HEADLEY (1968). They find significant differences between the respective marginal value products, in particular a factor of around 60 between the exponential and other specifications. The authors do not report any particular reason for this difference. CHAMBERS and LICHTENBERG (1994) point out that it might be due to a misspecification. The exponential abatement function of CARRASCO-TAUBER and MOFFITT contains a single parameter which might not be enough to provide sufficient flexibility. Moreover, the model gives \( q = 0 \) for \( x = 0 \) which is inconvenient because production in the absence of PPA is not necessarily zero. A more basic criticism is that important variables are missing and likely to cause simultaneous-equation bias.

BABCOCK et al (1992) estimate the output quantity and quality effects of PPA use in apples. They initially establish the model\(^6\)

\[
q = \alpha \Pi \beta_j g(x_1, x_2, x_3)
\]

with

\[
g(x_1, x_2, x_3) = [1 - \exp(\lambda_0 + \lambda_1 x_1 + \lambda_2 x_2)][1 - \exp(\lambda_3 + \lambda_4 x_3)].
\]

\(x_1, x_2\) and \(x_3\) are fungicides, canopy rating (pruning) and insecticides, respectively. The insecticide term is later eliminated due to severe nonlinear multicollinearity and because the authors assume that insecticides improve the quality rather than the quantity of the output. \(\lambda_0\) allows of positive yields in absence of pest control. The abatement function contains one effectiveness parameter for each type of PPA. As compared to the specification of CARRASCO-TAUBER and MOFFITT, an additional parameter, \(\lambda_0\), is introduced. This makes the function more flexible and suitable to measure marginal productivities. However, when there are (many) observations close to no pruning nor fungicide use, \(\lambda_0\) is related to potential damage rather than marginal productivity. Thus, the suitability of the production function depends on the data. The estimated values of \(\lambda_0, \lambda_1\) and \(\lambda_2\) are \(-9.45, -0.0699\)

\(^6\)The notations of the quoted studies are slightly adapted for reasons of consistency throughout this thesis.
and 2.37, respectively. Evaluated at no pruning \((x_2 = 5)\) and average fungicide use \((x_1 = 41)\) abatement is 0.37 which is a reasonable value (between 0 and 1). At no pruning and no fungicide use \((x_1 = 0)\) abatement is -10.02 which is far outside the expected range implying that \(\lambda_0\) cannot strictly be interpreted as potential damage. \(\lambda_0\) might reflect the "need for a degree of freedom" to fit the slope of the curve in the economic range rather than damage in absence of control.

In order to examine potential simultaneity of the relationships between PPA usage and output, Babcock et al (1992) estimate a fungicide demand equation with the result that "less than 5% of the variation in fungicide use levels was explained by prices, orchard characteristics, and human capital variables". This is the only study known to the author that tries to justify a production model on the grounds of empirical evidence for the insignificance of simultaneity between production and input allocation. However, the question persists regarding what actually causes the fungicide variance. Since insecticides and fungicides are found to be multicollinear and the authors claim that insecticides are used to improve quality, the assumption that factors which do not affect production are responsible for the input variance appears at least questionable. The authors also argue that fungi infestation levels in apples are unobservable before significant damage occurs so that growers spray fungicides preventively according to a predetermined schedule. That would make input allocation exogenous to the production of a given season or, more precisely, the indicators of production that are observable during the season.

Harper and Zilberman (1992) estimate a cotton production function with an exponential damage abatement term

\[
g = 1 - \exp(\lambda_0 + \sum \lambda_i x_i + \lambda_4 \delta), \quad i = 1,2,3.
\]

\(x_i\) are the masses of three different types of insecticide active ingredients. \(\delta\) is pest pressure measured as pest damage in untreated cotton plots. We understand that data on \(\delta\) stems from on-farm experiments. The estimated parameters \(\lambda_i\) are 0.78, 2.46 and 0.37 for chlordimeform, pyrethroids and organophosphates, respectively. Differentiation yields \(g_{\lambda_i} = -\lambda_i (1-g)\). \(\lambda_i/\lambda_j\) is thus the ratio between the marginal physical productivities of \(x_i\) and \(x_j\). The ratios (2.46/0.78; 2.46/0.37; 0.78/0.37) are considerable, illustrating
that physical productivities may vary widely across types of PPA (cf. Subsection 2.3.4). The marginal value products are not reported.

GOTSCHE et al (1993) and GOTSCHE and REGEV (1996) study participants in a Swiss wheat disease and pest warning system. Using a quadratic production function, they estimate the marginal revenue of fungicide applications at 275 Swiss francs / ha. The costs of machinery, fungicides, labor and wheeling losses are 200-1100 francs per sprayround. Thus, the revenue of the marginal franc invested in fungicide applications is between 1.25 and 2.38, calculated as \((275 + 1100) / 1100\) and \((275 + 200) / 200\), respectively. Since spray decision-making is based on a disease warning system, the omission of pest pressure is particularly grave.

ROLA and PINGALI (1993a) estimate insecticide productivity in rice in order to compare productivity benefits and health costs of PPA use. We discuss the deterministic parts of their production model (called "model I" by the authors) at this point before we turn back to the health aspects in later chapters. Unfortunately, the presentation of the model is ambiguous. The definition of the variables and the presentation of the results imply that fertilizer enters the estimation model in logs, while insecticides enter it as doses. At the same time, the authors claim to use a Cobb-Douglas function which would imply using logs of both fertilizer and insecticides. Let us assume the first is true. Abstracting from a season-dummy, the deterministic part of the production function is then

\[
q = \exp(\beta_0 + \beta_1 \ln z + \beta_2 x)
\]

where \(q\) is the yield, \(x\) is the insecticide dose per season and hectare, and \(z\) is the nitrogen level. The second derivative with respect to \(x\) is

\[
q_{xx} = \beta_2^2 \exp(\beta_0 + \beta_1 \ln z + \beta_2 x) = \beta_2^2 q > 0.
\]

The specification is thus convex for all values of \(x\), preventing its use in economic analysis. Now assume the authors actually use the Cobb-Douglas production function

\[
q = \exp(\beta_0 + \beta_1 \ln z + \beta_2 \ln x).
\]
\( \beta_2 \) is estimated to be 0.007. With this extremely low parameter, multiplication of insecticide use by 15—corresponding to a change from current practices to what the authors call "complete control"—increases yields by 2% only \((15^{0.007} - 1 = 0.019)\). An intercept shifter model for four different strategies ("model II" in the same study) indicates that relative yield differences between the average farmer's practice and "complete control" are 15% which is far removed from the former result.

Table 2 gives an overview of the quoted studies.

### Table 2: Econometrical estimates of marginal PPA productivity

<table>
<thead>
<tr>
<th>Source</th>
<th>Crop</th>
<th>Country</th>
<th>PPA</th>
<th>Production function</th>
<th>MVP *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headley (1968)</td>
<td>many</td>
<td>USA</td>
<td>all</td>
<td>Cobb-Douglas</td>
<td>3.90–5.66</td>
</tr>
<tr>
<td>Campbell (1976)</td>
<td>fruits</td>
<td>Canada</td>
<td>all</td>
<td>Cobb-Douglas</td>
<td>12.78</td>
</tr>
<tr>
<td>Carrasco-Tauber and Moffitt (1992)</td>
<td>many</td>
<td>USA</td>
<td>all</td>
<td>Cobb-Douglas</td>
<td>5.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Weibull</td>
<td>6.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>logistic</td>
<td>7.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>exponential</td>
<td>0.11</td>
</tr>
<tr>
<td>Babcock et al (1992)</td>
<td>apples</td>
<td>USA</td>
<td>fungicides</td>
<td>Cobb-Douglas and exponential quantity models</td>
<td></td>
</tr>
<tr>
<td></td>
<td>apples</td>
<td>USA</td>
<td>insecticides</td>
<td>quality model</td>
<td>0.16</td>
</tr>
<tr>
<td>Gotsch et al (1993)</td>
<td>wheat</td>
<td>Switzerland</td>
<td>fungicides</td>
<td>quadratic</td>
<td>1.25–2.38</td>
</tr>
<tr>
<td>Harper and Zilberman (1992)</td>
<td>cotton</td>
<td>California</td>
<td>insecticides</td>
<td>exponential</td>
<td>not reported</td>
</tr>
<tr>
<td>Rola and Pingali (1993a)</td>
<td>rice</td>
<td>Philippines</td>
<td>insecticides</td>
<td>Cobb-Douglas or increasing returns</td>
<td>unclear</td>
</tr>
</tbody>
</table>

Notes: * MVP reported in dollars of revenue per dollar of PPA. Most studies do not explain how they deal with the labor required for the application of PPA. \(^{a}\) The MVP estimated with a Cobb-Douglas specification is 10 times that obtained with an exponential specification.

Apparently, productivity estimates vary widely. Of course, the examples refer to different crops, regions and times. Therefore, some variation is natural. However, the range of estimates found is likely to reflect the problems of identification, missing variables and functional specification rather than regional or crop specific characteristics. Table 2 illustrates the inadequacy of
some historical econometrical approaches to the estimation of the marginal productivity of PPA.

2.5.2 Own-price elasticity of PPA demand

CHAMBERS and LICHTENBERG (1994) extend the framework of LICHTENBERG and ZILBERMAN (1986) to the multi-output case and discuss the duality of the technology when abatement has the form of a cumulative distribution function (cdf). For example, they estimate the demand elasticity of PPA with a profit maximization model applied to time-series data. Exponential and logistic abatement functions are used. Both functions have two parameters which the authors judge sufficient to avoid the problems found by CARRASCO-TAUBER and MOFFIT (1992). Reasonable negative own-price elasticities are estimated. The results contrast with other studies that obtained positively sloped pesticide demands (CHAMBERS and POPE, 1994) possibly due to the failure to account for the "unique role that abatement plays in the [Lichtenberg and Zilberman] biological production model" (CHAMBERS and LICHTENBERG, 1994).

ANTLE and PINGALI (1994 and 1995) estimate a system of a log-linear cost function and four cost-share functions for labor, fertilizer, insecticides, and herbicides. The studies refer to the same area as ROLA and PINGALI (1993a). Estimated own-price demand elasticities of herbicides and insecticides are between -0.9 and -1.0. The production function dual to the log-linear cost function does not have a cdf form in damage control inputs. However, the demand elasticity estimates cannot be rejected on the grounds of plausibility.

In that study, omitting pest pressure from the model is justified on the grounds that "IRRI [International Rice Research Institute] entomologists and economists find that these farmers do not utilize integrated pest management strategies or other sequential decision rules that would cause pesticide applications to be endogenous to output" (ANTLE and PINGALI, 1994 and 1995). This is surprising given that ROLA and PINGALI (1993a) write that "farmers consider the presence of pests, the degree of pest infestation (as they perceive it), [...] when they time pesticide applications. A survey by the Social Sciences Department of the [IRRI] showed that most farmers (58 percent) spray when pest infestation is heavy. But a large minority (42 percent) spray whenever pests are present, irrespective of pest density". This implies that pest pressure and presence is not constant and that farmers take pest pressure or presence into account at spraying. If this is true, the cost-function
model of Antle and Pingali and the production models in Rola and Pingali suffer simultaneous-equation bias due to omission of variables. Conflicting evidence is given in two studies on the same region and crop, illustrating the uncertainty about the sources of input variance.

### 2.5.3 PPA and risk

PPA may have positive or negative effects on the variation of revenue or profits from agricultural production, i.e., risk. Although production risk is not addressed in any of our case studies, a short review is justified on the following grounds. Firstly, risk is widely believed to be a determinant of PPA use (Horowitz and Lichtenberg, 1994). Developing country farmers tend to be more risk averse than their colleagues in developed countries. Secondly, risk is the reason why "many commonly held beliefs about policy effects are not supported unambiguously by economic theory. A tax on pesticides will not necessarily reduce pesticide use or average output, for example. A reduction in price of agricultural output will not necessarily lead to a reduction in use of water or agricultural chemicals" (Leathers and Quiggin, 1991).

Ellis (1988) gives the following history of the notions "risk" and "uncertainty" in economic literature. The traditional notion of risk was restricted to situations where probabilities can be attached to the occurrence of events that influence the outcome of a decision-making process. Uncertainty, by contrast, was used to denote situations where the likelihood of the occurrence of events is neither known by the decision-maker nor anyone else. This distinction has been superseded in economic literature. It is pointed out that in most decision situations the crucial factor is the decision-maker's personal degree of belief about the occurrence of events. This changes the analysis of risk and uncertainty from an objective to a subjective matter, with the following changes in the definitions of risk and uncertainty: Risk refers to subjective probabilities attached by farm decision-makers to the likelihood of occurrence of different events. Uncertainty does not refer to probabilities or their absence at all. It merely describes the character of the economic environment, an environment which will contain a wide variety of uncertain events.

For a formalization of risk consider the production function \( q = f(x, \varepsilon) \) where \( \varepsilon \) is a random variable (state of nature). \( \varepsilon \) is thought to be an index for random variables affecting production and is defined in such a way that large
values represent favorable conditions for production. In general, the input is expected to raise production in all states of nature, $f_x(x,\varepsilon) > 0$, although there may be inputs whose marginal product is zero or negative for some values of $\varepsilon$ (Horowitz and Lichtenberg, 1994). When an input raises production more in bad states of nature than in good states, $f_x(x,\varepsilon) < 0$ and the input $x$ is said to be risk reducing (Quiggin, 1991). Such an input "cushions the fall in yield" induced by adverse conditions (Leathers and Quiggin, 1991).

A risk-reducing input can be characterized in three ways (Quiggin, 1991): (a) A risk-averse producer would use more of it than a risk-neutral one, (b) the input causes a monotone spread in the distribution of output, and (c) a producer with output insurance would use less of the input. The risk effect of PPA may have either sign, depending on the sources of uncertainty, as illustrated by the following examples.

- Assume the most important source of uncertainty is random pest infestation. In absence of pest control, yields vary according to the damage caused by this random factor. When pest control is practiced, some portion of the damage is abated. When abatement is correlated positively with potential damage—which is the usual and reasonable assumption—the variation of yields is reduced.

- Now let the uncertainty reside in PPA effectiveness. Potential damage shall be relatively certain. This may be realistic in some situations because the effectiveness of PPA depends on a number of environmental and technical factors that may vary while potential damage might be relatively stable in a homogenous agronomic region. In absence of pest control, yields show relatively low variation. When an attempt to control pests is made, the variation of yields is increased due to the variation in PPA effectiveness.

- In the Mexican project area, the relative contributions to risk of different weed control techniques seem to be important. An (admittedly superficial) appreciation of weed pressure suggests a low variation in this variable. Uncertainty refers to rainfall during the canícula (dog-days). Herbicides are applied in preemergence and/or postemergence of the crop. For simplicity, assume that the cost of achieving a given level of weed control is the same with both types of herbicides and that each farmer chooses only one type. Preemergence herbicides are applied at sowing, i.e. well in advance of the canícula, implying that profits are those derived from a high
or low yield depending on the rainfall, minus herbicide costs. Some postemergence applications, by contrast, are made during or after the canícula. When water is scarce, weed growth is slowed down and some postemergence applications can be saved. Hence, with postemergence herbicides, yields vary between a high yield minus full herbicide costs and a low yield minus reduced herbicide costs. Therefore, postemergence herbicides reduce risk as compared to preemergence herbicides.

In their theoretical treatise, HOROWITZ and LICHTENBERG (1994) find that PPA are likely to reduce risks when uncertainty relates to pest damage only. Such situations may be found in irrigated, arid areas where "water availability is controlled by the grower, and factors such as solar radiation and diurnal temperature patterns typically do not fluctuate much during much of the growing season" (HOROWITZ and LICHTENBERG, 1994). The same authors quote the above-mentioned study by BABCOCK et al (1992) as an empirical example for uncertainty that is predominantly related to crop growth conditions. In that study, insecticides are found to affect quality only, and this effect is assumed proportional to total output. Thus, improved growth conditions increase insecticide productivity and risk. Outcomes are indeterminate in mixed situations of uncertainty about both growth conditions and pest damage. PANELL (1991) points out that "it is important to consider more sources of risk than the ones most commonly considered: uncertainty about pest density and pest mortality".

PINGALI and CARLSON (1985) estimate a system of five simultaneous equations with two-stages-least-squares. They avoid the dilemma of either making crucial assumptions regarding the demand functions that impede the estimation of marginal value products or neglecting input allocation completely. Instead, they explain discrepancies between input allocation and utility maximization by means of the farmer's subjective appreciation of pest damage probabilities. The accuracy of these estimates is thought to be a function of human capital. Anticipated values that affect input decisions were elicited directly from farmers. They include subjective estimates of the mean and variance of fruit damage due to insects, diseases and weather. Comparison with distribution parameters obtained by researchers shows that farmers tend to overestimate average insect and disease damage. A regression model for the differences between subjective and objective distribution parameters indicates that formal schooling, age, scouting time, and an extension scheme called "apple school" reduce the error made in anticipating pest damage.
The absolute errors in the subjective probabilities of insect and disease damage have positive effects on the demands for insecticides and fungicides, respectively. The perception error in disease damage reduces the demand for pruning, a mechanical disease control technique. Similarly, the variance of insect and disease damage increases the respective PPA demands and reduces the demand for pruning.

The positive effect of human capital on the accuracy of subjective damage estimates and the negative effect of the latter on PPA demand, signify that investments in human capital may reduce PPA demand. In addition, human capital may have a direct production effect through "increased technical abilities in the production of a pest-free environment" (PINGALI and CARLSON) which affects the marginal productivity and, hence, the input demand. The authors find a negative net effect of human capital on PPA demand.

PINGALI and CARLSON also report some evidence that fungicides tend to be applied preventively, while observed infestation plays a role in insecticide application decisions. The reason might be that disease infestation is more difficult to observe than insect pest infestation (BABCOCK et al, 1992). Conversely, farmers are found to estimate disease damage more accurately than insect pest damage.

GOTSCH et al (1993) and GOTSCH and REGEV (1996) find that both fungicides and nitrogen increase risk defined as yield variance. Surprisingly, they also find that risk increases fungicide use and that usage levels of both inputs correlate positively with risk-aversion. This would signify that the inputs are risk-reducing after characteristic (a) of QUIGGIN (1991).

HOROWITZ and LICHTENBERG (1993) examine PPA and nitrogen usage practices of farmers with and without crop insurance. Under the hypothesis that these inputs reduce production risk, they are substitutes for insurance and therefore farmers with insurance would be expected to use less of them. However, results indicate that insured farmers use more nitrogen, insecticides, and herbicides, suggesting that these inputs are risk-increasing.

The studies quoted underline the importance of risk for PPA allocation. However, due to the many difficulties in establishing reasonable econometric crop protection models, the possibilities of including risk in models that are not specifically built to examine risk remain limited. Moreover, it is most difficult to include more than one stochastic variable in a model. Since the
sources of uncertainty may be numerous, accounting for stochasticity of a single variable does not necessarily improve the model.

2.6 Conclusions

We have discussed critical features of the econometrics of PPA. The inherent simultaneity of production and input allocation pose an identification problem, namely when data on prices, initial pest pressure and managerial skills is lacking. Aggregation of PPA variables is inevitable although sometimes questionable because separability cannot be ensured. The specification of pest control functions has drawn considerable attention in the past decade but as yet there is little empirical evidence on the suitability of different forms. Specifications of the form of cumulative distribution functions appear biologically and technically more appropriate than traditional specifications. They also imply certain peculiarities with respect to the effects of missing variables and the relationship between average and marginal productivities of the damage control agents. The following conclusions are offered.

- Common production data sets hardly ever allow the identification of full sized production models. Data should thus be collected specifically for that purpose and include information about pest pressure or potential damage and the managerial skills of the farmer.

- Non-linear restrictions on the production function may prove useful to obtain identified models.

- The assumption of profit maximization is operative for production analysis in that it allows to model behavior. However, it also impedes the estimation of marginal value products in the economic range when data on anticipated pest damage or yields (as compared with actual pest damage and yields) is not available.

- On-farm research data may improve the estimation prospects because some variables are controlled. This facilitates the formulation of identified models as underlined by the fact that in the studies reviewed, pest pressure information is either absent or stems from on-farm research like data sources.
3 Case Study: Effectiveness of different PPA use strategies

The effectiveness of PPA depends on the timing of applications with respect to pest population development. Timing may be preventive, i.e., with no or little consideration of the actual pest infestation levels or responsive, i.e., based on observation of pest populations or infestation symptoms. Preventive spraying is likely to favor adverse side-effects of PPA (such as pest resistance, pest resurgence and secondary outbreaks) more than responsive spraying which, on the other hand, requires labor for monitoring pest infestations. The productivities of these two strategies are estimated for cotton in Coimbatore district, Tamil Nadu, India. The estimation model is a transformation of a simultaneous-equation model consisting of a production function and input allocation equations. Chemical plant protection is profitable with both strategies. Responsive spraying leads to a 36% reduction in insecticide expenditure to achieve a given level of control. Pest monitoring is justified, namely because the responsive strategy examined does not require sophisticated scouting techniques. The effectiveness of hired spray labor is estimated and not found significantly different from that of family spray labor. It is also shown that the inclusion of variables that affect pest pressure leads to higher estimates of average PPA productivity, suggesting that disregarding pest pressure leads to underestimation of PPA productivity.
3.1 Introduction

As an application of the considerations brought forward in Chapter 2 we estimate the PPA productivity in cotton in the Indian project area with an input demand model derived from a cumulative distribution type of production function and the assumption of profit maximization. Information about pest control decisions and employment of spray labor is used to infer on productivity differences between PPA use strategies and between hired and family spray labor.

Information about pest infestation levels is essential for the effective use of PPA. The farmer may gather such information with formal, predetermined scouting schemes or informal observations. Monitoring and observing pest populations is expected to increase the productivity of PPA as compared to preventive fixed schedule spraying. Observation entails a labor cost which is seen as a major reason why farmers in developing countries have not readily adopted integrated pest management (IPM) practices in many cases where they were promoted (GOODELL, 1984). A further reason for low IPM adoption may be the complexity of the decision-making process involved (ZILBERMAN and CASTILLO, 1994). Abstracting from such psychological factors, monitoring costs are justified if they are smaller than the PPA application cost savings over fixed schedule spraying. The value saved depends on the actual pest population. Figure 8 illustrates the concept.
Figure 8: Costs and benefits of responsive and preventive PPA use

\[ R = M + PPA_R \]
\[ P = PPA_P \]

Include a monitoring cost \( M \) and pesticide and application costs \( PPA_R \). The spraying frequency increases with pest pressure and therefore \( PPA_R \) is sloped upwards. The costs of preventive spraying \( P \), by contrast, consist of pesticide and application costs \( PPA_P \) only, and are constant over pest pressure. For simplicity, damage abatement is assumed complete with both strategies. Hence, the net costs are \( D \), \( R \), and \( P \) for "doing nothing", responsive spraying and preventive spraying, respectively. The least cost solution (bold line) is "doing nothing" while the potential damage \( d \) does not exceed the threshold level \( d_1 \), responsive spraying between \( d_1 \) and \( d_2 \), and preventive spraying above \( d_2 \).

In reality, damage abatement at a given pest pressure varies across strategies for several reasons. Besides providing a base for the decision whether to spray or not, monitoring allows to fine-tune the application. Therefore, a single sprayround is likely to be more effective with the responsive than with the preventive strategy. Moreover, continued use of PPA may decrease PPA efficacy due to selection of PPA-tolerant pests or destruction of natural control mechanisms. These effects are believed stronger with preventive than with responsive spraying. On the other hand, observation-based spraying involves the risk of overlooking manifestations of pest populations. It should
also be recognized that observation-based spraying does not necessarily reduce PPA use in all cases. To summarize, the relative advantages in terms of productivity of the two strategies depend on

- the expected distribution parameters of potential damage;
- the relative costs of labor for spraying, labor for monitoring, and PPA;
- the farmer's relative skills in monitoring pests and applying PPA;
- the susceptibility of natural and other non-chemical control mechanisms to PPA use and the potential for pest tolerance to PPA.

3.2 Pest control in cotton in Tamil Nadu

Cotton is widely grown in the Indian project area. It is a relatively risky crop within the polycrop pattern in South India. Success depends on uncertain events such as the availability of water and pest pressure. Virtually the whole cotton area is irrigated with well and/or channel water. However, water availability depends on erratic rainfalls to fill up wells and reservoirs and is not ensured. The area irrigated with water from existing public reservoirs has been expanded recently, increasing the uncertainty about water availability. Insect pests represent further risks. To farmers, cotton and vegetables are "gambler crops", while coconut and others are the "insurance".

Farmers use the words "kaipuru" (worms) and "peen" (sucking pests) for the insect pests found in cotton, corresponding approximately to the entomological classification into chewing and sucking pests. Important sucking pests are aphids, jassids, thrips and—to a lesser extent, as vector of virus diseases—whitefly (ALL INDIA COORDINATED COTTON IMPROVEMENT PROJECT, 1989). The major "kaipuru" is the American bollworm (Helicoverpa (= Heliothis) armigera Hübner) since the late 80s. The polycrop pattern in South India suits the polyphagous nature of H. armigera (PASUPATHY and REGUPATHY, 1994). H. armigera is a migrant pest (DENT,

7In addition to these factors, scheduling rigidities such as those created by re-entry regulations may affect the choice between preventive and responsive spraying as pointed out by LICHTENBERG et al (1993).
1991); it has been observed, for example, that the moths spend the daytime in groundnuts and migrate to cotton only for oviposition during the night (JOYCE, 1985). The pink bollworm (*Pectinophora gossypiella*) is a late season pest of minor and more sporadic importance.

Field sanitation after harvest, multicropping and chemical control are the most important insect control methods (ICAR, 1989). Occasionally, larvae in the 4th to 6th stage are controlled by manual picking. PPA are broadly classified into products to control sucking pests and products to control chewing pests*. The active ingredients used in the area are listed in Table 3, together with the recommendations of use.

<table>
<thead>
<tr>
<th>Active ingredient</th>
<th>General recommendation</th>
<th>Specific recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cypermethrin</td>
<td>bollworm</td>
<td>different formulations for early &amp; late instars</td>
</tr>
<tr>
<td>Deltamethrin</td>
<td>bollworm</td>
<td>late instars</td>
</tr>
<tr>
<td>Demeton-S-methyl</td>
<td>sucking pests</td>
<td>aphids</td>
</tr>
<tr>
<td>Dichlorvos</td>
<td>bollworm</td>
<td>late instars, in mixtures with other ai</td>
</tr>
<tr>
<td>Dimethoate</td>
<td>sucking pests</td>
<td>aphids</td>
</tr>
<tr>
<td>Endosulfan</td>
<td>bollworm</td>
<td>early instars</td>
</tr>
<tr>
<td>Fenvalerate</td>
<td>bollworm</td>
<td></td>
</tr>
<tr>
<td>Monocrotophos</td>
<td>sucking pests</td>
<td></td>
</tr>
<tr>
<td>Quinalphos</td>
<td>aphids, bollworm</td>
<td>early bollworm instars</td>
</tr>
</tbody>
</table>


The farmers' typical approach to insect pest control is as follows (RAJA PANDIAN, 1995). The first two sprayrounds are directed against sucking pests, undertaken at 20 to 25 and 30 to 35 days after planting with active ingredients such as dimethoate and demeton-S-methyl. At that stage, some farmers are thought to spray independently of pest populations. The coverage of sucking pests with the spray is generally poor due to the location of these pests on the lower side of the leaves. At 40 to 45 days after sowing, organophosphates and organochlorines such as monocrotophos, quinalphos

*Recently, products became available to control bollworm at the egg stage. These products were of no or negligible importance in the year of data collection.*
or endosulfan are sprayed against *H. armigera*. However, monocrotophos is not suitable for that purpose and the quality of the spray work is sometimes inadequate. At 50 to 55 and 60 to 65 days, two more sprayrounds with pyrethroids such as cypermethrin or fenvalerate are directed against *H. armigera*. At that time, sucking pests resurge, or, in the farmers' words, "pyrethroids grow peen". Farmers who had no success in controlling the pests start to use PPA less systematically. Spraying continues at intervals of 5 to 10 days. Pyrethroids are predominantly used when sucking pest populations are large. This PPA use pattern is quite typical for much of the Old World cotton production (cf. BRADER et al, 1985; RÉPUBLIQUE FRANÇAISE, 1984). Insect pest control accounts for around 25% of the production costs (20% PPA costs, 5% application costs) according to data from a demonstration plot scheme implemented as a part of the project.

ICAR (1989) point out that IPM could significantly reduce insecticide use on cotton in the light of experiences gained in "IPM-villages" in Coimbatore district. Average insecticide costs were reduced from 1806 to 896 Rs / ha, the average number of sprayrounds from 10.71 to 6.37. Average yields decreased slightly from 2214 to 2135 kg / ha. The labor costs of "scouting" or pest monitoring are not reported.

Pasupathy and Regupathy (1994) report the status of American bollworm resistance to cypermethrin, fenvalerate, endosulfan, and quinalphos in 1992-93 in the project area. They found considerable levels of resistance to cypermethrin, fenvalerate and quinalphos. In the winter, high multiplication of *H. armigera* and intensive insecticide use in cotton coincide and cause a high selection pressure and peak resistance levels. Resistance carries over to subsequent seasons due to continuous cropping of hosts (ICAR, 1989).

Weeds are almost entirely controlled by physical means, i.e. by ploughing, bund forming and hand weeding. Weed control accounts for 8 to 10% of production costs, according to data from the above-mentioned scheme.

---

9Resistance levels were measured as survival of larvae of 30-40 mg to diagnostic doses of 1.0, 0.2, 0.75 and 10 mg of active ingredient per larvae of cypermethrin, fenvalerate, quinalphos and endosulfan, respectively. In larvae from Udumalpet, the central village of the project area, survival rates were 80, 100 and 40 percent for cypermethrin, fenvalerate and endosulfan, respectively.
3.3 Data

3.3.1 Survey

Cotton yields, plant protection strategies and use of inputs such as fertilizer, PPA and partly labor were surveyed among 215 farmers. The data refers to the winter season 1994 / 95. In order to assess yields, the survey was performed after harvest, in spring 1995, several months after the earliest applications of PPA. This time-lag and the large numbers of sprayrounds were anticipated to reduce the respondents' recall capacities and complicate the elicitation of agronomic details. Moreover, health data were collected in the same survey, limiting the number of questions that could be dedicated to PPA use without unduly inflating the questionnaire. (Data of the same survey is used in Chapters 8 and 9.)

To achieve the required simplicity, we asked for the quantities, prices and values of each brand used. Details about individual sprayrounds such as doses and timing were not elicited. This procedure was judged advantageous for the following reasons. (a) The number of questions could be reduced. (b) The dose per application may be a question of habits, for which farmers may not be able to report it in a way that allows subsequent translation into kg active ingredient or formulation per hectare. Moreover, farmers are likely to remember expenses better than doses in physical units because the former "hurt". (c) Elicitation of the dosages of each application would be complicated by the fact that some brands are formulated as powders, others as liquids and that some farmers spray "cocktails", i.e. mixtures of several brands.

3.3.2 Yields and input use

Average yields are around 630 kg / acre (Table 4). Cotton prices vary by quality. 24 and 12 Rs / kg were paid on average for qualities I and II, respectively. The average share of quality II in the total yield is around 10-15%. The weighted average of the prices for the two qualities is 22.5 Rs / kg. Gross benefits are thus approximately 14,000 Rs / acre. The produce is paid by the cotton mill at the farm gate. Transport costs beyond the farm are borne by the mill. Farmers who lack cash towards the end of the cotton season sell to brokers. The value of total PPA use is around 1300 Rs / acre with a very large standard deviation.
Table 4: Sample statistics

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yields [kg / acre]</td>
<td>632</td>
<td>312</td>
</tr>
<tr>
<td>PPA use [Rs / acre]</td>
<td>1296</td>
<td>1148</td>
</tr>
<tr>
<td>Number of spray rounds</td>
<td>8.33</td>
<td>4.23</td>
</tr>
<tr>
<td>Fertilizer [Rs / acre]</td>
<td>1327</td>
<td>1201</td>
</tr>
<tr>
<td>Irrigation [% of cotton fields]</td>
<td>71%</td>
<td></td>
</tr>
</tbody>
</table>

3.3.3 Decision bases for insecticide spraying

Table 5 summarizes the answers to a question about the decision bases for PPA use.

Table 5: Bases for decision whether and when to spray PPA

<table>
<thead>
<tr>
<th>Category</th>
<th>Respondents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection of crop</td>
<td>76</td>
<td>40.0%</td>
</tr>
<tr>
<td>When pest is present</td>
<td>82</td>
<td>43.2%</td>
</tr>
<tr>
<td>When pest is sufficiently frequent</td>
<td>11</td>
<td>5.8%</td>
</tr>
<tr>
<td>Own experience</td>
<td>75</td>
<td>39.5%</td>
</tr>
<tr>
<td>Advice from extension service</td>
<td>24</td>
<td>12.6%</td>
</tr>
<tr>
<td>Advice from Ciba Foundation(^{10})</td>
<td>11</td>
<td>5.8%</td>
</tr>
<tr>
<td>Advice from family member</td>
<td>6</td>
<td>3.2%</td>
</tr>
<tr>
<td>When neighbor, family member, etc., sprays</td>
<td>6</td>
<td>3.2%</td>
</tr>
<tr>
<td>According to a fixed schedule</td>
<td>73</td>
<td>38.4%</td>
</tr>
<tr>
<td>Scouting and threshold levels</td>
<td>14</td>
<td>7.4%</td>
</tr>
<tr>
<td>Scouting, but no threshold levels</td>
<td>11</td>
<td>5.8%</td>
</tr>
<tr>
<td>Counting pest population</td>
<td>14</td>
<td>7.4%</td>
</tr>
</tbody>
</table>

Base: 190 farmers. Multiple answers were possible.

For the analysis, we discriminate between farmers reporting to spray according to fixed schedules (38.4%) and the remainder of farmers. Average insecticide costs are 1415 and 1219 Rs / acre with "fixed schedule spraying" and

\(^{10}\)Ciba Foundation has been active in a part of the study area corresponding to about half of the observations.
other strategies, respectively. The overall average is 1296 Rs / acre. The distributions of insecticide use levels and sprayrounds over farmers adhering to the two strategies (or groups of strategies) are reproduced in Figure 9.

Figure 9: PPA use with different strategies

Insecticide usage levels and the number of sprayrounds vary widely in both groups. Unexpectedly, the standard deviation of PPA usage is larger among "fixed schedule sprayers" than among "responsive sprayers" (1251 as com-
pared to 1065 Rs / acre) due to a considerable proportion of farmers with use levels above 3000 Rs / acre in the former group. The most plausible explanation for the unexpectedly large variance is that "fixed schedule spraying" refers to the initial intention of the respondent rather than actual practices that may be adapted during the season. Farmers who start the season with calendarized spraying are more likely to face problems of pest resistance or resurgence. When this occurs farmers may be tempted to spray quite unsystematically. This would explain the observations of high insecticide use.

Apparently, what farmers report as "fixed schedule spraying" does not refer to a single, calendarized scheme with fixed doses of fixed brands, but to a collection of strategies that are—at least initially—not or only minimally observation-based. The strategy variable can thus not be interpreted strictly as calendarized spraying. It rather codes for the farmers' initial control strategy choice. This choice may have an important impact on the pest population dynamics, for which we expect a considerable difference in PPA effectiveness between the two strategies.

3.3.4 Spray labor

It is apparent from Table 5 that the practices summarized as "other strategies" and contrasted with "fixed schedule spraying" do not necessarily cause explicit monitoring costs. Only 7.4% of the farmers report that they scout and spray according to threshold levels; another 5.8% scout but do not consider predetermined threshold levels. It must be assumed that the remainder of farmers who spray according to pest infestation merely casually inspect the crop. This makes it quite impossible to arrive at a reliable cost estimate for observing pests. An upper limit of the labor required for observing pests is the time needed to scout systematically and regularly. That is around 2 hours every 5 days over a period of around 70 days. A very rough estimate of formal scouting costs is Rs 350, based on an 8 hour working day and a shadow wage rate of Rs 100 / day for the farm manager. The labor needed for a casual observation of pest presence is certainly small compared to that for systematic scouting. It can be safely assumed below Rs 350 / farm.

Information about the costs of spray labor is somewhat contradictory. The average fee per tank for contract spraymen is around 11 Rs according to the survey, around 6 Rs according to the project field staff. These fees include the costs of the sprayer and the gasoline, which are provided by the contrac-
tor. (Motorized backpack mistblowers are used throughout.) With four tanks per acre, costs are 24-45 Rs, equivalent to 15-29% of the PPA value of Rs 155 per acre and sprayround. This amount contrasts with the costs incurred when spraying is carried out by (day) laborers who are paid approximately 35 Rs / day. Survey data indicates that laborers spray an average of 3.5 acres per day. Hence, the cost per acre and sprayround would come to around 10 Rs. This cost does not include equipment and the cost of employing laborers in times of low work load. Further information comes from the above-mentioned demonstration plot scheme. It indicates that labor costs, including family labor, were around 25 to 30% of the PPA value, corresponding to 40 Rs / acre. As a compromise we use a labor cost of 20% of the PPA value in the subsequent calculations.

Third party spray labor might detract from the effectiveness of PPA applications. Spraymen have less incentives than farmers to meticulously ensure a high quality application. The remuneration of contractors on a per tank load basis favors too high dilution of the PPA and therefore runoff of the watery spray from the cotton plant. The dose of active ingredient sprayed per hectare is not necessarily affected because the farmer provides the PPA used to spray a given area and so controls the rate.

3.4 Model

We first establish a simple model that accounts for the two strategies. Extension to labor is straightforward and is done directly in the estimation model derived towards the end of this section. As argued above, farmers using either of the strategies take the presence of pests into account when deciding whether to spray. Inputs are endogenous, therefore a simultaneous-equation model applies. The strategy is assumed to be a function of human capital, which is exogenous to the production of a single season. Therefore, we treat the strategy as exogenous.

The LICHTENBERG and ZILBERMAN (1986) production model \( q = f(z, g(x)) \) is used with an exponential abatement term

\[
g(x) = (1 - \delta \exp(-\lambda x))^\gamma.
\]
$x$ are insecticides, aggregated by value. $z$ is a vector of standard inputs and $q$ is the cotton yield. Input and output variables are specified as quantities per acre. $\delta$ allows for positive yields in absence of pest control. Proportional changes in the effectiveness parameter $\lambda$ are easy to interpret as the inverse of the corresponding proportional changes in $x$ required to achieve a given abatement.

To account for the strategy $\tau$, we specify the effectiveness parameter $\lambda$ as a function of $\tau$, $\lambda = \lambda_0 \lambda_1^{\tau}$. $\tau$ takes value 1 for fixed schedule spraying and value 0 for the other procedures. $\lambda_0$ is the effectiveness parameter of observation-based spraying and $\lambda_1$ gives the ratio of PPA quantities needed to achieve a given level of control with the two strategies. Since the form of the production function depends on $\gamma$ as well as on $\lambda$, one might consider specifying $\gamma$ as a function of $\tau$. When both $\gamma$ and $\lambda$ depend on $\tau$, the equation $g(x, \tau \mid \tau = 0) = g(x, \tau \mid \tau = 1)$ has a positive finite solution in $x$, implying that the two strategies are equally effective at some level of PPA. That seems unreasonable, and therefore we let $\gamma$ be a parameter. The production model is then

\[ q = h(\alpha, z)[1 - \delta \exp(-\lambda_0 \lambda_1^{\tau})]. \]

$h(\alpha, z)$ is potential output in function of $z$ and non-choice variables $\alpha$ representing growth conditions.

Since $\tau$ is assumed exogenous, profits are $\Pi = pq - s'z - wx$, where $p$, $s$ and $w$ are the output and inputs prices. $x$ is the value of insecticides. Hence, $w$ is the sum of marginal capital, labor, PPA acquisition and transaction costs involved in insecticide use per unit of $x$. The first order conditions for profit maximization are the demand equations $pq_x = w$ and $pq_z = s$. The following simultaneous-equation system is obtained with the semi-specification (8):

\[ q = h(\alpha, z)[1 - \delta \exp(-\lambda_0 \lambda_1^{\tau})]. \]

\[ w = h(\alpha, z)[1 - \delta \exp(-\lambda_0 \lambda_1^{\tau})] \frac{pq \lambda_0 \lambda_1^{\tau} \delta}{\exp(\lambda_0 \lambda_1^{\tau}) - \delta} \]

\[ s = pq_z \]
The model formally fulfills the order condition of identification. It is complete in the sense of containing one equation for each of the endogenous variables and each of the equations is identified due to the prices. However, the data does not contain variances in prices. Therefore, $w$ and $s$ have to be treated as parameters which causes underidentification. Estimation of the simultaneous-equation model would not yield reliable estimates. However, since we are predominantly interested in the effectiveness parameters $\lambda_0$ and $\lambda_1$, a single-equation model obtained by transformation of (9) might be sufficient. The simplest transformation is the production function itself. If we could ensure that $x$, $z$, $\delta$, and $\alpha$ captured all productive effects of inputs and environmental factors, orthogonality of the error terms of the technical and behavioral equations could be assumed. However, this is impossible because of missing data on pest pressure, soil types, etc. Hence, the production function is not identified because we cannot assume that the unexplained variance in $x$ and $z$ is due to factors that do not affect production.

A more promising transformation is obtained by substitution of $q$ in the first demand equation and subsequent solving for $x$. The following model results.

\[(10) \quad x = \frac{1}{\lambda_0 \lambda_1^r} \left[ \ln \left( q \frac{\beta' \lambda_0 \lambda_1^r}{w} + 1 \right) + \ln \delta \right] + u \]

$h(\alpha, z)$ has been eliminated. (10) is thus independent of any multiplicative contributions to yields. It is evident from the large variance of yields that $h(\alpha, z)$ varies widely (cf. Table 4). Hence, variables absent from (10) can be assumed to show a large variance and to identify the transformed model.

(10) may look unfamiliar because $x$ is expressed as a function of $q$. Nevertheless, we find (10) defensible on the following grounds:

- The transformed model accounts for productive and allocative relationships and therefore rules out the major source of simultaneous-equation bias in production function models. Potential yield $h(\alpha, z)$ is absent from the model, contributing to identification.

- Farmers make some error in allocating inputs. This error is captured in $u$ and thus does not affect the model estimate (much) as long as it is symmetrically distributed around 0. Moreover, farmers might make a sys-
tematic error such as over- or underestimating the marginal productivity of \( x \). Such errors are equivalent to under- or overestimating the cost of PPA. Since \( pl/w \) always appears together with \( \gamma \), the estimate \( \hat{\gamma} \) would be affected but not \( \hat{\lambda}_0 \).

The presence of \( \delta \) in the model causes estimation problems. Since \( 1 \) might be small as compared to \( q\rho\gamma_0\lambda_{\lambda}^i/w \), \( \ln(p\gamma/w) \) almost acts as an additive term within the square brackets and complicates the estimation of \( \delta \). In fact, we did not succeed with nonlinear estimation of (10) and used a first order linear approximation to the sum in the log. According to \( \ln(a + b) \approx \ln a + b/a \), (10) is approximated by

\[
(11) \quad x = \frac{1}{\lambda_0\lambda_1^r} \left[ \ln \left( \frac{q\rho\gamma_0\lambda_{\lambda}^i}{w} \right) + \frac{w}{q\rho\gamma_0\lambda_{\lambda}^i} + \ln \delta \right] + u
\]

which was estimated in the form (Model I)

\[
x = \frac{1}{\lambda_0\lambda_1^r} \left[ \ln \beta_1 + \ln q + \ln \lambda_0 + \tau \ln \lambda_1 + 1/(\beta_1 q\rho\lambda_0\lambda_{\lambda}^i) + \beta_2 \right] + u,
\]

where \( \beta_1 = p\gamma/w \) and \( \beta_2 = \ln \delta \). Nonlinear estimation techniques were used (iterative minimization of the sum of the squared residuals).

A second model (Model II) was estimated with \( \delta \) specified as a function of exogenous variables thought to affect the pest environment such as irrigation \( z_1 \) and a dummy \( z_4 \) that distinguishes between two areas: \( \ln \delta = \ln \delta_0 + \Sigma \delta_i z_i, i = 1,4 \). Model III includes further variables that might affect pest pressure but are not truly exogenous, i.e. fertilization \( z_2 \) and thinning of the crop \( z_3 \). Model IV was specified to infer on the relative effectiveness of hired spray labor and family labor. The dummy \( v \) codes 1 for respondents who hire all spray labor and 0 for those who do otherwise. The dummy \( \pi \) codes 1 for farmers who do not hire spray labor at all. In Model IV, the abatement term is specified as

\[
g = [1 - \delta(z_1, z_4)\exp(-\lambda_0\lambda_{\lambda}^i\lambda_{\lambda}^i\lambda_{\lambda}^i x)]\gamma.
\]
3.5 Results

Table 6 reproduces the variable means in the full sample and for the two strategies.

Table 6: Sample statistics

<table>
<thead>
<tr>
<th>Var.</th>
<th>Description</th>
<th>Full sample</th>
<th>$\tau = 0$</th>
<th>$\tau = 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>PPA expenses [1000 Rs / acre]</td>
<td>1.296 (1.15)</td>
<td>1.219 (1.07)</td>
<td>1.415 (1.26)</td>
</tr>
<tr>
<td>$q$</td>
<td>Cotton yield [100 kg / acre]</td>
<td>6.326 (3.12)</td>
<td>6.394 (3.18)</td>
<td>6.219 (3.05)</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Dummy for fixed schedule sprayers</td>
<td>0.389</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>$\upsilon$</td>
<td>Dummy for hired spray labor only</td>
<td>0.037</td>
<td>0.034</td>
<td>0.041</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Dummy for family spray labor only</td>
<td>0.337</td>
<td>0.353</td>
<td>0.311</td>
</tr>
<tr>
<td>$z_1$</td>
<td>Dummy for irrigation</td>
<td>0.713</td>
<td>0.691</td>
<td>0.747</td>
</tr>
<tr>
<td>$z_2$</td>
<td>Fertilizer use [1000 Rs / acre]</td>
<td>1.327 (1.20)</td>
<td>1.346 (1.27)</td>
<td>1.297 (1.09)</td>
</tr>
<tr>
<td>$z_3$</td>
<td>Dummy for thinning</td>
<td>0.505</td>
<td>0.491</td>
<td>0.527</td>
</tr>
<tr>
<td>$z_4$</td>
<td>Dummy for area</td>
<td>0.479</td>
<td>0.414</td>
<td>0.581</td>
</tr>
</tbody>
</table>

Note: N = 190. Figures are sample means and conditional sample means. Figures in parenthesis are standard deviations, reported for continuous variables only.

Table 7 reproduces the estimation results. Note that the price ratio $p/w$ cannot be estimated separately from $\gamma$. 
Table 7: Estimation results

<table>
<thead>
<tr>
<th></th>
<th>Model I</th>
<th></th>
<th>Model II</th>
<th></th>
<th>Model III</th>
<th></th>
<th>Model IV</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>ASE</td>
<td>Estimate</td>
<td>ASE</td>
<td>Estimate</td>
<td>ASE</td>
<td>Estimate</td>
<td>ASE</td>
</tr>
<tr>
<td>$\lambda_0$</td>
<td>0.541</td>
<td>(0.141)</td>
<td>0.642</td>
<td>(0.151)</td>
<td>0.747</td>
<td>(0.177)</td>
<td>0.623</td>
<td>(0.151)</td>
</tr>
<tr>
<td>$\lambda_1$</td>
<td>0.744</td>
<td>(0.200)</td>
<td>0.733</td>
<td>(0.170)</td>
<td>0.725</td>
<td>(0.147)</td>
<td>0.771</td>
<td>(0.179)</td>
</tr>
<tr>
<td>$\lambda_2$</td>
<td>0.876</td>
<td>(0.110)</td>
<td></td>
<td></td>
<td>0.979</td>
<td>(0.070)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda_3$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.788</td>
<td>(0.080)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p_{\gamma}/w$</td>
<td>0.986</td>
<td>(0.118)</td>
<td>0.852</td>
<td>(0.129)</td>
<td>0.744</td>
<td>(0.138)</td>
<td>0.872</td>
<td>(0.138)</td>
</tr>
<tr>
<td>$\ln\delta$</td>
<td>-0.788</td>
<td>(0.080)</td>
<td>-0.849</td>
<td>(0.096)</td>
<td>-0.867</td>
<td>(0.111)</td>
<td>-0.879</td>
<td>(0.099)</td>
</tr>
<tr>
<td>$\ln\delta_0$</td>
<td></td>
<td></td>
<td>-0.849</td>
<td>(0.096)</td>
<td>-0.867</td>
<td>(0.111)</td>
<td>-0.879</td>
<td>(0.099)</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>0.072</td>
<td>(0.103)</td>
<td>0.013</td>
<td>(0.120)</td>
<td>0.081</td>
<td>(0.103)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\delta_2$</td>
<td>0.107</td>
<td>(0.056)</td>
<td></td>
<td></td>
<td>0.075</td>
<td>(0.097)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\delta_3$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.215</td>
<td>(0.104)</td>
<td>0.192</td>
<td>(0.118)</td>
</tr>
<tr>
<td>$\delta_4$</td>
<td></td>
<td></td>
<td>0.215</td>
<td>(0.104)</td>
<td></td>
<td></td>
<td>0.201</td>
<td>(0.108)</td>
</tr>
<tr>
<td>Raw $R^2$</td>
<td>0.687</td>
<td></td>
<td>0.701</td>
<td></td>
<td>0.712</td>
<td></td>
<td>0.703</td>
<td></td>
</tr>
<tr>
<td>Corr $R^2$</td>
<td>0.286</td>
<td></td>
<td>0.318</td>
<td></td>
<td>0.343</td>
<td></td>
<td>0.322</td>
<td></td>
</tr>
</tbody>
</table>

Note: N = 190. * denotes significant differences from 0 for $\lambda_0$, $p_{\gamma}/w$, $\ln\delta$, $\ln\delta_0$ and $\delta_1$ and significant differences from 1 for $\lambda_1$, $\lambda_2$ and $\lambda_3$ at the 5% error level.

Comparison of the Models I to III shows that the estimated $\lambda_0$ increases and $p_{\gamma}/w$ decreases as the specification of $\delta$ becomes more detailed. $\lambda_1$ is the parameter least affected by the specification of $\delta$.

$\lambda_1$ is smaller than 1 in all models, significantly so at the 10% level in Model II. This implies that fixed schedule spraying is less effective than responsive spraying, as expected. "Fixed schedule sprayers" need one third more PPA than the remainder of farmers to achieve a given level of control ($1/\lambda_1 - 1 = 1/0.733 - 1 = 0.364$, Model II). At average PPA use of 1300 Rs / acre, this corresponds to around 420 Rs / acre. Accounting for labor costs of about 20% of the PPA value and an average cotton acreage of 3.2, approximately 1600 Rs / farm are saved at constant control levels. The comparably small opportunity cost of monitoring or casually observing pests justifies observation-based spraying.

The parameter $\lambda_2$ suggests that contract spraymen are less effective than family labor in applying PPA (Model IV). However, the parameter is not significantly different from 1 which is not surprising given that very few
farmers report that they hire all spray labor. $\lambda_3$ is practically 1 with a small standard error, implying that hired and family spray labor are almost equally effective.

The geographical location, $z_4$, has a significant effect in Model II, suggesting that pest pressure varies across locations. Fertilization appears to reduce the potential damage expressed as proportion of yields (Model III). This should be taken as an indication only, because Model III is explorative rather than analytical given that fertilization and thinning are not exogenous.

In order to estimate the potential damage to yields, $1 - g(x, \tau | x = 0) = 1 - (1 - \delta)^{\gamma}$, and other figures. $\gamma$ has to be recovered. $w$ reflects the opportunity costs of capital plus the marginal labor cost for application of insecticides (plus marginal transaction costs). Given the low inflation of the Rupee in 1994 and the fact that cotton is grown when cash is not too scarce, we assume an opportunity cost of capital of 10% over 6 months. The marginal cost of labor was estimated previously at 20% of the PPA costs. Hence, $w = 1000 \cdot 1.10 \cdot 1.2 = 1320$. The quality-weighted cotton farmgate price was 2250 Rs / 100 kg and harvesting costs are around 8% of the value of the yield. Hence, the cotton price net of harvesting is 2070 Rs / 100 kg and $p/w = 1.568$. Table 8 evaluates the potential and actual damage to yields, potential yields and the benefit-cost ratio of PPA use.
Table 8: Yield loss and average PPA productivity

<table>
<thead>
<tr>
<th>Model</th>
<th>I</th>
<th>II</th>
<th>II</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(τ = 0)</td>
<td>(τ = 1)</td>
<td>(τ = 0)</td>
<td>(τ = 1)</td>
<td>(τ = 0)</td>
<td>(τ = 1)</td>
</tr>
<tr>
<td>γ</td>
<td>0.629</td>
<td>0.543</td>
<td>0.543</td>
<td>0.543</td>
<td>0.474</td>
<td>0.556</td>
</tr>
<tr>
<td>δ(ζ)</td>
<td>0.455</td>
<td>0.499</td>
<td>0.492</td>
<td>0.512</td>
<td>0.557</td>
<td>0.484</td>
</tr>
<tr>
<td>Potential damage a</td>
<td>0.317</td>
<td>0.313</td>
<td>0.308</td>
<td>0.322</td>
<td>0.320</td>
<td>0.308</td>
</tr>
<tr>
<td>Actual damage a</td>
<td>0.161</td>
<td>0.138</td>
<td>0.129</td>
<td>0.153</td>
<td>0.120</td>
<td>0.139</td>
</tr>
<tr>
<td>Prevented damage a</td>
<td>0.156</td>
<td>0.175</td>
<td>0.178</td>
<td>0.170</td>
<td>0.200</td>
<td>0.169</td>
</tr>
<tr>
<td>Prevented damage [Rs/acre]</td>
<td>2438</td>
<td>2665</td>
<td>2711</td>
<td>2580</td>
<td>2974</td>
<td>2575</td>
</tr>
<tr>
<td>Prevented damage [Rs/farm]</td>
<td>7800</td>
<td>8527</td>
<td>8675</td>
<td>8255</td>
<td>9517</td>
<td>8240</td>
</tr>
<tr>
<td>PPA cost b [Rs/farm]</td>
<td>5474</td>
<td>5474</td>
<td>5149</td>
<td>5977</td>
<td>5474</td>
<td>5474</td>
</tr>
<tr>
<td>Net benefits [Rs/farm]</td>
<td>2326</td>
<td>3053</td>
<td>3526</td>
<td>2278</td>
<td>4043</td>
<td>2766</td>
</tr>
<tr>
<td>Benefit-cost ratio</td>
<td>1.425</td>
<td>1.558</td>
<td>1.685</td>
<td>1.381</td>
<td>1.738</td>
<td>1.505</td>
</tr>
</tbody>
</table>

Note: a Potential damage, actual damage and prevented damage are given as proportions of the potential yield. b PPA costs include expenses for PPA (Rs 1296 / acre), 20% labor and 10% capital costs. The yields are valued at the weighted cotton price minus 8% harvesting costs. The models for τ = 0 and τ = 1 are evaluated at conditional sample means (except acreage).

The potential pest damage is around 32% of the potential yield. The net benefits of PPA use of Rs 2300-4000 per farm and the benefit-cost ratios of 1.38-1.74 indicate that PPA are profitably used. The savings of observation-based spraying over fixed schedule spraying are Rs 1250 per farm, calculated as the difference between the net benefits from PPA use between τ = 0 and τ = 1.

Comparison of Models I to III shows that the PPA effectiveness estimate increases as the specification of δ becomes more detailed, suggesting that disregarding pest pressure leads to underestimation of PPA productivity.

### 3.6 Conclusions

The productivity of chemical plant protection was estimated with an input demand model obtained by transformation of the structural model for the technology. The transformation was possible due to the multiplicative specification of production with respect to damage abatement and standard con-
tributions to yields. That is, we identified the model by imposing restrictions on the form of the production function. Common sources of simultaneous-equation bias could be ruled out with the exception of a portion of the effect of pest pressure. PPA effectiveness was expressed as a function of a predetermined strategy variable and the share of hired manpower in total spray labor. All parameter estimates were reasonable. The following conclusions are offered.

- Observation-based (responsive) spraying is more effective than preventive spraying.
- Hired spray labor tends to be less effective than family spray labor but the difference is not significant.
- Mathematically simple input demand functions result from multiplicative abatement specifications.
- A relatively weak variable coding for plant protection strategies yielded a significant, large parameter estimate, implying that the effectiveness of PPA use varies widely between farmers. Plant protection strategies are not categorical in practice. The degree to which pest management decisions respond to observed pest infestations is a continuous variable.
- The inclusion of exogenous variables that affect pest pressure in production models improves the fit and significance, suggesting that pest pressure should be included in PPA productivity models as a variable or a function, but at least as a parameter.
Integrated pest management (IPM) programs are often expected to reduce the use of PPA. There are many "success stories" in that sense, but also empirical evidence to the contrary. We discuss the relationship between human capital and the demand for damage control agents. It is argued that the demand effect of human capital can have either sign, depending on the current level of damage abatement. A positive demand effect is likely where abatement is low. The formal framework developed applies to IPM, because IPM is basically an enhancement of human capital. Data from small-scale maize production in Southern Mexico is used by way of illustration. It contains pairs of observations corresponding to farmers and private extension workers. A second order approximation to the function for the yield difference between the two shows that both the average and marginal productivity of the technicians are higher than those of the farmers, suggesting that human capital increases the demand for PPA.

\[\text{The definition of IPM has varied with time and across authors. For a short history on the concept cf. MOORE (1996). We find that most definitions of IPM are compatible with our perception that IPM is basically an enhancement of human capital and information about the pest interactions with the agroecosystem.}\]
4.1 Introduction

Crop protection is a highly complex technology, given the large number of underlying biological interactions that are accessible to human intervention. Therefore, human capital assumes a key role in making plant protection more effective and sustainable. "Integrating" the interactions between humans and the agroecological system into a more comprehensive framework has been the objective of research and, in many cases, plant protection practice. The perception of the need for integration was triggered by failures of single-dimensioned plant protection, namely strategies that relied heavily on chemical PPA\(^{12}\). Consequently, a reduction of chemical PPA use has often been expected from IPM programs. This may be surprising to the economist who derives the demand for a factor from its marginal value product. When human capital increases the marginal factor productivity a positive demand effect results (ceteris paribus).

There is empirical evidence for both cases (cf. TÜTTINGHOFF, 1990; ROLA and PINGALI, 1993; WARBURTON et al, 1995; WHITE and WETZSTEIN, 1995; ICAR, 1989; Chapter 3), although the common view is that IPM reduces the use of synthetic PPA. The explanation is intuitive. Benefits from plant protection stem from damage abatement. They are thus limited to potential damage. Neither inputs nor human capital can increase yields (much) when damage abatement is close to complete. Still, a benefit can be secured by increasing the effectiveness of damage control agents and reducing their usage. When abatement is low, human capital increases the marginal value product of and, hence, the demand for damage control agents.

PINGALI and CARLSON (1985) argue that human capital improves the precision of the producer's estimate of potential damage. Here, we are entirely concerned with the effect of human capital on the effectiveness of damage control. The producer's ability to find optimal input levels is not discussed.

\(^{12}\)In this chapter, PPA is to be read as plant protection agent in a more general sense than chemical pesticides, i.e. as any agent that protects crops from damage due to pests. Where necessary, we specify whether we refer to chemical PPA, i.e. synthetical pesticides, or non-chemical PPA.
The chapter is organized as follows. The production factor demand under varying levels of human capital is derived generically in Section 4.2 and for damage control agents in Section 4.3. Section 4.4 describes the plant protection practices in the Mexican project area where the data for the empirical part was collected. In Section 4.5, we develop an econometrical model for the yield differences that are due to different levels of human capital. Section 4.6 presents the results. Conclusions are offered in Section 4.7.

### 4.2 Generic analysis

Suppose the argument \( \theta \) of the production function \( q = f(\theta) \) can be partitioned into components \( \theta = (x, \lambda) \), where \( \lambda \) is a vector of parameters and \( x \) a vector of choice variables. The producer faces the profit maximization problem \( \max_x \Pi = pq - w'x \). \( p \) and \( w \) are the output and factor prices, respectively. Treating prices as fixed, the first order conditions for a local maximum are the following.

\[
(12) \quad pf_x - w = 0
\]

Sufficiency is ensured by the negative definiteness of the Hessian matrix \( F_{xx} \) of \( f(\cdot) \). Differentiation of the demand equations (12) with respect to \( \lambda \) gives a system of equations for the marginal demand effects of \( \lambda, X_\lambda \). In formula:

\[
(13) \quad X_\lambda = -F_{xx}^{-1}F_{x\lambda}
\]

\( F_{x\lambda} \) is the matrix of the derivates of the marginal productivities with respect to \( \lambda \). In the case of a scalar \( \lambda \), affecting a single marginal productivity \( f_{x^k}, f_{x^k\lambda} = 0 \) for \( i \neq k \). (13) is reduced to

\[
(14) \quad x_\lambda^k = -\frac{f_{x^k\lambda} \det(F_{xx}^{k,k})}{\det(F_{xx})}
\]

where \( F_{xx}^{k,k} \) is the matrix obtained by eliminating row and column \( k \) of \( F_{xx} \). Since \( F_{xx} \) is assumed negative definite, \( \det(F_{xx}^{k,k}) \) and \( \det(F_{xx}) \) have opposite
signs. Hence, $x^\lambda_1$ takes the sign of $f_{x^\lambda}$, That is, $\lambda$ increases (decreases) the input demand if it increases (decreases) the corresponding marginal productivity. When $f_{x^\lambda}$ may be of either sign, negative and positive demand effects are possible even if $\lambda$ affects only a single marginal productivity.

When $\lambda$ affects several elements of $\mathbf{f}$, (13) is difficult to discuss. Differentiation of (12) with respect to $\mathbf{w}$ yields $F_{x^\lambda} = \mathbf{pXw}$. $X_w$ are the own-price and cross-price input demand effects. By substitution into (13) one obtains $X_\lambda = -pX_wF_{x^\lambda}$, a single equation of which can be rearranged as follows.

$$\left(15\right) \quad \frac{x^\lambda_1}{x^\lambda} = -\sum_j f_{x^\lambda} \frac{\lambda}{f_{x^\lambda}} x^\lambda_j w^j$$

A single input's demand elasticity with respect to $\lambda$ is the negative sum of the elasticities of the marginal productivities of all inputs with respect to $\lambda$, each weighted with the corresponding (cross-) price elasticity. The demand effect of $\lambda$ may be interpreted as the sum of a direct and an indirect effect. The first is the right-hand side of (15) when $i = j$, that is the negative elasticity of the marginal productivity of the input in question with respect to $\lambda$, times the own-price elasticity. The indirect effect is the negative sum of the elasticities of the other inputs' marginal productivities with respect to $\lambda$ times the corresponding cross-price elasticities.

Consider the case where $\lambda$ increases the marginal productivities of $x^j$ and a set of inputs, $x^j, j = 1...n$, that act as complements to $x^i$. Complementary inputs have negative cross-price elasticities. Hence, the sum on the right-hand side of (15) is negative, resulting in a positive demand effect. Thus, when $\lambda$ increases only the marginal productivities of complementary inputs, it has positive demand effects only. When $x^i$ and $x^j$ are substitutes, the cross-price elasticities are positive. The demand effect $x^\lambda_1$ is reduced for each substitute $x^j$ for which $f_{x^\lambda} > 0$, and may eventually become negative.
### 4.3 Damage abatement

#### 4.3.1 Form of the production function

Lichtenberg and Zilberman (1986) suggested the form \( q = f(z, g(x)) \) for production functions involving damage abatement. \( x \) are damage control agents, which produce abatement \( g \). \( g_x \geq 0 \) \( \forall i \) and \( f_g > 0 \). \( g(x) \) has the form of a cumulative distribution function (cdf), because abatement is limited to potential damage. In the economic range, \( f_{gg} < 0 \) and the Hessian matrix of \( f \) is negative definite. \( z \) are production factors meeting \( f_z \geq 0 \) in the economic range. Abatement is limited from the top, \( \lim_{x \to \infty} g(x) = g^\text{max} \). Maximum abatement is not necessarily approached when only one damage control agent increases, \( \lim_{x \to \infty} g(x) \leq g^\text{max} \). The marginal productivities of the damage control agents approach 0 as the individual input levels increase, \( \lim_{x_i \to \infty} g_{x_i} \geq 0 \) \( \forall i \). Therefore, \( f^\text{max}(z) = \lim_{x \to \infty} f(z, g(x)) = f(z, g^\text{max}) \), \( f_x = f_g g_x \geq 0 \) \( \forall i \) and \( \lim_{x \to \infty} f_x = 0 \), implying that \( f \) has also the form (not values) of a cumulative distribution function with respect to \( x' \) \( \forall i \).

#### 4.3.2 Effects of human capital

Let \( \lambda \) be skills and knowledge (human capital) specifically related to plant protection. Such skills are the farmer's ability to identify pests, knowledge about dosage, timing and control spectrum of PPA, information about economic threshold levels of pest populations, etc. \( \lambda \) does not represent types of human capital such as school education, which are not specific to damage abatement. For the case of a single damage control (choice) variable \( x \) we may write \( g = g(x, \lambda) \). The following properties are derived. First, \( \lambda \) increases average abatement of the damage control input, \( g_\lambda \geq 0 \). Second, \( \lambda \) does not affect \( g \) in the absence of damage control activities, \( g_\lambda(x, \lambda \mid x = 0) = 0 \). Third, as \( x \) increases, the marginal productivity of \( \lambda \) increases first to allow \( g_\lambda > 0 \) and then decreases to allow \( g \) to converge to \( g^\text{max} \). We conclude that if \( g \) is sufficiently smooth, \( g_x \lambda > 0 \) at small values of \( x \) and \( g_x \lambda < 0 \) at large values of \( x \). Moreover, it follows from \( f_g > 0 \) that \( \lambda \) increases (decreases) the marginal productivity of \( x \) in the lower (upper) range of \( x \), implying that the
input demand effects of $\lambda$ are positive (negative) according to (14). Figure 10 illustrates the idea.

**Figure 10:** Production function and marginal product with two different levels of human capital

The upper and lower charts show production and marginal production, respectively, each for two different levels of $\lambda$. The areas under the marginal production curves correspond to complete abatement and are assumed independent of $\lambda$. Hence, the two curves must cross at (at least) one point $[x^*, q^*_x]$. To the left (right) of $x^*$, $\lambda$ has a positive (negative) effect on the marginal productivity of $x$. The input demand effects are similar. According to (14), $x_\lambda > 0$ when $f_{x\lambda} > 0$, that is when $w/p > q^*_x$.

How does a plant protection related learning process affect the input use level? A simple model for the adoption of pest management skills is continuously increasing $\lambda$. To derive the input demand effects of $\lambda$, we implicitly assumed the input demand differentiable with respect to $\lambda$ over the
whole range of $x$. In practice, some minimum skills are required for producers to profit from the input at all. Input use is thus zero when human capital is below a minimum level $\lambda^a$. At $\lambda = \lambda^a$, $x$ shifts to an interior solution, $x^a$. When $f$ is concave near 0, $x^a$ is near 0. Otherwise a more than marginal quantity enters the solution at $\lambda^a$, implying that $x(\lambda)$ is not differentiable in $\lambda = \lambda^a$. Therefore, (14) does not hold when $\lambda \leq \lambda^a$. It is also reasonable to assume limits to the effects of human capital. As human capital increases, abatement approaches some limit function $g^o(x)$ determined by technical constraints. One may or may not claim an upper limit of human capital, so that $g^o(x)$ is reached either at a finite or infinite level of $\lambda$. However, if $\lambda$ is restricted to some finite interval, it is easy to transform it to $[0, \infty]$. Therefore, $x_\lambda \to 0$ as $\lambda \to \infty$. Let $x^o$ be profit maximizing in $f^o = f(z, g^o(x))$. As $\lambda$ goes from $\lambda^a$ to $\infty$, (14) describes the movement of $x$ from $x^a$ to $x^o$. Three cases are possible: (a) $x_\lambda < 0 \mid x = x^a \Rightarrow x_\lambda < 0$, (b) $x(\lambda)$ has an interior maximum, and (c) $x_\lambda > 0 \mid x = x^o \Rightarrow x_\lambda > 0$, as depicted in Figure 11.

**Figure 11:** Input demand in function of human capital

- a: Input demand decreases with human capital
- b: Input demand with interior maximum
c: Input demand increases with human capital

The lower curve in each panel is a cross-section of a production function at $\lambda = \lambda^0$. As $\lambda$ increases, the cross section approaches $f^0$ and the profit maximizing $x$ moves along the expansion path $x(\lambda)$. Increasing skills related to plant protection may thus be associated with increasing or decreasing use of PPA.

### 4.3.3 Adoption of IPM

The implications of these findings shall be discussed for two scenarios, A and B, representing the baselines of "classical IPM" programs and IPM in low value crops in developing countries, respectively. We further distinguish between two types of PPA, i.e. pesticides $x$ (chemical PPA) and non-chemical PPA $y$, such as labor, biological control, cultivation, etc. The characteristics of A and B are summarized in Table 9.

#### Table 9: IPM scenarios (starting points)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>A &quot;classical IPM&quot;</th>
<th>B &quot;low value crop in DC&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage of chemical PPA, $x$</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Usage of non-chemical PPA, $y$</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>• Labor</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>• Biological control agents</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Damage abatement</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>
In classical situations where IPM is introduced (e.g. cotton), baseline usage of chemical PPA is high, producing a large damage abatement although in some cases chemical control may already have started to fail due to, for example, development of secondary pests. Wages are relatively high implying low labor use for plant protection. Non-chemical control methods may be used, but to a low extent as compared to what would be technically possible. IPM in low value crops in developing countries differs in that the baseline usage of chemical PPA is low, partly due to deficient human capital, partly due to the low output-input price ratios. Labor use may be high, e.g. for weeding. Damage abatement is thought to be low.

Table 10 gives an overview of the demand effects according to equation (15) in the two scenarios. The prices of chemical and non-chemical PPA x and y, are denoted with w and s, respectively.

Table 10: Input demand effects of IPM

<table>
<thead>
<tr>
<th>Input</th>
<th>Case</th>
<th>Demand effect</th>
<th>Direct effect</th>
<th>Indirect effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical PPA</td>
<td>A1</td>
<td>-</td>
<td>-</td>
<td>+ (+)</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>+</td>
<td>-</td>
<td>- ? ?</td>
</tr>
<tr>
<td>Non-chemical substitutes</td>
<td>A2</td>
<td>+</td>
<td>-</td>
<td>- ? +</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>(-)</td>
<td>-</td>
<td>- + +</td>
</tr>
<tr>
<td>Non-chemical complements</td>
<td>A3</td>
<td>?</td>
<td>-</td>
<td>- - -</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>(+)</td>
<td>-</td>
<td>- + -</td>
</tr>
</tbody>
</table>

Note: The elasticity notation is suppressed for graphical simplicity. Question marks and parenthesis denote indeterminate and probable signs, respectively.

In scenario A, incremental skills are most likely to decrease the marginal product of x and increase that of y. Non-chemical inputs y are typically substitutes for x, suggesting \( x_s > 0 \). However, the productive effect of non-chemical inputs may stem mainly from a reduction of the adverse side effects of chemical PPA. y is then complementary to x, suggesting \( x_s < 0 \). The direct effect \( f_{x\lambda}x_w \) seems likely to be predominant, which entails a negative total pesticide demand effect (A1). The effect on the demand for non-chemical substitutes is positive (A2). That for non-chemical complements is indeterminate due to the balancing of the effects of \( f_{y\lambda} > 0 \) and \( f_{x\lambda} < 0 \) (A3).
In scenario B, the direct effect on the demand for $x$ is positive because human capital increases the marginal productivity of pesticides. The indirect effect depends on the nature of the non-chemical PPA. The traditional practice of hand-weeding, for example, is likely to be technically efficient, for which $\lambda$ will not affect its marginal product ($f_{x\lambda} = 0$). The indirect effect on the pesticide demand would then be 0. "Modern" non-chemical PPA might add positive or negative indirect effects (B1). The demands for non-chemical PPA may show any sign (B2 and B3). Weeding, to stay with the example, is commonly seen as a substitute for herbicides, suggesting that labor for weeding decreases as the marginal effectiveness of herbicides increases (B2). Situations where pesticides and traditional control methods are complementary may also exist, for example when herbicides and labor are combined to control the most susceptible and more problematic weeds, respectively. Adoption of such a technique is likely to increase with $\lambda$ (B3). More generally, the demand for non-chemical PPA increases (decreases) with each feature that complements (substitutes) chemical PPA. Moreover, when human capital increases the marginal productivity of a non-chemical PPA which reduces the adverse side-effects of a chemical, it raises the demand for the latter. In scenario B, an IPM program may thus increase the demand for chemical pesticides through enhancement of the effectiveness of both chemical pesticides and their non-chemical complements. The following empirical study gives evidence for $f_{x\lambda} > 0$ which is expected to raise the demand for agrochemicals.

4.4 Pest control in maize in Southern Mexico

Data for illustration is drawn from the Mexican project area in the Fraylesca region, Chiapas. Twenty-eight small-scale maize growers participated in a demonstration plot scheme in 1994. Each participant let the extension workers conduct chemical plant protection on $\frac{1}{4}$ hectare of a maize field. The farmers cared for pest control in the remainders of the fields. Factors such as non-chemical plant protection measures, soil quality and preparation, seed variety and sowing density, fertilization, climate, initial weed and pest populations, etc., were constant over the two plots in each field. Relatively successful, reputable farmers had been selected as participants in order to optimize the communication impact of the demonstration. The sample is thus not representative for the population of small-scale maize farmers in the Fraylesca. Nevertheless it is suitable for illustration.
Important weeds are *Cenchrus brownii*, *Cynodon dactylon*, *Digitaria horizontalis* and *Melampodium divaricatum* (van Nieukoop et al. 1992, Hibon et al., 1992). Hibon et al. (1992) estimate actual yield loss due to the perennial grasses *C. dactylon* and *D. horizontalis* to 1.2 tons / ha in about one third of the area of the Fraylesca. Weed damage to yields is around 90% if not controlled at all (Aguirre Morales, 1995). Weed control techniques include burning stubble before sowing, soil preparation, manual and mechanical control (which are constant over the two plots) and herbicides. The latter include: (a) Preemergence herbicides that control mainly broad leaf weeds and some annual grasses (triazines). Those are selective to maize in any growth stage. (b) Preemergence herbicides that control broad leaf weeds and a larger number of grass varieties (metolachlor or triazines formulated in mixtures with terbutrine or metolachlor). Those are selective to maize when applied in preemergence of the crop. (c) Postemergence herbicides that reduce all kinds of weed populations (desiccants, including paraquat, diquat, and glyphosate). (d) Postemergence herbicides that control broad leaf weeds only (2,4-D).

The most important soil insect pests are wireworms (many species of the families Elateridae: *Melanotus*, *Agriotes*, etc.,) and diabrotica rootworms (*Diabrotica*). Soil pests are controlled by soil preparation and insecticides. The latter are applied either as seed dressings or to the soil as granules. Crop rotation would reduce soil insect pest populations. However, maize seems to be the most profitable crop for the majority of small-scale farmers. It is usually planted year after year. Among the foliar insect pests, the fall armyworm (*Spodoptera frugiperda*) and the false looper (*Mocis latipens*) are the most important ones causing damage to leaves. *Heliotis* ssp. damages cobs. *Spodoptera frugiperda* is widespread and present almost every year, usually in the whorl at early stages of crop development. Late populations damage the tassel or feed on cobs (Ortega, 1987). Important *Mocis latipens* populations occur more sporadically and later in the season. They can be controlled with insecticides and by eliminating the grassy weed where they develop (Shaxson and Bentley, 1991). In the year of data collection, 1994, *Mocis latipens* pressure was very low and did not justify control actions.

The effectiveness of plant protection practices varies widely across farmers. Underrating of chemical PPA is common. Most farmers know that herbicides are effective only at sufficient soil humidity, but some do not follow this rule strictly. Weed coverage with herbicides is sometimes poor. Postemergence herbicides are often applied late, when weeds have grown too
large. They are presumed to be generally less effective than preemergence products and entail higher labor costs. However, preemergence herbicides are relatively expensive per application. Seed treatment is less effective than soil insecticides. Most farmers control foliar insect pests late, i.e. after the third stage of the larvae. Tolerance to methyl-parathion has been hypothesized for *S. frugiperda*.

Based on these observations, the project advises and trains farmers in (a) correct identification of pests and weeds and choice of suitable PPA, (b) adequate coverage, (c) use of labeled ratings, (d) application of herbicides at sufficient soil humidity, (e) predominant use of preemergence herbicides, (f) use of specific products where perennial grasses are frequent, (g) application of foliar insecticides at early larval stages, (h) rotation of different chemical types of foliar insecticides to prevent pest tolerance, (i) control of soil insect pests with soil insecticides.

### 4.5 Model

Pesticides are a heterogeneous production factor. Field data usually comprises a large number of brands, with different active ingredients, at different concentrations, etc. The aggregated monetary value of pesticides is an adequate variable for the purpose of estimating the economic effectiveness. All PPA variables used here are in monetary units. In order to account partly for the heterogeneity, we differentiate between types of herbicides and insecticides.

The relevant plant protection costs are those that differ between the farmers' and technicians' plots. They break down into labor and pesticide costs which are independent to a certain degree. A change in the dose per application, for example, does not entail labor costs. A change in the number of spray-rounds, by contrast, affects labor use. Hence, the application cost would ideally be modeled as a separate variable. For simplicity and lack of degrees of freedom, we exclude labor from the initial model and turn back to it at the interpretation of the results.

The data allows construction of a binary human capital variable. However, instead of explicitly introducing such a variable, we specify a model for the yield differences between technicians and farmers. The yield difference is composed of (a) a portion that is entirely due to human capital, i.e. the yield difference technicians would achieve at the farmers' input levels, (b) a por-
tion that is due to the difference in input levels, i.e. the yield difference
farmers would realize with the technicians' input levels, and (c) an interac-
tion of the two. For a single $x$, first order approximations to (a) and (c) and a
second order approximation to (b) produce the model

\[
\Delta q = \beta_0 + \beta_1 \Delta x + \beta_2 \Delta^2 x + \beta_3 x_f + \beta_4 x_f \Delta x
\]

The letter $\Delta$ denotes differences between technicians and farmers. $x_f$ is the
farmer's input level. (16) is obtained also as follows.

\[
q(x) \approx q(\bar{x}) + (x - \bar{x})\left[q'(\bar{x}) + (x - \bar{x}) q''(\bar{x})/2\right]
\]

is a second order approximation to the production function. ($^\text{c}$ denotes sam-
ple means.) Establishing it for technicians and farmers (denoted with sub-
scripts $t$ and $f$, respectively), taking differences and substituting $x_f + \Delta x$ for $x_t$
yields a quadratic model on $x_f$ and $\Delta x$. The parameter of $x_f^2$ is half the differ¬
ence between the second derivates of the two functions. That is small and
difficult to estimate, given that the variances of some inputs are small.
Therefore, we approximate $x_f^2$ by $2x_f\bar{x}_f - \bar{x}_f^2$. The model

\[
\Delta q \approx q_t(\bar{x}_t) - q_f(\bar{x}_f) - \bar{x}_t q'_t(\bar{x}_t) + \bar{x}_f q'_f(\bar{x}_f) + (\bar{x}_t^2 - \bar{x}_f^2)q''_t(\bar{x}_t)/2
+ \Delta x[q'_t(\bar{x}_t) - \bar{x}_t q''_t(\bar{x}_t)]
+ \Delta^2 x q''_t(\bar{x}_t)/2
+ x_f[q'_f(\bar{x}_f) - q'_f(\bar{x}_f) - \Delta \bar{x} q''_f(\bar{x}_f)]
+ x_f \Delta x q''_f(\bar{x}_f)
\]

results, which is formally equivalent to (16).

\hspace{1cm}^{13} \text{Since this model is derived from the production functions for farmers and technicians, it is potentially subject to simultaneous-equation bias. However, most of the simultaneity between productive and allocative relationships disappears as yield differences are modeled.}
The model should distinguish between weed and insect pest control, pre- and postemergence herbicides, soil and foliar insecticides. For several independent inputs, the respective right hand sides of (16) could simply be combined linearly. However, the variance of soil insecticides is not sufficient to estimate the parameters of the quadratic terms. Therefore, we use the first order approximation $\Delta q = \beta_5 + \beta_6 \Delta x$ for soil insecticides. Moreover, the two types of herbicides are not independent. Since they abate the same type of damage, the marginal productivity of either one is a function of total herbicide use rather than of the individual levels. Hence, we establish (16) for pre- and postemergence herbicides, but replace the corresponding $x_j$ by total herbicide use. The model is then:

$$\Delta q = a_0 + a_1 \Delta x_1 + a_2 \Delta x_2 + a_3 \Delta x_3 + a_4 \Delta x_4 + a_5 \Delta x_5 \Delta x_6 + a_6 \Delta x_7 + a_7 \Delta x_8 + a_8 \Delta x_9 + a_9 \Delta x_{10} + a_{10} \Delta x_{11} + a_{11} \Delta x_{12} + a_{12} \Delta x_{13}$$

(17)

$x_1$ and $x_2$ are soil and foliar insecticides, $x_3$ and $x_4$ pre- and postemergence herbicides, $x_5 = x_3 + x_4$ total herbicides, respectively. $a_0 + a_4 x_{2,f} + a_{12} x_{5,f}$ estimates the effect of human capital at the farmers' input levels. It is expected to be positive at sample means. The differences in marginal productivities, obtained by substitution of $x_{i,t} - x_{i,f}$ for $\Delta x_i$ and $q_i - q_f$ for $\Delta q$ in (17), subsequent differentiation with respect to $x_{i,t}$ and $x_{i,f}$ and taking differences, are

$$\frac{\partial q_i}{\partial x_{2,t}} - \frac{\partial q_i}{\partial x_{2,f}} = a_4 + a_5 \Delta x_2$$

and

$$\frac{\partial q_i}{\partial x_{3,t}} - \frac{\partial q_i}{\partial x_{3,f}} = \frac{\partial q_i}{\partial x_{4,t}} - \frac{\partial q_i}{\partial x_{4,f}} = a_{12} + a_8 \Delta x_3 + a_{11} \Delta x_4.$$
Thus, the signs of $\alpha_4$ and $\alpha_{12}$ are the signs of the respective demand effects of human capital.

### 4.6 Results

The following tables reproduce sample statistics and estimation results.

#### Table 11: Sample statistics

<table>
<thead>
<tr>
<th></th>
<th>Average (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Technicians</strong></td>
</tr>
<tr>
<td>Yield $q$ [kg / ha]</td>
<td>7416 (2516)</td>
</tr>
<tr>
<td>Soil insecticides $x_1$</td>
<td>125.48 (59.7)</td>
</tr>
<tr>
<td>Foliar insecticides $x_2$</td>
<td>62.34 (46.5)</td>
</tr>
<tr>
<td>Preemergence herbicides $x_3$</td>
<td>165.77 (51.6)</td>
</tr>
<tr>
<td>Postemergence herbicides $x_4$</td>
<td>30.82 (35.8)</td>
</tr>
<tr>
<td>Total herbicides $x_5$</td>
<td>196.59 (58.9)</td>
</tr>
<tr>
<td># of soil insecticide applications</td>
<td>0.82</td>
</tr>
<tr>
<td># of foliar insecticide applications</td>
<td>1.54</td>
</tr>
<tr>
<td># of preemergence applications</td>
<td>1.00</td>
</tr>
<tr>
<td># of postemergence applications</td>
<td>0.82</td>
</tr>
<tr>
<td>Total # of herbicide applications</td>
<td>1.82</td>
</tr>
<tr>
<td>Net benefits [N$/ ha]</td>
<td>1903</td>
</tr>
</tbody>
</table>

Notes: $N = 28$. The unit of the $x_i$ is N$/$ ha. N$\$ stands for Mexican "Nuevos Pesos". In 1994 the exchange rate was an approximate 0.28 US$ / N$. 


Table 12: Estimation results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_0$</td>
<td>constant</td>
<td>$-120.311$</td>
<td>$(1509.74)$</td>
<td>$-0.080$</td>
<td>$0.938$</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>$\Delta x_1$</td>
<td>$-1.636$</td>
<td>$(2.831)$</td>
<td>$-0.578$</td>
<td>$0.572$</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>$\Delta x_2$</td>
<td>$45.918$</td>
<td>$(19.166)$</td>
<td>$2.396$</td>
<td>$0.030$</td>
</tr>
<tr>
<td>$\alpha_3$</td>
<td>$\Delta^2 x_2$</td>
<td>$-0.343$</td>
<td>$(0.244)$</td>
<td>$-1.405$</td>
<td>$0.180$</td>
</tr>
<tr>
<td>$\alpha_4$</td>
<td>$x_{2f}$</td>
<td>$10.109$</td>
<td>$(7.728)$</td>
<td>$1.308$</td>
<td>$0.211$</td>
</tr>
<tr>
<td>$\alpha_5$</td>
<td>$\Delta x_{2f}$</td>
<td>$-0.924$</td>
<td>$(0.300)$</td>
<td>$-3.074$</td>
<td>$0.008$</td>
</tr>
<tr>
<td>$\alpha_6$</td>
<td>$\Delta x_3$</td>
<td>$27.308$</td>
<td>$(15.104)$</td>
<td>$1.808$</td>
<td>$0.091$</td>
</tr>
<tr>
<td>$\alpha_7$</td>
<td>$\Delta^2 x_3$</td>
<td>$-0.049$</td>
<td>$(0.046)$</td>
<td>$-1.070$</td>
<td>$0.301$</td>
</tr>
<tr>
<td>$\alpha_8$</td>
<td>$\Delta x_{3f}$</td>
<td>$-0.160$</td>
<td>$(0.093)$</td>
<td>$-1.725$</td>
<td>$0.105$</td>
</tr>
<tr>
<td>$\alpha_9$</td>
<td>$\Delta x_4$</td>
<td>$24.650$</td>
<td>$(9.513)$</td>
<td>$2.591$</td>
<td>$0.020$</td>
</tr>
<tr>
<td>$\alpha_{10}$</td>
<td>$\Delta^2 x_4$</td>
<td>$0.230$</td>
<td>$(0.100)$</td>
<td>$2.303$</td>
<td>$0.036$</td>
</tr>
<tr>
<td>$\alpha_{11}$</td>
<td>$\Delta x_{4f}$</td>
<td>$0.001$</td>
<td>$(0.100)$</td>
<td>$0.013$</td>
<td>$0.990$</td>
</tr>
<tr>
<td>$\alpha_{12}$</td>
<td>$x_{4f}$</td>
<td>$3.694$</td>
<td>$(16.312)$</td>
<td>$0.226$</td>
<td>$0.824$</td>
</tr>
</tbody>
</table>

Notes: $N = 28$; P-values are 95%, 2-tail; adjusted multiple $R^2 = 0.538$; standard error of estimate: 642.2; P-value of regression $= 0.011$.

The effect of human capital on the yield difference is 630 kg / ha at the farmers' sample means (with an SE of 858 kg / ha). That is, the effect of human capital on yields at constant input levels is 10%. 50% of the total yield difference are due to human capital alone.

The difference in soil insecticides yields an unexpected negative estimate. Technicians seem to have overused soil insecticides, but the estimate is not significant.

Yields are valued at the maize price of N$ 650 / ton minus the costs that vary with yields of N$ 145 / ton (harvest, thresher, transportation). The opportunity cost of capital is around 40% p.a. Preemergence herbicides are applied at sowing in June, postemergence herbicides and foliar insecticides in July and August, mainly. Harvesting is in November and December, but the farmer does not usually receive cash before January. For the respective PPA, the time periods between investment and returns are thus 7 and 5.5 months. The opportunity costs of capital are 22% and 17% ($1.4^{7/12} - 1; 1.4^{5.5/12} - 1$). The net present value (NPV) of 1 N$ invested in PPA is the valued and discounted marginal yield effect minus the corresponding costs, composed of 1 N$ for PPA and labor costs. The latter are 0 when the in-
vestment is due to an increase in the dose per application or the use of more expensive PPA. However, when the use of more PPA involves an additional sprayround, the marginal labor cost is approximated by the average ratio between labor and PPA costs. By taking NPV differences between technicians and farmers, the marginal investment in PPA—which is identical for the two—is subtracted. Similarly, a certain share of the marginal labor costs is also subtracted. Table 13 shows the NPV differences (ΔNPV) excluding labor and under the extreme assumption that technicians invariably needed more labor when using more PPA, while farmers invariably stuck to current numbers of applications. Note that the numbers of applications per N$ of PPA do not vary much between farmers and technicians, except for post-emergence herbicides, where they are in favor of technicians. The NPV "without labor" are thus closer to reality than those "with labor".

Table 13: Differences in marginal productivities

<table>
<thead>
<tr>
<th></th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$x_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield effect [kg]</td>
<td>10.11</td>
<td>(7.7)</td>
<td>3.69</td>
</tr>
<tr>
<td>Benefit [N$]</td>
<td>5.11</td>
<td>(3.9)</td>
<td>1.87</td>
</tr>
<tr>
<td>Discounting factor</td>
<td>1.17</td>
<td></td>
<td>1.22</td>
</tr>
<tr>
<td>ΔNPV without labor [N$]</td>
<td>4.36</td>
<td>(3.3)</td>
<td>1.53</td>
</tr>
<tr>
<td>Labor / PPA ratio</td>
<td>0.48</td>
<td></td>
<td>0.33</td>
</tr>
<tr>
<td>ΔNPV with labor [N$]</td>
<td>3.88</td>
<td>(3.3)</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Note: Figures in parenthesis are standard errors.

The NPV differences are positive in all cases. That is, the marginal productivities of the three input types increase with human capital in the range of the farmers' input levels. Farmers would use more inputs if human capital increased marginally. The standard errors are large. This may be due to the small sample size and variances of some $x_{i,t}$.

Technicians use less postemergence herbicides, although they have a larger marginal productivity in that input than farmers. This does not contradict the generic finding that the demand effect of human capital takes the sign of the effect on the marginal productivity. Remember that Table 13 refers to a marginal increase in human capital, while the difference in use levels is a non-marginal effect. Moreover, the use of more preemergence herbicides reduces the marginal productivity of postemergence products ($\alpha_8 < 0$). The two types of herbicides are thus substitutes in the economic range.
4.7 Conclusions

We have examined the relationship between the skills with which inputs are used and input demand for the case of PPA. Since PPA are damage control agents and damage abatement has the form of a cumulative distribution function, increasing average factor productivity may be associated with decreasing marginal factor productivity in the upper range of input use and damage abatement. Therefore, human capital may increase the average productivity of a factor and, at the same time, reduce the factor demand. The common view that IPM reduces the use of synthetic pesticides is found to be a special case which depends essentially on the form of the production function. Input use reductions by investments in human capital cannot be modeled with production functions that imply constant elasticities of input substitution such as the Cobb-Douglas specification. The following conclusions are offered.

- Human capital embodied in a damage control agent has a positive, none or a negative input demand effect, depending on the current level of abatement and the rates of substitution between different damage control inputs.

- Where abatement is low, human capital is likely to increase the marginal productivity of and, therefore, the demand for one or several control agents. This may be the case where abatement is expensive when compared to the value of the crop due to scarcity of control solutions and/or human capital. Therefore, positive control agent demand effects of human capital are likely to be found in low value crops in developing countries.

- Human capital reduces the total demand for damage control agents where abatement is currently large. Potential yield effects are then small and human capital is predominantly used to reduce input levels. The demands for individual inputs may still increase with human capital.

- Non-chemical plant protection inputs may reduce adverse side-effects of chemical PPA, such as pest tolerance to chemicals. An increase in the marginal effectiveness of this feature raises the demand for chemical PPA.
PART II:

HEALTH IMPACTS ON USERS OF PLANT PROTECTION AGENTS
This chapter gives an overview of technical aspects of occupational exposure to PPA, adverse health effects produced by such exposure, their assessment and prevention. We are solely concerned with occupational exposure of rural populations resulting from the use of PPA in agriculture. We refrain from considering exposure of consumers to residues in food and intentional exposure, i.e. suicide attempts with PPA. The yearly incidences of acute adverse health effects to farmers, agricultural laborers and contract spraymen are between negligible levels and around 30% in developing countries (WHO, 1990), depending on a large number of factors that influence the elements of the causal chain of relationships which produce the health impact. Firm epidemiological evidence of chronic effects of PPA exposure is exceptional (MARONI and FAIT, 1993, p. 141), partly due to the difficulties of assessing exposure variables over longer time periods. Thus, neither the existence nor the absence nor the magnitude of such effects is well established. Further studies on acute and chronic health effects of occupational exposure to PPA are required.
The chapter is organized as follows. Health damage from exposure to PPA is characterized in terms of the populations at risk (Section 5.1), types of toxic effects (Section 5.2) and types of health impacts (Section 5.3). Section 5.4 presents an overview of the variables that may be used to describe health risks and costs. Section 5.5 gives an introduction to the factors that influence the health risk such as toxicity, exposure, absorption and susceptibility. Section 5.6 deals with prevention. In Section 5.7 we briefly discuss health risk assessment methodologies.

5.1 Populations at risk

WHO (1990) identifies a number of subpopulations whose health is potentially at risk due to PPA use in developing countries (Table 14). Expected exposure levels vary widely between these groups.

Table 14: Populations at health risk due to PPA use in developing country agriculture

1. Rural populations with traditional life-style and virtually no pesticide exposure
2. Rural populations in areas with low use of pesticides
3. Rural populations in areas with high use of pesticides, who are exposed through food, air, and water supply
4. Rural populations in areas with high use of pesticides, additionally exposed through direct contact (for instance, occupation)
5. Urban populations in areas with low use of pesticides on crops
6. Urban populations in areas with high use of pesticides on crops
7. Urban populations with additional direct contact exposure

Source: WHO (1990)

Here, we are concerned with the occupational exposure of group number 4 in Table 14. Occupational exposure is compared with non-occupational and intentional exposure (WHO, 1990). Agricultural PPA users or operators include farmers, laborers and contract spraymen who engage in handling and application of PPA.

The group of PPA operators differs from other groups at potential risk in a number of ways:
• PPA operators face relatively large health risks. The yearly incidence of acute adverse health effects and the prevalence of chronic effects attributed to PPA are between few percents and 30% in this group, according to different studies quoted in WHO (1990). The same publication estimates that for every 500 symptomatic cases, there are 11 hospital admissions and one death on average.

• Since acute health effects in this group are relatively frequent, operators must be assumed to be at least partly conscious of the health risk. This conjecture is also supported by the fact that PPA are a common means for suicides among the poor in rural areas in developing countries (WHO, 1990; UTSCHE, 1991). PPA users must be assumed to know about such suicide attempts in their social environment and, hence, to be aware of the toxic quality of PPA. This factor is important because it allows the use of interview surveys, which would be unsuitable in the case of health problems which are not consciously perceived by the person who suffers them.

• Occupational exposure is more accessible to investigation than, for example, exposure resulting from residues in food. It is larger and the resulting health effects can be tracked down more easily to their source. Thus, PPA operators provide opportunities for investigation, particularly on account of the different types and levels of exposure they undergo. Epidemiological data on this group provide direct observations on humans in the real scenarios of exposure. Therefore, studies on occupational exposure contribute valuable information for the investigation of associations between pesticide exposure and health effects (MARONI and FAIT, 1993). Exposure through food or water, by contrast, is commonly so small that health effects are unlikely, and, where they exist, difficult to detect epidemiologically.

• Occupational exposure stems from private activities and the adverse health effects due to occupational exposure represent internal costs. PPA operators are, at least theoretically, in a position to reduce adverse health effects by reducing exposure. Therefore, the group is particularly suitable for examining relative preferences between health and income.

To summarize, epidemiological data on occupationally exposed subjects possess unique features for the investigation of technical and economic aspects of PPA related health risks.
5.2 Toxic effects of PPA

Toxic effects of PPA are acute, subacute, or chronic. Acute poisoning is due to a single, relatively high dose. Sub-acute effects are caused by repeated doses within a relatively short time. Chronic effects result from long-term, repeated exposure. The doses leading to chronic effects may be small and cause no acute effects. The association between chronic and acute effects is not necessarily pronounced (MARONI and FAIT, 1993). With PPA that have high acute toxicities but are readily metabolized and/or eliminated, the main hazard stems from acute, short-term exposure. With others that have lower acute toxicities but tend to accumulate in the body, the main hazards arise from long-term exposure, even to relatively small doses. Other PPA, that are rapidly eliminated but induce persistent biological effects, also present a hazard in connection with long-term, low-dose exposures (WHO, 1990).

5.3 Types of health impacts

The expression "health effect of PPA" covers an extremely wide range, namely from skin irritation to death. Therefore, "health risk" does not mean much if it is not accompanied by a qualitative or quantitative measure for the severity of the effects examined. Health is a multidimensional variable. It includes the possibility of occurrence of different symptoms, in different intensities, for different time periods, to individuals with different preferences. The types of potential health impacts of PPA are thus very heterogeneous. Roughly, one may discriminate between (a) mortality, (b) overt disease morbidity (disease that disables the victim at least temporarily), (c) lesser symptoms, and (d) physiological or biochemical changes that do not result in clinical symptoms. Table 15 lists the factors that should be taken into account when evaluating the public health significance of PPA use in developing countries (WHO, 1990).
Table 15: Variables determining the public health significance of PPA

1. Effects on mortality in general and their influence on
   - Productivity (age-specific mortality)
2. Effects on overt disease morbidity and their influence on
   - Occurrence of permanent disability
   - Productivity (absence from work and daily duties)
   - Medical care services (staff use, drug use, bed use, costs)
3. Effects on the occurrence of lesser symptoms, and of physiological or biochemical changes and their influence on
   - Sensitivity to other environmental factors, nutritional deficiencies, etc.

Source: WHO, 1990

5.4 Health variables

Epidemiologists usually define discrete health variables, i.e. variables that assume only a finite number of values, e.g. "healthy" and "sick". The value assumed is the result of a chain of causal relationships which are subject to uncertainty. This leads to the notion of health risk, defined as the distribution parameter (mean) of a random binary health variable. Referring to a binary variable, the risk parameter fails to measure most quantitative aspects of health.

The health impacts of a product or project are typically composed of many different changes in health (from skin irritations to chronic diseases or death). Table 15 suggests that a differentiation of health effects by severity is required to describe health impacts with any degree of accuracy. A continuous health variable would be preferable with values indicating the degree of severity. Health economists have proposed a number of health indexes (WARNER and LUCE, 1982), such as "quality-adjusted life-years".

When evaluating different projects affecting health, it is sometimes sufficient to consider the costs per increase in the health index, i.e. to perform a cost-effectiveness analysis (WARNER and LUCE, 1982). Clearly, of two projects that increase the health index by a given amount, the one entailing lower costs is preferred. Since the health index is a relative scale, cost-effectiveness analysis allows the evaluation of a project only in relation to some other project. Therefore, cost-effectiveness analysis does not answer
the questions of whether a project should be realized or not, what size a project should have, or whether two projects that were initially considered as alternatives should both be implemented. For example, consider a project A that saves 10 lives at a cost of 10 millions and a project B that saves 5 lives at the same cost. Clearly, when the option is to choose either A or B, A appears optimal. However, when the range of options includes doing nothing or implementing A and B simultaneously, cost-effectiveness analysis is not sufficient as a decision rule. To decide whether project A is better than doing nothing, for example, the analyst or policy-maker will have to judge the value of a life, i.e., perform a cost-benefit analysis. Indeed, excluding the option of doing nothing merely conceals the fact that implementing at least one of the projects is considered better than doing nothing. In the example, the costs of saving one life are at least one million (project A). Thus, restricting the options is equivalent to postulating that one life is worth not less than one million. Thus, cost-effectiveness analysis does not rule out the need to value health. It just assigns this task to the decision-maker instead of the analyst (WARNER and LUCE, 1982).

Traditionally, total costs or benefits are broken down into tangibles and intangibles. Tangibles are defined as costs or benefits that can be appraised at actual or approximate prices or economic values. Intangibles are costs or benefits that, although having values, "cannot realistically be assessed in actual or approximate monetary terms" (GITTINGER, 1982). However, with the development of methods to value certain public goods that were treated as intangibles two decades ago, this distinction has lost much of its relevance.

Health economists break down the total value of a change in health into the cost of illness and a remainder which is approximately an economic measure for the psychic value of health (CROPPEP, 1994). The cost of illness includes reductions in available income by labor loss, reduced labor productivity, defensive or averting expenditures such as expenses for medical care, medication, and protective clothing. Cost components beyond these "tangibles" are the disutility associated with illness, the loss of leisure, and changes in life expectancy (CROPPEP and FREEMAN, 1991, quoted in ANTLE and PINGALI, 1995). In practice, different health measures accounting for differ-

---

14For early studies on the valuation of public goods cf e.g. BISHOP and HEBERLEIN (1979), FREEMAN (1979), McCONNELL (1979), BATIE and SHABMAN (1979).
ent proportions of the cost of illness and the psychic value of health are used in cost-benefit and cost-effectiveness analysis (Warner and Luce, 1982).

5.5 Health risk factors

The causal chain that produces health risks (and impacts) breaks down into four major components: exposure, absorption, toxicological properties of the substance and the susceptibility of the exposed individual. Hazard is defined as a measure of the risk resulting from the combination of toxicity and exposure (Bonsall, 1985a; Goulding, 1985; Turnbull, 1985a). According to this definition, hazard is a characteristic of the practice of using PPA rather than of a substance. Figure 12 gives an overview of health risk factors.
Figure 12: Factors determining health risks due to PPA use

5.5.1 Toxicity

The formulated PPA are composed of active ingredients and constituents such as solvents, carriers, and emulsifiers. Both types of components may be toxic (WHO, 1990). The toxicological properties of PPA vary across active ingredients and different formulations of the same active ingredient. It goes
beyond the purpose of this chapter to give an overview of toxic effects of PPA. Generally, the effects of toxicant absorption depend on the dose and range from manifestations that are detectable only in the laboratory to death, as depicted in Figure 13.

**Figure 13: Manifestations of toxicant absorption**

![Graph showing manifestations of toxicant absorption](image)


The effects of PPA may be detected before adverse clinical health effects occur by measuring minor biochemical changes (WHO, 1990). The "poisoning dose" is defined here as the dose where the first clinical symptoms appear.

### 5.5.2 Exposure

Exposure is defined as the quantity of a substance coming into contact with some organ of the body during a certain time. It is a function of two other variable quantities, the rate of contamination and time. "Actual exposure" is the absolute amount of the PPA either landing on the skin (not clothing) and therefore available for absorption, or present in the air and therefore avail-
able for inhalation (and possibly ingestion of larger particles or droplets) in a given time (BONSALL, 1985a).

Exposure can occur during any activity that involves the handling of PPA, i.e. pouring, mixing, loading, spraying, storage, transportation. Complementary activities such as cleaning and maintenance of application equipment or even unfolding sprayer booms, entail an exposure potential as well (ABBOTT, 1984). Moreover, farmers and agricultural workers who are not involved in the use of PPA may be exposed, for example, when entering a field shortly after PPA applications (TICKNELL, 1985). Accordingly, the rate and duration of exposure depend on technical aspects of PPA use, such as the type of the PPA package (TURNBULL, 1985b), the application equipment (SUTHERLAND et al, 1990), the way the product is transported to the farm and the field, usage, dilution factors and practices such as clothing, hygiene habits, eating, drinking and smoking habits during or after spraying, etc., (GOULDING, 1985), until the way clothing and equipment is washed and maintained after the spraying operation.

A major reason why farmers in developing countries are generally at a higher risk than their colleagues in developed countries, is the widespread use of knapsack sprayers. These sprayers involve short distances between the operator and the spray as well as a large number of mixing operations. COPPLESTONE (1985a) mentions carelessness, unavailability of adequate protective equipment, and the malfunction of application equipment among the "usual root causes" of over-exposure. CROME's (1985) review of exposure studies shows that seemingly minor changes in practices may have significant effects on exposure rates. SUTHERLAND et al (1990) stress the importance of spills from leaking or damaged sprayers even where care is taken to use clean and sound appliances.

The route of exposure is a critical factor which must be considered in prevention. In most cases of PPA use, the largest share of exposure is dermal, as opposed to oral and respiratory exposure (AMBRIDGE et al, 1990; BONSALL, 1985a). It is well-established that mixing, loading and high volume application of non-volatile PPA, other than wettable powder and dusty granular formulations, do not usually generate significant amounts of inspirable particulates (CHESTER, 1996). Dermal exposure is often 100 times larger than respiratory exposure (TURNBULL et al, 1985; CROME, 1985).
Inhalation is the second, ingestion the third most common route of acute occupational exposure to PPA in agriculture (WHO, 1990). Inhalational hazard is mainly relevant in the case of vapors, particularly when PPA are applied in an enclosed space, and possibly in the case of fine sprays from ULV equipment or dust (TICKNELL, 1985). "The vapors of pesticides or aerosol droplets smaller than 5μm in diameter are absorbed effectively through the lungs. Larger inhaled particles or droplets may be swallowed after being cleared from the airways. Ingestion can also occur from the consumption of contaminated food or the use of contaminated eating utensils. Contaminated hands may also lead to intake of pesticides, for example from cigarettes." (WHO, 1990).

5.5.3 Hazard

A simple classification of PPA by hazard may be useful for practical purposes (EDELMAN, 1991). The most widespread classification of this kind is that of WHO. It is largely based on the oral and dermal LD$_{50}$-values$^{15}$ of the active ingredient or the formulated product, the physical state of the product and the expected route of exposure (cf. Table 16).

---

$^{15}$The LD$_{50}$ (lethal dose 50) is the dose that kills 50% of a population of test-organisms (animals), reported typically in mg per kg of body weight. Thus, large values indicate low toxicity. The values are specific, inter alia, to the animal species and the way of exposure. Rats are the most common test animal used to assess the LD$_{50}$-values as predictors of human toxicity.
Table 16: WHO classification of PPA by hazard to humans

<table>
<thead>
<tr>
<th>Hazard class</th>
<th>Oral $a$</th>
<th>Dermal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid $b$</td>
<td>Liquid</td>
</tr>
<tr>
<td>Ia</td>
<td>5 or less</td>
<td>20 or less</td>
</tr>
<tr>
<td>Ib</td>
<td>5-50</td>
<td>20-200</td>
</tr>
<tr>
<td>II</td>
<td>50-500</td>
<td>200-2000</td>
</tr>
<tr>
<td>III</td>
<td>500-2000</td>
<td>2000-3000</td>
</tr>
<tr>
<td>IV</td>
<td>&quot;Unlikely to present acute hazard in normal use&quot;</td>
<td></td>
</tr>
</tbody>
</table>

Source: WHO (1990) $a$ "Oral" and "dermal" refer to the expected routes of exposure. $b$ "Solid" and "liquid" refer to the physical states of the formulations.

This is only a rough classification (WHO, 1986) for the following reasons:

- Quantitative aspects of exposure are largely left out of account.

- The LD$_{50}$ gives only a single point of the dose-response curve. The doses agricultural workers are exposed to are far below the LD$_{50}$. Responses in that range are not necessarily described well by extrapolations from the LD$_{50}$. The WHO classification takes this partly into account by correcting the hazard rating of irritating substances (skin and eye effects).

- The LD$_{50}$ values of an active ingredient and a given route of exposure can vary depending on type, sex and health of the animal, type and concentration of the solution used, and the purity of the substance (UTSCH, 1991).

- Hazard may be influenced by the rate of evaporation, odor and irritating properties, and the potential for accumulation. These properties may vary between different formulations of the same active ingredient.

- Antagonistic and synergistic effects of PPA mixtures are not considered.

- Besides the numerical features of toxicity, there are several other important aspects of the acute toxicity of a product which should be taken into account when appraising hazard. Examples of more qualitative features of hazard are the delay in the onset of toxic symptoms, slow reversion to
normality after effects have occurred, or the lack of an effective antidote (Ticknell, 1985).

5.5.4 Absorption

Exposure is not synonymous with uptake into the body, i.e. absorption. Absorption depends on protective measures, individual attributes, characteristics of the contaminating substance, and environmental conditions (Table 17). Given that occupational exposure to PPA is largely dermal, the most important way of absorption is through the skin.

Table 17: Factors influencing skin absorption of PPA

<table>
<thead>
<tr>
<th>Skin characteristics</th>
<th>• sores and abrasions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• wetness of skin</td>
</tr>
<tr>
<td></td>
<td>• location on the body (absorption occurs readily through eyes and lips, for example)</td>
</tr>
<tr>
<td></td>
<td>• vascularization</td>
</tr>
<tr>
<td>Environmental factors</td>
<td>• temperature</td>
</tr>
<tr>
<td></td>
<td>• humidity</td>
</tr>
<tr>
<td>Pesticide characteristics</td>
<td>• acidity (pH)</td>
</tr>
<tr>
<td></td>
<td>• vehicle</td>
</tr>
<tr>
<td></td>
<td>• physical state (solid, liquid, gas)</td>
</tr>
<tr>
<td></td>
<td>• concentration of the active ingredient</td>
</tr>
</tbody>
</table>

Source: WHO (1990)

The formulation, in particular its physical state and the nature of solvents present in the product, may markedly affect the dermal absorption of PPA (Ticknell, 1985). PPA penetrate different regions of the body surface at different rates. Absorption through sites rich in hair follicles is highest. The backs of hands, abdomen and groin are most permeable (Maibach et al, 1971).

5.5.5 Susceptibility

The toxic effects depend on characteristics of the individual, namely its health state (Forget, 1991). Malnutrition and dehydration are likely to increase the susceptibility to PPA exposure (WHO, 1990). Toxic effects are a
function of the ratio of the absorbed quantity and the body weight. Persons of low body weight are thus generally more susceptible. Some toxic effects apply only to one sex (some reproductive effects, for example) or to the unborns. Ethnical differences and dietary habits possibly explain some of the inconsistencies found in epidemiological studies conducted in industrialized countries on the health effects in humans due to long-term exposure to PPA (Maroni and Fait, 1993).

5.5.6 Interactions

Interactions between the factors contributing to the health risk may play an important role. Some of them are obvious. The ambient temperature, for example, may affect exposure (through evaporation rates), absorption (through changes in skin properties) and susceptibility (through dehydration). Interactions between two and more PPA are less obvious. Simultaneous exposure to different toxicants may result in synergisms or antagonisms. These interactions are rarely accounted for in epidemiological models simply because the main effects are themselves rather difficult to measure. WHO (1990) points out that "[e]ffects that result from the interaction of pesticides, although hard to quantify, are probably of more importance than is generally recognized".

5.6 Prevention of adverse health effects

Prevention may aim at any variable in the causal chain of relationships that produce the health risks, i.e. exposure, toxicity, absorption and susceptibility. These variables, and the means to influence them, may be very specific to certain products, ways of use and types of users. Therefore, the promotion of prevention by safe use recommendations should be specific as well. Health risk reductions can generally be achieved through (a) substitution, (b) education, (c) protective devices, (d) protective practices (Edelman, 1991).

5.6.1 Education, training and information

Education, training and information are preconditions for effective prevention by means of substitution, appropriate use of protective devices and protective practices (Bonsall, 1985b; Turnbull, 1985b). "Misuse of pesticides is often the result of ignorance, which can only be dealt with by education and training" (WHO, 1990). "A high proportion of pesticide intoxica-
tions appear to be due to lack of knowledge, unsafe attitudes, and dangerous practices" (FORGET, 1991). WARBURTON et al (1995) find formal school education positively associated with adoption of protective gear and conclude that there is a "need for well-targeted training programs on the need for and safe use of pesticides".

5.6.2 Substitution

Substitution is meant here to include reduction of PPA use, replacing PPA by other means of plant protection and substituting relatively harmless products for those of a more hazardous nature. Product is understood here as the combination of features of a PPA brand that affect user safety, such as the active ingredient, formulation, container, recommended uses, etc.

Adoption of "good agricultural practices" (GAP) may be the first step not only towards more effective, but also towards safer PPA use (TURNBULL, 1985b). IPM programs may certainly contribute to user safety as their objective is more rational use of plant protection techniques. More effective use of PPA means achieving the same degree of pest control with less PPA and often, but not necessarily, implies a reduction of profit maximizing PPA use levels (cf. Chapter 4).

Many advances have been made in developing safer PPA and safer application methods, formulations (WHO, 1990), and packages. Examples are the use of seed dressings, spot treatments, solid formulations, microencapsulation, water soluble PPA containers, etc. Many newly developed PPA are highly specific to the target organisms, because their action results from the characteristic behavioral or physiological features of these organisms. The specificity makes these products relatively inoffensive to human health. In general, such products are expensive (cf. e.g. SILVEIRA, 1994) with price differentials over more toxic products likely to exceed the farmers' willingness to pay to avoid health risks. As a rule, modern PPA also require specific knowledge. For example, the more specific a product is to a certain target organism, the greater the importance of correct pest identification. In conclusion, the market share of modern PPA is likely to remain relatively low in developing countries.
5.6.3 Protective devices

Adequate protective devices and proper use is almost a science in its own right. The case study to be presented in Chapter 7 shows that the actual protective effect of protective devices may differ considerably from the expected effect and that the largest health risks are due to lack of hygiene and proper maintenance of appliances.

Recommended protective equipment for PPA applications with manual knapsack sprayers includes long sleeved shirts and trousers, rubber boots or leather shoes, a plastic back cover, protection of the head for WHO categories I to III PPA, and an additional overall in the case of more toxic PPA (Ciba-Geigy, 1988). Since the hands are subject to a large proportion of exposure (cf. Figure 15, p. 114), gloves seem to be particularly important (Abbott, 1984; Copplestone, 1985b). Labels often recommend the use of rubber gloves at least while mixing highly toxic PPA (Rosenstein, 1993). Others recommend the use of gloves only when these are of very good quality (low penetration rate), well maintained and properly used, that is, put on and taken off with care (Ciba-Geigy, 1988). Apparently, there is controversy about protective clothing, mainly due to the large differences that exist between the protective properties of clothing of different qualities and the fact that proper use cannot be presumed.

The potential exposure reduction of protective clothing depends, inter alia, on the thickness of the material. However, the operators' acceptance of wearing heavy protective gear may be low in hot climates (Warburton et al, 1995). Normal cotton or polyester clothing may provide significant protection as well, especially when laundered shortly after usage.

5.6.4 Protective practices

Practices that influence exposure and health risks include hygiene, carefulness, proper maintenance of the application equipment and protective devices, safe storage and proper disposal of containers, etc. Personal hygiene needs most attention (Copplestone, 1985b). Soap and water should be available where spraying, mixing, loading, etc., take place and should be used to wash skin and clothing (Abbott, 1984). A change of attire after spraying over a certain area or period of time would reduce penetration rates. In order to reduce absorption, washing should take place as soon as possible after exposure. Careful handling is crucial to prevention, because
very high exposure may result from spills. It would seem that the outsides of PPA packages are often contaminated, leading to exposure of the hands (Calumpang, 1996).

5.7 Health risk assessment

For effective and efficient prevention, exposures and health risks have to be assessed. This involves the following steps: (a) hazard identification, (b) exposure assessment, (c) dosage-response characterization, and (d) risk characterization (Edelman, 1991). Hazard identification involves the evaluation of activities that utilize PPA and the determination of whether any of them poses a potential health risk, without addressing its magnitude. In the second step, exposure assessment, groups that are or may be exposed are identified and exposure levels quantified. Next, the dosage-response relationship is evaluated to determine the correlation between intensity of exposure and probability of health effects. The fourth step, risk characterization, deals with the quantification of the probabilities of various outcomes for a given exposure scenario (Edelman, 1991). These stages apply to both epidemiological and experimental assessments.

5.7.1 Experimental health risk assessment

Ex ante health risk assessments are required for regulation (e.g. registration of PPA), good product stewardship and post-registration surveillance (Chester, 1996). They require two types of experimental information: (a) information about the absorption, biotransformation and elimination of chemicals, the mechanisms of toxicity, and dose-response relationships, and (b) information about the exposure of humans who engage in different activities involving the chemical under consideration (Turnbull, 1985).

Experimental investigations of the toxicology of a compound are typically conducted on animals. More recent experimental methodologies include molecular epidemiology and the use of bio-markers to improve the measurement of exposure. The use of experimental findings to predict effects in humans requires extrapolation of information from species to species and from high doses to low doses (Maroni and Fait, 1993).

Occupational exposure assessment involves the simulation of activities such as mixing, loading and spraying PPA or surrogates, and the measurement of
the quantity of chemicals landing on protective clothing, the skin, present in
the respired air or in a body fluid (WHO, 1985). Actual or potential expos-
ure levels are measured on absorbent patches, the clothing, or the body it-
self. The absorption of chemicals is evaluated with biological monitoring in
combination with human metabolism and pharmacokinetics data (CHESTER,
1996). A large variance of the measured exposure has been found in many
experiments (e.g. CIBA-GEIGY, 1985; CROME, 1985). One reason for this is
that accidental spills may account for a large share of exposure. The number
of spills and the exposure masses resulting from spills vary widely and so
increase the variance of total exposure. The researcher may control spills,
but by doing so limits the usefulness of the experiment to predict exposure
under field conditions.

To summarize, ex ante health risk assessment is subject to considerable
variances or even uncertainties. In order to protect unsafe users of PPA,
safety factors are incorporated in standards (BONSALL, 1985a).

5.7.2 Epidemiological health risk assessment

Epidemiological studies on humans provide more direct information than
experiments. A brief summary of methods to establish links between actual
health outcomes and their causes is given below. Such methods contrast
with others used to quantify single elements of the causal relationship be-
tween PPA use and health effects, e.g. exposure, absorption or dosage
(COPPLESTONE, 1985b).

Study designs

Long-term health outcomes that might result from PPA belong to the group
of degenerative or chronic diseases, the genesis of which is usually multifac-
toral. There is thus no possibility of making a priori associations of health
outcomes and their causes. This makes the investigation of long-term risk
factors inherently difficult (MARONI and FAIT, 1993). A similar situation ex-
ists with respect to acute effects of PPA poisoning. Generally, acute symp-
toms are not specific (FORGET, 1991). The diagnosis of some minor acute
poisoning that causes, for example, headache or nausea, is thus not evident.
Some digestive diseases may cause clinical symptoms quite similar to those
of minor intoxications with organophosphates (CABRERA, 1994).
Due to the non-specificity of intoxication symptoms, evidence for causal relationships between exposure to PPA and health has to be established statistically. An epidemiological health risk assessment therefore consists of a survey of actual health states and variables that may influence health, and the application of statistical methods to estimate the relationship between the two. The variables required to estimate the parameters of a causal relationship between a health response and PPA are the response, the suspected explanatory variables, i.e. exposure to PPA and proxies thereof, and confounding factors.

In order to achieve a variance in these variables, it is necessary to include subjects or situations of varying exposure levels in the study. This can be achieved by (MARONI and FAIT, 1993):

- following up a group of workers over a period of time (prospective or historical cohort studies). The basic outcome is the disease frequency over this time;

- comparing the exposure profile of subjects suffering from the disease of interest (cases) with that of other subjects (controls) who were free of disease at the times when the cases were identified (case-control studies);

- comparing the distribution of causes of death among workers with the corresponding distribution among a reference population (proportional mortality studies). Exposure is not assessed, but assumed to vary according to hypothesized patterns between the groups. Therefore, controlling for confounding factors may be difficult in proportional mortality studies.

- assessing the prevalence of disease and explanatory variables in a cross-section (cross-section study).

Case studies of subjects that are suspected to have contracted an adverse health effect due to exposure to PPA may contribute to the identification of research needs, but do not provide statistical data, of course.

*Developed countries*

The following summary of methodological problems is largely based on the review of 440 studies conducted by MARONI and FAIT (1993). Those studies refer almost exclusively to developed countries. Data on exposures and confounding factors should be detailed to allow the detection of associations.
between health states and suspected causes. This may be difficult to achieve because the relevant exposures may have occurred several years before the diagnosis. It is thus not surprising that the lack, or inadequacy, of exposure variables is the major problem in epidemiological assessment of the long-term effects of PPA on human health (Bonsall, 1985b; Maroni and Fait, 1993). In their review, Maroni and Fait (1993) conclude that (a) in many cases, the nature (quality) of exposure was not even defined, which does not allow any valid conclusion to be reached, and (b) in most studies, quality and quantity of exposure were poorly documented. The lack, or inappropriateness, of exposure variables tends to bias estimates toward the null and dilute exposure-response gradients due to non-differential misclassification. Such a bias is of greater concern in interpreting studies that seem to indicate the absence of an effect. A second methodological problem lies in the large sample sizes required to detect small risks. Where sufficient sample sizes are available, stratification by exposure categories or exposure level often causes a heavy reduction in numbers in the strata. If exposure was assessed in more detail and with consistent methods, stratification could be avoided by taking continuous or interval exposure variables, thus increasing the effective sample sizes. Third, agricultural populations tend to have a mixed exposure to many PPA, making it difficult to attribute health effects to single compounds (Bonsall, 1985b). Fourth, empirical evidence of the existence or absence of certain health effects of PPA is sometimes established, but the results are not sufficient to obtain reliable risk factors.

Developing countries

Elicitation of both health states and exposures may pose considerable difficulties in developing countries. The types of problems depend on whether chronic or acute health effects are surveyed.

Chronic symptoms are not normally obvious, neither to the person who suffers them, nor to medical professionals. This implies that the diagnosis of chronic symptoms must be a specialized medical one. Records kept at hospitals or by physicians are often deficient, both with respect to the number of patients and the kind of information (Ravindra, 1995). Moreover, the percentage of cases who consult medical doctors is usually small and uncertain (cf. Crissman et al, 1994), precisely because some chronic symptoms are not truly appreciated by the patient and because of the scarcity of public health care services. The patients' histories with respect to true or at least potential exposure to PPA must be known in some detail in order to allow
the estimation of meaningful statistical models. When farmers or laborers are under examination in a retrospective study, the only way to assess exposure is to conduct interviews on their history of PPA use.

Some problems encountered when trying to establish the incidence of acute symptoms are the following. An unknown and uncertain percentage of the actual cases consult medical professionals (cf. UTSCH, 1991). Hence, specially designed surveys have to be conducted. A professional diagnosis of health states would be preferable in order to achieve best possible accuracy in the response variable. In practice, this may be difficult. Trained medical staff would have to be present when and where intoxications happen, that is, at the time of spraying in the farmers' fields or at least after conclusion of the work in the farmers' villages or homes. It cannot be excluded that this presence induces farmers to change their behavior temporarily towards safer practices. This would cause a bias.

In order to reduce costs and potential interviewer bias, health states may be surveyed simply with interviews. In that case it is sufficient for the interviewer to visit the farmer some time after possible occurrence of exposure and acute health effects. The farmer could thus not change behavior in function of whether he is interviewed, but reporting errors are nevertheless possible. The survey should be complemented with an assessment of the accuracy of the farmers self-diagnosis. Moreover, so-called strategic bias may result when farmers feel that the survey might incite political action.

**Review of epidemiological studies on long-term health impacts of occupational exposure to PPA in developing countries**

The 440 studies reviewed by MARONI and FAIT (1993) have found it difficult, with few exceptions, to detect long-term effects of PPA on human health. Almost all of these studies are from North America, Europe, Australia, and New Zealand. Some studies from developing countries, by contrast, show significant effects, even when sample sizes are small.

CRISSMAN et al (1994) find that Ecuadorian potato growers exposed to PPA perform significantly worse in several neurophysiological tests and show an increased incidence of chronic dermatitis, as well as some other symptoms that might be related to long-term exposure to PPA. Costs of illness due to acute effects are around US$ 10 income loss plus US$ 18 of expenses for
private health care per case, but unfortunately, the frequency of such cases is not reported.

PINGALI et al (1994 and 1995) present a cross-section study on rice farmers in the Philippines. The farmers were medically examined for a number of diseases which were regressed on exposure and confounding factors with a logit model. Insecticides of WHO categories I and II were found to significantly increase the risks ofpolyneuropathy, skin problems, and gastrointestinal disorders in a sample of rice farmers in the Philippines. Improvised cloth covers over the mouth tend to increase pulmonary diseases and significantly increase the risk of multiple impairments. The exposure variables are defined as the number of recommended doses applied in a single season. They are thus only rough approximations to actual exposure, given that the examined health effects are suspected to relate to long-term exposure, i.e. exposure over many seasons. The use of approximations would be expected to dilute the results, i.e. to bias parameter estimates toward the null (MARONI and FAIT, 1993). Hence, the true association between exposure and health outcomes might be even more accentuated. On the other hand, the authors rely heavily on the assumption that health impairments do not influence input allocation. This assumption is contradicted, or at least questioned, by another study on the same area (ANTLE and PINGALI, 1994 and 1995) in which reductions in health are found to increase production costs. Thus, PPA use and health problems are potentially simultaneous, implying that the results are potentially biased.

ROLA and PINGALI (1993a) reproduce results of another study from the Laguna area in the Philippines (MARQUEZ et al, 1992). The prevalence of diseases in two groups with different exposure levels were compared. The group with higher exposure showed significantly elevated prevalence of the eye disease pterygium, skin and nail problems and respiratory diseases. Control for confounding factors such as age and drinking habits yielded significant differences in some other diseases as well.

RITA et al (1987, quoted in MARONI and FAIT, 1993) found a positive association of adverse reproductive effects and exposure to various PPA in a retrospective cohort study on 12 couples employed as applicators in grape gardens.

There are thus some studies establishing causal relationships between occupational exposure to PPA and chronic health effects. Acute health effects are
so frequent in developing countries (TURNBULL, 1985a; WHO, 1990; RAVINDRA, 1995) that we abstain from reviewing literature. Empirical evidence on the frequency of acute effects in the project areas is given in Chapters 6, 7 and 8. An annotated bibliography on health impacts from PPA to operators is given in VALMONTE-GERPACIO (1995).
6 Case Study: Occupational exposure to PPA

Prevention may aim at any link in the causal chain of relationships between the health risk and features of PPA use such as toxicity, exposure, absorption and susceptibility. The masses of operator exposure may vary by several orders of magnitude which suggests that exposure patterns are a crucial feature to be considered in the design of safe use recommendations. This study presents the results of a visual survey of 330 Mexican small-scale maize farmers. Exposure occurrences and their distribution over the body were recorded during various activities. Results indicate that most exposure occurs before the actual spraying operation starts, i.e. during mixing, loading and putting on the backpack sprayer. Accidental spills account for large proportions of total exposure. The hands are often exposed, in particular to the concentrated PPA during mixing and loading. Where such exposure patterns prevail, prevention should aim at making the mixing operation safer through avoidance of spills and hygiene. Since the actual mass of exposure from spills varies widely and is virtually unobservable to the PPA operator, we doubt that operators know that spills account for a major share of exposure and, hence, health risks. Safe use communication efforts should take this into account and teach farmers that health risks relate predominantly to dermal exposure and spills on the hands. Safer PPA formulations and packages might also reduce exposure to the concentrate to a large extent.
6.1 Introduction

There is a dual motivation for including this rather technical case study in a thesis that basically tries to arrive at economic measures for the health impacts of PPA. First, an interdisciplinary approach seems appropriate as researchers with little experience on the technical aspects of exposure, such as economists (including the author), have tended to regard prevention of operator exposure to PPA mainly as use of protective gear (e.g. ANGLE and CAPALBO, 1994; CRISSMAN et al, 1994; CROPPER, 1994). However, protective clothing is only one of several means of prevention and perhaps not the most obvious one. Second, from the very beginning of the project we were confronted with the need to define priorities for communication. The literature and extension materials available usually enumerate a great number of measures to prevent exposure to PPA. However, extension should focus on recommendations that (a) reduce health risks by significant proportions, (b) are not currently practiced, and (c) are expected to be accepted and adopted. In areas where the incidence of acute adverse health effects is low although no special protective gear is used, operators will certainly be reluctant to invest much in reduction of the already low risks. This is the case, for example, in the Mexican project area which provides the data for this study. Hence, recommendations should be highly practical and, whenever possible, provide benefits that go beyond health risk reduction. In other regions, average acute health risks and associated health costs are higher, increasing the potential benefits of prevention and therefore the operators' motivation for change (cf. Chapters 7 and 8). However, priority setting is crucial in those areas too, because the motivation for change should not be frustrated by recommendations that yield insignificant risk reductions.

Just as economically optimal production techniques vary between regions—or recommendation domains (HARRINGTON and TRIPP, 1984)—according to variations in the economic, social and agroecological circumstances, ways to improve PPA operator safety may have to be differentiated depending on local characteristics. Some standard recommendations for safe use, by contrast, appear to have been formulated on the sole consideration of the experimentally assessed exposure reduction achieved by different practices, neglecting aspects of comfort, omitting maintenance of protective gear and equipment, ignoring the need to prioritize communication (TURNBULL, 1985b), and without taking the farmers' readiness to adopt measures into
account (Calumpang, 1996). In this study we examine PPA exposure in order to facilitate the required differentiation by highlighting the specificity of exposure patterns.

The study is organized as follows. Section 6.2 reviews earlier studies that show how exposure patterns vary and presents an instructive visualization of exposure. In Section 6.3, the data collection method is described. Section 6.4 reproduces the results on exposure patterns and the incidence of adverse health effects. Conclusions are presented in Section 6.5.

6.2 Operator exposure to PPA

A comprehensive review of exposure assessment studies is given in Crome (1985) and Turnbull et al (1985). It is interesting to note that exposure levels from seemingly similar activities vary by several orders of magnitude. Actual skin contamination at the operation of mixing for knapsack sprayers, for example, ranges from 0.7 to 19.3 mg formulation / person / hour. Actual dermal exposure to the dilution at spraying different crops with knapsacks is between 0.03 and 3 mg spray / person / hour. The quoted figures show also that exposure to the active ingredient at mixing may be a multiple of that at spraying. This is confirmed by Abbott (1984) who reports that exposure at mixing and loading may account for more than 50% of total exposure.

The large variance in exposure levels is amazing in view of the fact that the studies reviewed by Crome (1985) were conducted under controlled conditions, that is, excluding heavy spills (Turnbull et al, 1985). Ciba-Geigy (1985) finds that the carefulness of the operator is a major source of the variance. Sutherland et al (1990) write that "contamination occurring during the normal application of sprays is of minimal significance when compared with contamination caused by leaking and damaged sprayers". In a survey of Utsch (1991), many PPA users "indicated that when they strap the full tank on to their backs the pesticide solution spills over the top of the tank because it is too full or not properly closed." Similar findings are reported by Calumpang (1996) who finds exposure levels to farmers spraying the same crop with the same PPA and similar clothing to vary largely, as shown in Figure 14.
Figure 14: Actual exposure to methyl-parathion residues of four farmers having sprayed string beans at fruiting stage with manual knapsack sprayers wearing normal working clothes


Note that exposure of farmer #1 is around 10 times that of farmer #2. Most of the exposure at spraying is to the legs and thighs. CALUMPANG explains the difference in exposure between farmers #1 and #2 with minor but important differences in the ways the two farmers moved their arms and body at spraying and the fact that farmer #1 walked through wet weed which wetted his trousers and so increased the penetration rates of the PPA through the clothing. The difference between farmers #2 and #4 is partly due to differences in the types of clothing worn.

While exposure at spraying is in the range of 1 to 15 mg, CALUMPANG found 500 mg of PPA on the hands of one farmer exposed to a spill of the formulated product at mixing! She points out that spraying extremely hazardous PPA in high crops with practices that are less safe than those recommended results in exposure below tolerable levels when spills are avoided: The extrapolated no-observable-effect-level (NOEL) of exposure to methyl-parathion is around 20 mg, a level which is exceeded with the spraying practices examined after spraying 1000-2500 m². We report this finding to
stress the importance of spills—of course, health risks are not zero even when spills are avoided.

As evident from the above-mentioned example, the hands may be exposed to very high levels of PPA. Davis et al (1983) find that 95 to 99% of total exposure is to the hands, although with appliances that differ from those used in the study area. Abbott (1984) finds the hands to account for 85% of average exposure at mixing and loading and for 33% at spraying, as shown in Figure 15. 53% of the total exposure from both activities are to the lower legs and feet.

**Figure 15:** Exposure of body parts during different activities (herbicide, knapsack sprayer with single front lance)

![Bar chart showing exposure percentages for different body parts during mixing, loading, and spraying.](chart.png)

Source: Abbott (1984)

Figure 16 visualizes exposure to a fluorescent PPA tracer (surrogate) under ultraviolet light. The pictures show the participants of a seminar on PPA safety after they had simulated mixing and spraying with different tools and appliances. Special clothing was worn to more clearly show potential exposure. Bright spots indicate contamination (except seams and zippers).

---

Figure 16: Exposure patterns

a: Exposure to a spill from a badly closed knapsack sprayer

b: Exposure to mist (spraying upwards with a mist blower in an orchard)

c: Contamination of gloves at pouring out PPA from an impractical canister

d: Contamination of hands through thin plastic gloves

Source: Photographs are courtesy of Ciba-Geigy
The figure shows that exposure patterns depend largely on random events such as spills. Where exposure patterns such as those depicted in panels a, c, and d prevail, it is not surprising that exposure levels vary widely under apparently similar conditions. It is also apparent that thin plastic gloves are by no means a panacea to the exposure of the hands\textsuperscript{17}.

6.3 Survey and data

Three hundred and thirty small-scale maize growers were each observed during one day of PPA application work, from the time they left the house in the morning until they concluded the operations related to PPA. Observations were recorded separately for each of the 1272 tank loads prepared and sprayed, that is, for 3.85 tanks per farmer on average. (The farmers prepare the dilution for one tank load at the edge of the field, spray that load and return to prepare the next one.) The mixing/loading operations were observed from a few meters away. The spraying operations were observed from larger distances since it was too inconvenient to follow the farmers into the fields while they walked and sprayed up and down the maize rows.

Visible contacts of the clothing or skin with the PPA formulation or the dilution were recorded at the operations of mixing/loading, putting on the sprayer, and spraying. The data includes information about the distribution of these contacts over the body. It should be recognized that the data collection method gives only an approximate picture of exposure patterns, since the mass of actual exposure was not recorded. However, we will see that the results allow conclusions on some characteristics of exposure.

\textsuperscript{17}When made of appropriate materials (e.g. Neoprene), washed and maintained carefully, gloves may reduce exposure and, hence, health risks to a large extent, as implied by the high potential exposure of the hands. However, it will be a long time before this state-of-the-art is achieved, not only in developing but also in developed countries. When not used properly or of inappropriate materials, gloves are penetrated rapidly and may give a false feeling of safety. Gloves are extremely cumbersome in hot climates. They reduce dexterity which is problematic at mixing, because it may cause additional spills. Exposure may also result from touching the contaminated outsides of gloves when putting them on and taking them off. We think that currently there are many practical means of exposure reduction which have not yet been adopted, and which are easier to implement and more effective than gloves.
The PPA used on the day of observation included herbicides (85% of the farmers) and insecticides. The main herbicide active ingredients used were paraquat (WHO hazard class II) and 2,4-D (II). The most frequently used insecticide active ingredient was methyl-parathion (Ia). Data was collected in 1995 towards the end of the season. Therefore, PPA usage is not representative for the whole maize season. All the farmers used manual knapsack sprayers with single front lances.

After conclusion of the work, the farmers were asked whether they felt ill and those who did whether they had already been aware of the symptom before starting work.

The presence of the observer during the spray work might influence the farmers' practices. The effect can be expected to decrease with time, i.e. to be more important at the first tank loads of the day than at the last loads. Examination of the data showed that the practices are virtually independent of the time of the day. Therefore, the presence of the observer is unlikely to have introduced a bias.

6.4 Results

6.4.1 Sources of exposure

Table 18 reproduces the sample statistics with respect to visible, potential exposure of the operators to the concentrated (formulation) or diluted PPA. Note that potential dermal exposure refers to contacts of PPA with the skin or clothing, while actual dermal exposure is the amount coming into contact with the skin. The column "Farmers" gives the percentage of farmers who were subject to the exposure type given in the left column at least once during a given activity. The column "Operations" gives the percentage of the 1272 mixing, loading and spraying operations (tank loads) that lead to a particular exposure type.
Table 18: Visible sources of potential exposure

<table>
<thead>
<tr>
<th>Activity</th>
<th>Contact with ...</th>
<th>Farmers</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixing, loading</td>
<td>dilution</td>
<td>17.0%</td>
<td>8.6%</td>
</tr>
<tr>
<td>Mixing, loading</td>
<td>formulation</td>
<td>17.6%</td>
<td>9.0%</td>
</tr>
<tr>
<td>Mixing, loading</td>
<td>formulation or dilution</td>
<td>27.9%</td>
<td>15.9%</td>
</tr>
<tr>
<td>Putting on sprayer</td>
<td>dilution</td>
<td>11.5%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Spraying</td>
<td>dilution (spray mist)</td>
<td>12.4%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Spraying</td>
<td>dilution (spills from leaking, badly closed or wet sprayers)</td>
<td>11.8%</td>
<td>10.2%</td>
</tr>
<tr>
<td>All</td>
<td>formulation or dilution</td>
<td>59.1%</td>
<td>-</td>
</tr>
<tr>
<td>Sample size</td>
<td></td>
<td>330</td>
<td>1272</td>
</tr>
</tbody>
</table>

A large proportion of the farmers is exposed at mixing or at putting on the sprayer. The mixing operation may result in potential exposure to the formulation (concentrated PPA) which is particularly hazardous, namely when liquid PPA are used. Such exposure may stem, for example, from splashes of the formulation poured into the measuring device, or from touching contaminated PPA containers, strainers and other tools. Exposure to the spray mist was observed in 12% of the cases. However, this is likely to be an underestimation since the spray mist is relatively difficult to observe. A considerable number of farmers is exposed to spills from leaky or carelessly operated sprayers.

In spite of the limitations of the data collection method, the results indicate that much of the exposure occurs before the actual spraying operation starts. This is in accordance to the literature presented above.

6.4.2 Distribution of exposure over the body

Figure 17 illustrates the distribution of exposure occurrences at mixing over the body as found in the visual survey.
The hands account for 96% and 72% of the observed occasions of exposure to the formulation and the dilution, respectively. The finding is consistent with ABBOTT (1984), suggesting that simple observation of contacts between the body or clothing and the PPA may indeed give a useful indication of exposure patterns.

Figure 18 gives the distribution over the body of visible exposure to spills when putting on the sprayer and to the spray mist.
Exposure to spills when putting on the sprayer mainly affects the back. Observation revealed that exposure to the spray mist is almost exclusively to the feet and legs. This is not surprising given that most farmers used herbicides.

To summarize, the hands are potentially exposed during mixing, the feet and legs during spraying. Much of the total exposure appears to be due to spills and splashes.

### 6.4.3 Protective practices

Potential exposure translates into actual exposure to the extent that the PPA lands on the skin or penetrates through the clothing and reaches the skin. Table 19 breaks down observed occurrences of exposure according to whether the contact was to the skin (directly) or the clothing.
Table 19: Potential and actual exposure

<table>
<thead>
<tr>
<th></th>
<th>Percentage of farmers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Skin</td>
<td>Clothing</td>
</tr>
<tr>
<td>Hands</td>
<td>26.7%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Feet</td>
<td>32.7%</td>
<td>10.6%</td>
</tr>
<tr>
<td>Legs</td>
<td>3.6%</td>
<td>17.3%</td>
</tr>
<tr>
<td>Trunk &amp; arms</td>
<td>7.9%</td>
<td>6.1%</td>
</tr>
</tbody>
</table>

Only three farmers of those subject to potential exposure of the hands were wearing gloves and therefore potential exposure to the hands translates directly into actual exposure. Moreover, the gloves used are of poor quality and penetration rates must be assumed large. In many cases, the feet were not protected either. (Some farmers spray barefooted or wearing sandals.) The legs were covered in most cases, the trunk and arms in about half of the cases. Cotton shirts and trousers may provide significant protection from exposure to the spray mist when they are clean and in good condition. However, spills of the type shown in Figure 16a are likely to completely soak the cloth. Under such conditions, cotton clothing cannot be expected to reduce exposure much (Calumpang, 1996).

6.4.4 Health problems

Ten farmers (3.0%) reported suffering some symptom of ill health at the end of the spraying operation, including 3 cases of headache, one case each of bodyache, backache, exhaustion and burning eyes. Four of these farmers (1.2%) claimed to have suffered the symptom already before starting the spray work, leaving a remainder of 6 farmers (1.8%) who are suspected to have contracted an adverse health effect of exposure to PPA. Moreover, symptoms such as backache and exhaustion appear to be due to carrying the sprayer rather than to PPA. The incidence of health problems is thus very small and only minor health problems were found. Interview-surveys of larger samples conducted several days after spraying operations (in other years) gave similar incidences of adverse health effects per day of PPA application work.

The low incidence of health effects might appear surprising in view of the large percentage of farmers who are exposed to the diluted or even the con-
centrated PPA and the highly toxic chemicals used. The overwhelming majority of farmers do not experience adverse health effects, even though they use PPA rather carelessly and are observably exposed to PPA. Apparently, observable exposure does not necessarily cause adverse acute health effects, implying that exposure levels sufficiently large to produce noticeable symptoms occur when operators are exposed repeatedly or continuously to large quantities.

However, what is observed is the occurrence of exposure rather than the mass or rate of actual skin contamination. This has important implications on the operators' possibilities to estimate risks based on experience. Most operators experience visible exposure quite frequently. Nevertheless, they rarely suffer health problems due to PPA. Therefore, we hypothesize that it is difficult for the operator to perceive the link between spills and health risks. Therefore, it is not surprising that most farmers are unaware that the bulk of the health risk is due to dermal exposure. Adverse health outcomes have an unpredictable accidental character to operators. This does not signify that operators would not have reached a subjective health risk estimate, namely where health effects are more frequent than in the Mexican project area. Operators might have an idea about the expected frequency of poisoning occurrences, based on their own experiences and those of their neighbors. However, the perception of the causal relationship between the mass of dermal exposure and the health risk is likely to remain problematic.

Due to the low incidence of adverse health effects, it was not possible to build and estimate meaningful statistical models relating the health outcomes to the number of exposure occurrences, the active ingredients or groups of brands. A logit model relating the health outcomes to PPA use practices in Zimbabwe—where health effects are more frequent—is presented in the next chapter.

\textsuperscript{18}UTSCH (1991) asked Sri Lanka farmers whether they considered health problems to be the result of PPA accidents or consequences of "normal use". Most respondents thought that the symptoms were side-effects of normal use. However, in the area examined by UTSCH, the incidence of health problems is much larger than in our case. Interestingly, a few farmers attributed the health effects to spills and still considered them results of normal use rather than accidents.
6.5 Conclusions

A relatively simple survey method has been used to examine exposure patterns. Results indicate that spills of the concentrated product over the hands are the major source of exposure. The mixing and loading operations are particularly risky. Literature indicates that exposure during spraying tends to be much lower and below tolerable levels even with practices that are less safe than those recommended. This clearly shows the importance of carefulness and hygiene during mixing. Indirectly, it also suggests that PPA formulations and containers should be designed such as to minimize the probability of spills, splashes and exposure (e.g. solid formulations, water soluble PPA bags).

The survey method certainly requires that results be interpreted with due care. In particular, the number of observed occurrences of exposure give only an approximate picture of actual exposure. However, the study highlights certain characteristics of operator exposure to PPA and the related health risks:

- Since much of the exposure results from spills, exposure patterns are likely to depend on details of the way the mixing, loading and spraying operations are performed. Exposure patterns are thus highly specific not only to the crop, the type of product used (liquid or solid, insecticide or herbicide, etc.) and the appliance, but also to the habits adopted when handling PPA.

- While the occurrence of exposure is visible in many instances, the mass of contamination is not. This implies that PPA operators are in a poor position to recognize the causal link between dermal exposure patterns and health risks. Figure 19 visualizes this hypothesis. The upper half of the figure shows the most important causal relationships that produce the health risk. The PPA user may well be aware that PPA involve a health risk (see later chapters for a discussion of awareness). However, the way the health risk is influenced by exposure patterns and, hence, by the way PPA are used is partly hidden to his perception—they are a black box, as shown in the lower half of the figure.
Figure 19: Hypothesized perceptions of causal relationships between PPA use and health risks

Since experience is the major source of information to farmers and fails to provide insight into the causal relationships between health and exposure patterns in this case, it is not surprising that PPA are used quite carelessly.

- Operators may have a notion about the frequency of health problems based on their own experience and that of their neighbors, but the risk at a given moment is largely hidden to their perception.

- Adverse health effects have the character of an accident, meaning that they occur when several unfortunate circumstances, e.g. heavy exposure from different sources, combine. This implies that prevention efforts should simultaneously address the most important sources of exposure, such as exposure of the hands to the formulation, exposure to spills and to splashes from leaking sprayers.
7 Case Study: Health risk effects of PPA use practices

We estimate the relative health risks due to different practices, including the use of protective gear, the maintenance of spraying equipment, the type of active ingredients used, the cropping stage and the time spent spraying. The health problems examined are the acute symptoms farmers report to have suffered during or after a day of PPA application, mainly nausea, giddiness, headache and skin problems. Data is from small-scale cotton farmers in Sanyati and Gokwe, Zimbabwe. Overalls, footwear and homemade cloth masks failed to prove efficacious in reducing health risks. Considerable proportions of adverse health effects are due to sprayer leaks and lack of hygiene during breaks. Hygiene seems to be the single most important precautionary measure. Hand-held ultra light volume sprayers are riskier per work day than knapsack sprayers. Simulations suggest that adoption of simple practices, such as basic hygiene, long sleeved shirts and trousers, and maintenance of spraying appliances, would reduce the incidence of adverse health effects from currently 12 to 4% per day of spray work. We conclude that safe use extension should follow a step by step approach, first promoting basic safety practices. The study provides evidence that farmers are generally able to recognize the link between poisoning symptoms and PPA.
7.1 Introduction

Should we try to convince farmers to use protective gear, to substitute relatively inoffensive PPA for the currently used products, to wash after spray work, or to fix their leaking sprayers? If the answer is that all these precautionary measures should be promoted, then where should we start? This chapter tries to help answer these questions. The health significance of a number of safety relevant practices in the project area in Zimbabwe are examined with epidemiological logit models. The study focuses on acute health effects because of the difficulties involved in assessing chronic responses. Three types of results are obtained. First, health risk factors are estimated. These are the proportional reductions and increases in health risks (odds ratios) to individuals that result from different practices. Second, the estimated risk factors are combined with information about the current adoption of preventive practices in order to predict health risks under hypothetical adoption of safer practices. Third, the regression results are used to draw conclusions about the accuracy with which farmers associate poisoning symptoms with PPA or, more precisely, the proportion of health problems farmers wrongly attribute to PPA. However, it does not allow conclusions to be reached on the potential existence of health problems that are due to PPA but wrongly attributed to other reasons.

The chapter is organized as follows. Section 7.2 gives an overview of the PPA use practices in the study area. Sections 7.3 to 7.5 present the generic epidemiological model, the data and variables and the estimation results. In Section 7.6, we simulate adoption of some safety practices and predict the resulting health risks. In Section 7.7, we draw conclusions about the accuracy of the survey method with respect to the health variables by examination of the predictive power of the statistical models. Conclusions are offered in Section 7.8.

7.2 PPA use practices in Sanyati and Gokwe

7.2.1 Types of PPA

The PPA used in cotton in the Zimbabwe project area are exclusively insecticides. The most frequently used active ingredients are organophosphates
(64% of the observations), carbamates (14%), pyrethroids (13%) and organochlorines (9%). The single active ingredients are listed in the following table, together with their respective oral and dermal LD$_{50}$-values and WHO hazard classes.

Table 20: Active ingredients used in cotton in Sanyati and Gokwe

<table>
<thead>
<tr>
<th>Common name</th>
<th>Chemical type</th>
<th>LD$_{50}$ (rats) [mg/kg body weight]</th>
<th>Oral</th>
<th>Dermal$^a$</th>
<th>WHO class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl</td>
<td>carbamate</td>
<td>300</td>
<td>&gt; 4000</td>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Carbosulfan</td>
<td>carbamate</td>
<td>209</td>
<td>&gt; 2000</td>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Cyhalothrin</td>
<td>pyrethroid</td>
<td>243</td>
<td>200-2500</td>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Demeton-S-methyl</td>
<td>organophosphate</td>
<td>40</td>
<td>30</td>
<td></td>
<td>Ib</td>
</tr>
<tr>
<td>Dimethoate</td>
<td>organophosphate</td>
<td>150</td>
<td>600</td>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Endosulfan</td>
<td>organochlorine</td>
<td>80</td>
<td>359</td>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Fenvalerate</td>
<td>pyrethroid</td>
<td>3200</td>
<td>&gt; 4200</td>
<td>unlikely</td>
<td></td>
</tr>
<tr>
<td>Fluvinate</td>
<td>pyrethroid</td>
<td>1097</td>
<td>&gt; 2000</td>
<td></td>
<td>II</td>
</tr>
<tr>
<td>Thiodicarb</td>
<td>carbamate</td>
<td>66</td>
<td>&gt; 2000</td>
<td></td>
<td>Ib</td>
</tr>
</tbody>
</table>

Sources: Types of active ingredients used: survey data; toxicity: WHO (1986), AMBRIDGE (1990), TOMLIN (1994);$^a$ dermal values of fluvinate and thiodicarb refer to rabbits, dermal toxicity of cyhalothrin depends on sex of test animal.

Table 21 presents the acute intoxication symptoms of these chemicals.

Table 21: Symptoms of acute intoxications with some types of PPA

<table>
<thead>
<tr>
<th>Type of PPA / Intoxication symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organophosphates:</strong> Weakness, headache, vertigo, blurred vision, nausea, stomachache, flow of tears, pupil contraction, salivation and sweating, dizziness, thoracic tension, bronchial secretion, muscular spasms, loss of motory control, slow cardiac rhythm, vomiting, convulsions, shock, involuntary defecation and urination, coma, respiratory failure</td>
</tr>
<tr>
<td><strong>Carbamates:</strong> Identical symptoms as with organophosphates, but faster recovery</td>
</tr>
<tr>
<td><strong>Organochlorines:</strong> Headache, fainting, trembling, tonic and clonic movements, muscular weakness, pallor, spasms, convulsions, coma. Nausea, dizziness and vomiting in the case of ingestion.</td>
</tr>
<tr>
<td><strong>Pyrethroids</strong> act as sensitizers. Common effects when respired: nasal occlusion, rhinorhea, feeling of roughness in the throat.</td>
</tr>
</tbody>
</table>

Source: AMIPFAC (n.d.)
7.2.2 Appliances

The insecticides are applied to the crop as sprays. Three types of appliances are used: lever-operated knapsack sprayers with single front lance, knapsack sprayers with a tailboom of up to six operating nozzles, and ultra-light-volume (ULV) sprayers. The latter are small, hand-held, battery driven spin disc sprayers. There are important differences between these sprayer types with respect to potential exposure, providing an example of how exposure patterns vary in relation to technical details of the spraying operation:

- Operators using single-lance manual knapsack sprayers pass along each row of cotton once while the crop is low and twice to cover both sides of the plant when the crop is high. The lance is held in front of the operator who therefore walks into the spray. The nozzles of the tailboom sprayer are located so that they cover the crop on both sides of the path. Therefore, the operator passes only once along each row. The tailboom is mounted on the back of the appliance and therefore the operator walks away from the spray mist. With ULV sprayers it is sufficient to pass along one of two or three rows. The sprayer is held so that light crosswinds may carry the droplets to a number of rows downwind of the operator.

- Single-lance and tailboom sprayers are loaded with a watery dilution of PPA. When spraying, the operator is potentially exposed to the diluted spray. ULV sprayers are loaded with the concentrate which increases the probability of the operator coming into contact with the concentrate at mixing and loading or when leakage occurs.

- The number of tank loads required to spray one hectare is much larger with knapsack sprayers than with ULV sprayers. Hence, the number of times an operator engages in loading the sprayer is reduced with ULV sprayers. This should reduce exposure.

- Since ULV sprayers are loaded with the concentrate, no water is required. This may signify that farmers do not haul any water for washing, either, especially when the water source is far away. Hence, hygienic practices may correlate with the appliance type.

- Experiments have found similar exposure levels of ULV and knapsack sprayers per acre when exposure from spraying is considered on its own (CIBA-GEIGY, 1985). However, ULV sprayers allow a larger area to be
covered in a given time than knapsack sprayers. The total expected exposure per day might thus be higher with ULV sprayers.

- The distribution of exposure over the body differs between appliances as shown in Figure 20. Besides hands and feet, trunk and arms are the body parts which suffer the greatest exposure with ULV sprayers. The legs suffer a relatively high degree of exposure when knapsack sprayers are used.

**Figure 20:** Exposure of body parts with different sprayer types  
(insecticide, spraying only, 1 meter high cotton)

Source: Data from CIBA-GEIGY (1985). Note: Exposure of hands and feet was not measured.

### 7.2.3 Protective gear

Protective gear, in the sense of clothing and other items specifically designed for the application of PPA, is not used. However, normal cotton working clothes should also provide significant protection, insofar as they are long-sleeved and washed after spraying (STONE et al, 1989). Penetration rates of specific protective clothing, such as overalls, gloves and boots in good condition are typically between 1 and 5%, corresponding to an expo-
sure reduction of the covered body parts by 95 to 99%. Normal trousers and shirts reduce exposure of the covered skin roughly by 80%. (Figures are courtesy of Ciba-Geigy. Similar exposure reductions have been found by Calumpang, 1996). The following gear is used.

- More than half the farmers use some type of closed footwear. Footwear should reduce exposure considerably during applications with knapsack sprayers, according to the exposure patterns presented in Figure 18 (p. 120) and Figure 20.

- Improvised plastic covers are also common. In spite of not being state-of-the-art protective gear, they should reduce exposure.

- Some farmers use home-made "face masks", i.e. simple pieces of cloth worn over the mouth and nose. The reason for this habit is the belief that the hazard is related to inhalation. Such face masks cannot be expected to provide any protection because exposure is largely dermal, with very little exposure to the head, and ordinary cloth does not retain vapors. On the contrary, face masks may increase exposure when they induce the operator to touch the face with contaminated hands in order to adjust the mask or to wipe off sweat. Pingali et al (1994 and 1995) find that cloth covers over the mouth increase health risks due to PPA.

- The survey indicates that a considerable proportion of farmers use overalls (coveralls). Overalls cover the whole body with exception of the head, hands and feet. Exposure when spraying may be predominantly to the legs and therefore properly maintained overalls should provide considerable protection during spraying. During mixing and loading, however, the hands suffer the highest degree of exposure. Overalls are thus not expected to provide much protection during those activities.

- Gloves are hardly used.

7.3 Model

7.3.1 Logit response model

The response variable of interest is health. From the survey data, a number of binary health variables can be constructed. They take value 1 for respon-
dents who report a given health problem, 0 for the others. The health variables have Bernoulli distributions, the expected values of which are the health risks. A general linear model (GLM) can be used to model the relationship between the risk $\pi$ and a set of explanatory variables. A logit model (18) is a special case of a GLM, relating the logit of $\pi$, $\log_e(\pi/(1 - \pi))$, to a linear combination of explanatory variables:

\begin{equation}
\log(\pi/(1 - \pi)) = \alpha + \beta'x + u
\end{equation}

$x$ is a vector of practices influencing the health risk. $\alpha$ and $\beta$ are the model parameters and $u$ is an error term.

Logit models are most common in epidemiology because (a) the dependent variables of epidemiological models are commonly binary such as ours, (b) the parameter estimates of categorical explanatory variables are simple to interpret as logs of the odds ratios, (c) logit models can be applied to prospective and retrospective data (AGRESTI, 1990), and (d) they are based on reasonable, yet very general, assumptions about the distribution of the explanatory variable (AGRESTI, 1990). They produce practically the same results as probit models, another reasonable specification.

The logit function approximates an exponential function in the range of low risks. Exponential risk models—corresponding to multiplicative specifications of risk—have been proposed e.g. by CROUCH and WILSON (1981) and may be used for "a broad variety of health risk problems. For instance, one can model [...] pesticide residue poisonings as a product of pesticide application levels, oxidation rates, dermal absorption rates, and dose-response rates." (LICHTENBERG and ZILBERMAN, 1988).

The elements of $x$ in model (18) may be doses or logs of doses (or other exposure variables) besides dummies for practices. When some elements are logs of doses, the health risk is zero when the dose is zero. This is inadequate, since we cannot presume that the reported symptoms are exclusively due to PPA. The model should allow positive health risks when exposure is zero. To achieve this, it should be specified either on doses or on logs of positive doses. We prefer to specify it on the log of exposure variables for the following reasons. (a) Specification on log-doses is usual in toxicology and therefore expected to reflect the biological interactions more precisely. (b) The only variable of this type, working hours, has a small variation and
does not include any zero values. (c) Specification on log-doses corresponds to the risk model proposed by CROUCH and WILSON (1981).

Logit models have been applied to examine PPA operator safety by UTSCH (1991) and PINGALI et al (1994 and 1995). UTSCH's sample of farmers in Sri Lanka is small and her models are largely inconclusive, perhaps with exception of the finding that protective gear reduces the risk of severe acute health effects. Due to the small sample size, UTSCH uses many score variables which reduce the inferential power of the model. The study of PINGALI et al has been discussed in Chapter 5.

7.3.2 Simultaneity and identification

Model (18) is potentially simultaneous because the health state or noticeable exposure may influence behavior. For example, farmers might wash themselves more thoroughly when spillage has occurred. Ideally, one would thus establish a system of simultaneous equations, composed of (18) and a number of equations that model the effect of exposure or health outcomes on practices. Identification of such a simultaneous-equation model requires variables that affect behavior but not health. In the case of washing, for example, a variable would be required that influences washing but not health. No such variables are contained in the data. Therefore, potential simultaneity must be dealt with heuristically.

The following feedbacks might lead to simultaneity:

- **Learning**: Health effects that have been experienced change knowledge about, and attitudes toward, PPA. This is illustrated, for example, by UTSCH (1991) who reports that the farmers' abilities to rank PPA brands by hazard correlates with their familiarity with the brands. Such learning effects may influence practices and, hence, exposure. A farmer who repeatedly experiences adverse health effects due to PPA may start to use protective items, for example.

- **Short-term reactions to adverse health effects**: Reactions to health effects that have been experienced may take place on a short-term basis. If a farmer starts to feel ill on a particular day, he may stop spraying or get help for the work that remains to be done. Many of the actions taken after spraying may also be consequences of exposure or adverse health effects rather than causes.
Since learning requires time, most learning effects can be ruled out by taking variables referring to a short time period. The variables used in the model refer to a single day of spray work, a period of time we consider sufficiently short to rule out most learning effects.

To deal with simultaneity introduced by short-term reactions we use instrumental variables contained in the data (KOUTSOYIANNIS, 1977). Such an instrument should be closely correlated with the variable of interest, but not correlated with the error term of the health function. Its parameter estimate measures the joint effect of the instrumental variable and the effect of the variables it represents. Different hygienic practices are likely to be closely correlated. Among different hygiene measures, those taken during spraying can be assumed independent of health due to the time lag in the onset of symptoms. Hence, washing during working breaks is instrumental for hygienic practices in general.

### 7.4 Data and variables

#### 7.4.1 Survey

One thousand small-scale cotton farmers were interviewed in the season 1992-93. One hundred and twenty-six respondents were not personally involved in the use of PPA and 9 of the remainder could not provide all the information required. This reduces the effective sample size for the analysis to 865.

Health data refers to the last occasion of spraying before the interview. Farmers were asked about health problems suffered due to the use of PPA. The questions were:

- "Have you yourself ever experienced any health problem due to pesticide spraying?"

If the answer was yes, the respondent was asked about the kind of problems ever experienced and then:

- "The last time you sprayed ... days ago, did you experience any problems [what problems]?"
Thus, the answers involve the farmer's assessment of whether the health effect is a "problem" and about the cause of the health problem (due to PPA or not).

Major methodological difficulties do not arise when only adverse health effects above the threshold level of being considered "problems" are reported. However, the farmer's judgment about the causes of the health effect may not always be accurate. The reported health problems may be due to PPA poisoning but also other factors such as weather, exhaustion or an illness that happened to present symptoms at the application. Therefore, the model is specified such as to allow for sources of health risks independent of exposure to PPA.

The questions about health problems are so phrased that we can assume respondents will report the health problems experienced during, or shortly after, a day of spraying. The duration of the spray work on that day varies between farmers. Reported practices refer also to the last application prior to the interview. Data about brands and quantities of PPA, by contrast, refer to the season up to the time of the interview, and the most often used brand. This greatly limits the possibilities for drawing conclusions on the effects of different chemical substances.

7.4.2 Response variables

Four response variables code different symptoms or combinations of symptoms: headache, giddiness or nausea, skin problems, and any symptom (including the before-mentioned).

- **Headache**: The variable is coded 1 for respondents reporting to have suffered from headache.

- **Giddiness or Nausea**: The variable is coded 1 for respondents reporting to have suffered any of these problems. The two symptoms are joined because (a) the difference between giddiness and nausea is not always obvious and probably merely semantic to the farmer, (b) both symptoms may be due to nervous disorder as it is caused by many PPA, (c) the individual responses are small and do not allow estimation of separate models.

- **Skin Problems**: Coded 1 for respondents who report having suffered from boils or rashes, burns, or skin problems in general.
• **Any Health Problem**: Coded 1 for respondents reporting to have suffered any health problem due to use of PPA. These include 42 cases of headache, 17 of running noses, 16 of giddiness, 13 of nausea, 13 of body pain, 7 of skin burns, 7 of stomach pain, 6 of skin problems in general, 3 each of fever, sneezing, sore eyes and backache, 2 of vomiting, 1 each of coughing, itching skin and boils, and 3 cases of not specified other symptoms. In total, 104 farmers reported that they suffered any health problem.

The symptoms body pain and backache seem more likely to be due to carrying the sprayer than exposure to PPA. However, it is not necessary to know the causes of the health problems in order to estimate the models since health effects of other causes simply affect the intercept. Therefore, the response variables are defined as broadly as possible.

### 7.4.3 Explanatory variables

The criteria for the selection of explanatory variables are the following. First, we include examples of different categories of factors that influence health risks, namely the type of compound used as a factor influencing toxicity; protective practices, type of appliance, cropping stage and working time as examples of factors influencing exposure; and age as a factor that potentially affects the susceptibility of the operator. Second, statistical considerations suggest that variables should be preferred which are expected to yield large estimates. Sparsity imposes restrictions on the number of categorical variables in the model. Among the dummy variables, those with means near 0.5 are preferred to variables with means near 0 or 1. This reduces the number of sampling zeros (empty cross-table cells) and increases the reliability of the estimates, but impedes the modeling of very infrequent and very frequent practices.

- **Age**: The variable AGE is the age of the respondent, standardized to 0 mean and standard deviation 1 for easier interpretation.

- **Chemical type of substance**: Nine different active ingredients are used (cf. Table 20, p. 127). Due to sparsity it is not possible to set up dummy variables for each active ingredient. We summarize use of pyrethroids in the variable PY. Pyrethroids (fenvalerate, fluvinate, cyhalothrin) are the most commonly used PPA in 120 cases. The remainder of PPA are organophosphates or carbamates which cause similar symptoms, with ex-
ception of the organochlorine endosulfan. Hence, the parameter of PY estimates the effect of pyrethroids as compared to organophosphates and carbamates. The data does not contain any information about the PPA used at the last spraying occasion. Therefore, we use the product most frequently used as a proxy for the product used on the occasion the interview refers to. The use of proxy exposure variables leads to conservative estimates (Maroni and Fait, 1993). Hence, only the sign of the parameter estimate of PY should be interpreted.

- **Toxicity:** A continuous toxicity variable was constructed. Since both the concentration and the toxicity are functions of the brand, they are multicollinear and must be packed into one variable. LOGCLD50 was defined as the log of the estimated concentration of the spray minus the log of the dermal LD$_{50}$ values.

- **Working time:** LOGHOURS is the log of the working time in hours. It refers to the last spraying occasion prior to the interview, i.e. the time spent spraying, mixing and loading on that particular day.

- **Breaks:** The spray work is usually interrupted for mixing and loading, sometimes for eating, drinking or smoking. These breaks may lead to additional exposure. However, some breaks may be consequences rather than causes of adverse health effects. For instance, a farmer suffering headache might interrupt the spray-work to recover. In order to avoid simultaneous-equation bias, we differentiate between breaks for different purposes. Breaks for food can be assumed to be planned before the spray operation starts because the farmer takes the food to the field in the morning. Breaks to fix the appliance are not conditioned by the health state of the farmer, either. The binary variable BREAK takes value 1 for farmers who interrupted work for eating or fixing the appliance. Breaks to recover from exhaustion, etc., are not accounted for because they are potentially related to health. Breaks for smoking are also excluded because smoking itself may cause several of the studied health effects. Since all operators interrupt spraying for mixing and loading with very few exceptions who have this work done by family members, a variable coding for these activities does not show sufficient variation to be included.

- **Hygiene:** Exposure at breaks may be reduced by precautions such as washing hands before eating. We code BPREC for farmers who report that they wash their hands with water and soap, or with water alone, at the
start of breaks for food. We assume that farmers who wash their hands during breaks exhibit more hygienic behavior at other occasions as well. BPREC is thus instrumental for hygiene.

- **Cropping stage**: STAGE codes for the cropping stage. It is a linear transformation of an ordinal scale with six stages into a variable with 0 mean and standard deviation 1. Large values represent late cropping stages and, hence, relatively high plants and large expected exposure.

- **Type of sprayer**: The variable ULV is coded 1 for ULV sprayers; 0 for knapsack sprayers with front lance or tailboom. The use of tailboom sprayers is not frequent enough to be modeled separately.

- **Condition of sprayer**: Respondents with sprayer leaks or nozzle problems are coded 1 in LEAK.

- **Clothing**: The following variables code for protective clothing:
  - **OVERALL**: Use of overalls at spraying.
  - **PLASTIC**: Use of improvised plastic jackets, home-made plastic covers, raincoats or jackets.
  - **FOOTWEAR**: Use of shoes or boots (not sandals).
  - **TROUSERS SHIRT**: Combined use of full-length trousers and long sleeved shirts.
  - **MASK**: Use of face or mouth covers.

Five models are estimated: four small ones with 9 explanatory variables each for the four response variables and a large one with 13 explanatory variables for ANY HEALTH PROBLEM.

### 7.5 Results

Table 22 gives the sample statistics. Table 23 and Table 24 reproduce the model results.
Table 22: Sample statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>Variable</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache</td>
<td>0.049</td>
<td>Stage</td>
<td>0.000 (1.000)</td>
</tr>
<tr>
<td>Giddiness or Nausea</td>
<td>0.029</td>
<td>Ulv</td>
<td>0.079</td>
</tr>
<tr>
<td>Skin Problems</td>
<td>0.023</td>
<td>Leak</td>
<td>0.138</td>
</tr>
<tr>
<td>Any Health Problem</td>
<td>0.120</td>
<td>Overall</td>
<td>0.667</td>
</tr>
<tr>
<td>Age</td>
<td>0.000 (1.000)</td>
<td>Plastic</td>
<td>0.246</td>
</tr>
<tr>
<td>Py</td>
<td>0.139</td>
<td>Footwear</td>
<td>0.607</td>
</tr>
<tr>
<td>LogHours</td>
<td>1.186 (0.600)</td>
<td>Trousers</td>
<td>0.084</td>
</tr>
<tr>
<td>Break</td>
<td>0.182</td>
<td>Mask</td>
<td>0.342</td>
</tr>
<tr>
<td>Bprec</td>
<td>0.138</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Standard deviations (SD) are reported for continuous variables, only. Total sample size is 865.

Table 23: Model results for individual symptoms

<table>
<thead>
<tr>
<th>Parameter estimates (standard errors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANY HEALTH PROBLEM</td>
</tr>
<tr>
<td>Intercept</td>
</tr>
<tr>
<td>AGE</td>
</tr>
<tr>
<td>PY</td>
</tr>
<tr>
<td>LogHours</td>
</tr>
<tr>
<td>Break</td>
</tr>
<tr>
<td>Bprec</td>
</tr>
<tr>
<td>Stage</td>
</tr>
<tr>
<td>Ulv</td>
</tr>
<tr>
<td>Leak</td>
</tr>
<tr>
<td>Overall</td>
</tr>
</tbody>
</table>

McFadden's $\rho^2$ 0.056 0.065 0.064 0.031
Model $P$ 0.000 0.099 0.204 0.315

Note: * significant at 5% level.
Table 24: Model results for any health problems

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>S.E.</th>
<th>Odds ratio</th>
<th>Estimate</th>
<th>95% Bounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-3.079</td>
<td>0.412</td>
<td></td>
<td>0.764</td>
<td>0.610</td>
</tr>
<tr>
<td>AGE</td>
<td>* -0.269</td>
<td>0.115</td>
<td>0.764</td>
<td>95% Bounds</td>
<td></td>
</tr>
<tr>
<td>PY</td>
<td>-0.283</td>
<td>0.334</td>
<td>0.753</td>
<td>1.450</td>
<td>0.391</td>
</tr>
<tr>
<td>LOGHOURS</td>
<td>* 0.464</td>
<td>0.205</td>
<td>1.591</td>
<td>2.378</td>
<td>1.064</td>
</tr>
<tr>
<td>BREAK</td>
<td>* 0.667</td>
<td>0.324</td>
<td>1.949</td>
<td>3.675</td>
<td>1.034</td>
</tr>
<tr>
<td>BPREC</td>
<td>-0.559</td>
<td>0.406</td>
<td>0.572</td>
<td>1.266</td>
<td>0.258</td>
</tr>
<tr>
<td>STAGE</td>
<td>0.172</td>
<td>0.111</td>
<td>1.188</td>
<td>1.477</td>
<td>0.956</td>
</tr>
<tr>
<td>ULV</td>
<td>* 0.782</td>
<td>0.372</td>
<td>2.187</td>
<td>4.532</td>
<td>1.055</td>
</tr>
<tr>
<td>LEAK</td>
<td>* 1.012</td>
<td>0.260</td>
<td>2.752</td>
<td>4.577</td>
<td>1.654</td>
</tr>
<tr>
<td>OVERALL</td>
<td>0.246</td>
<td>0.301</td>
<td>1.279</td>
<td>2.306</td>
<td>0.710</td>
</tr>
<tr>
<td>PLASTIC</td>
<td>-0.131</td>
<td>0.300</td>
<td>0.877</td>
<td>1.579</td>
<td>0.487</td>
</tr>
<tr>
<td>FOOTWEAR</td>
<td>0.085</td>
<td>0.245</td>
<td>1.089</td>
<td>1.759</td>
<td>0.674</td>
</tr>
<tr>
<td>TROUSERSSHIRT</td>
<td>-0.654</td>
<td>0.538</td>
<td>0.520</td>
<td>1.493</td>
<td>0.181</td>
</tr>
<tr>
<td>MASK</td>
<td>0.131</td>
<td>0.229</td>
<td>1.140</td>
<td>1.785</td>
<td>0.728</td>
</tr>
</tbody>
</table>

McFadden's $\rho^2$ 0.060
Model P 0.000

Note: * significant at 5% level.

The parameter estimates give the marginal effect of the predetermined variables on the log of the odds of the response variables. At low risks, the effect on the log of the odds is approximately equal to the effect on the log of the risk. Therefore, the inverse log of the parameter estimate is the odds ratio (approximately relative risk) of a marginal change in the predetermined variable. For variables that enter the model in logs (LOGHOURS), the parameter estimate gives the elasticity of the odds (approximately risk) with respect to the variable. (Refer to Appendix B for a more detailed note on how to interpret the parameters of the logit models and the odds ratios.)

7.5.1 Discussion

The McFadden's $\rho^2$ values around 0.060 are rather small. This might be due to the fact that much of the variance in exposure is due to accidental spills that are not accounted for in the variables. The model for headache per-
formed worst. The models for skin problems and headache are not significant as a whole.

Age: The incidence of all health problems examined is negatively associated with age. Elder operators apparently are at a lower risk than younger spray persons. This finding is not due to any presence of very young (susceptible) respondents in the sample since only persons of at least 18 years of age were interviewed. A possible explanation is that relatively unsafe or susceptible farmers reduce their personal involvement in PPA use as they age. This is confirmed by UTSCH (1991) who points out that health problems due to PPA are important reasons to elder farmers for not spraying personally.

Substance: None of the parameters of pyrethroid use is significant. The difference between the parameters for skin problems and giddiness or nausea is almost significant. The risk of suffering from giddiness or nausea is lower with pyrethroids than with other chemical types. The incidence of skin problems is positively related to the use of pyrethroids, as expected. Headache seems to be independent of the chemical type, although one would expect a lower incidence among pyrethroid users. The reduced risk of giddiness and nausea seems to be responsible for the negative parameter estimate of PY in the model for any health problems. Since PY codes the most often used brand, and not the brand used at the last occasion of spraying, its parameters are expected to be conservative.

Toxicity: The variable LOGCLD50 did not improve the quality of the models. The estimates had the expected (positive) signs for any health problems, giddiness or nausea, and skin problems, and a negative sign for headache. None of them was significant. The exclusion of the variable improved the fit. Therefore, the above tables present models without this variable.

Working time: LOGHOURS yields significantly positive parameter estimates in the model for ANY HEALTH PROBLEM and almost significant estimates in the models for GIDDINESS OR NAUSEA and SKIN PROBLEMS. The finding is as expected. A 10% increase in the time spent performing spray work raises health risks by 4.6% of the previous level. Farmers who suffer adverse health effects during a day of spray work are more likely to stop working earlier. Due to this feedback, the estimate is probably conservative.

Work breaks: Breaks to eat or fix the appliance correlate positively with the incidence of adverse health effects. This is due to additional exposure occurring during these activities. The parameter estimates are around 0.65 in
all models, the one for ANY HEALTH PROBLEM being significantly positive. The corresponding odds ratio is 1.9, indicating that the health risk is almost doubled for operators who interrupt their work to eat or fix the appliance.

**Hygiene:** The parameter estimate for precautions taken at breaks (Bprec) is negative in three of the four models presented in Table 23. The odds ratio of Bprec in the model for ANY HEALTH PROBLEM is 0.572 (Table 24). This means that the adverse effects of breaks are almost completely offset by the hygiene measures Bprec codes for. Note that the parameters of Bprec estimate the joint effects of break precautions and the hygiene measures positively correlated with it. Thus, hygiene reduces health risks considerably in general.

**Cropping stage:** As expected, STAGE yields positive parameter estimates. Spraying high crops is relatively risky.

**Sprayer type:** The parameter estimate of ULV is significantly positive in the models for ANY HEALTH PROBLEM. The use of ULV sprayers multiply health risks by 2 (odds ratio). As mentioned, there are a number of differences between knapsack and ULV sprayers that affect health risks positively or negatively. Therefore, it is not possible to evaluate whether the positive sign is reasonable.

**Leaks and nozzle problems:** As expected, the parameter estimates for LEAK are very high in all models. The estimated odds ratios and their significance bounds are given in the following table. They show that leaks double or even triple health risks. Leaks may cause very high exposure of limited areas of the skin. It is thus not surprising to find a particularly high estimate in the model for SKIN PROBLEMS. However, the differences between the parameter estimates of the four models are not significant.

<table>
<thead>
<tr>
<th>Table 25: Odds ratio estimates for sprayer leaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANY HEALTH PROBLEM</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Odds ratio</td>
</tr>
<tr>
<td>Upper limit (95%)</td>
</tr>
<tr>
<td>Lower limit (95%)</td>
</tr>
</tbody>
</table>
Overalls: Contrary to expectations, the parameter estimate for overalls is positive in three of the four models (Table 23). The odds ratios for overalls are given in the following table.

Table 26: Odds ratio estimates for overalls

<table>
<thead>
<tr>
<th>Any health problem</th>
<th>Giddiness or nausea</th>
<th>Skin problems</th>
<th>Headache</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odds ratio</td>
<td>1.605</td>
<td>1.375</td>
<td>0.627</td>
</tr>
<tr>
<td>Upper limit (95%)</td>
<td>2.582</td>
<td>3.388</td>
<td>1.572</td>
</tr>
<tr>
<td>Lower limit (95%)</td>
<td>0.998</td>
<td>0.558</td>
<td>0.250</td>
</tr>
</tbody>
</table>

There is evidence that overalls do not reduce PPA related health risks given the way they are currently used. The parameter estimates for GIDDINESS OR NAUSEA, SKIN PROBLEMS, and HEADACHE are not significantly different from each other, but suggest that overalls tend to reduce skin problems and increase headache and giddiness or nausea.

There are a number of possible explanations for the finding that overalls do not reduce health risks. First, the share of exposure suffered by the hands might be large and thus diminish the effect of overalls. Second, overalls might be poorly maintained, exhibit holes or not be washed sufficiently. Farmers might wash working clothes less often than every-day clothes, given that the former "get dirty again anyway". PPA residues in clothes contribute to exposure (NELSON and FLEEKER, 1988). Third, the discomfort of wearing overalls in hot climates might increase the risk of suffering symptoms such as headache either directly, or indirectly due to increased toxicant absorption through the sweating skin. Fourth, overall users might feel confident that they are protected and neglect other precautions. Reviewers of earlier drafts of this thesis also suggested that the translation of "overall" to the Shona language used in the survey might have been ambiguous and include what we understand as overalls as well as other types of working clothes. However, several tests conducted to infer on this hypothesis did not support it. Therefore, we accept the result as an indication of some technical, rather than semantic, relationship.

Plastic covers: The large model for any symptom (Table 24) yields a negative, non-significant parameter estimate for PLASTIC. Home made plastic covers seem to reduce health risks. Note that farmers tend to use plastic cov-
ers when spraying with a leaking appliance (cf. Table 27). The risk reduction may occur predominantly among those farmers.

Table 27: Crosstable of plastic cover use and sprayer leaks

<table>
<thead>
<tr>
<th>Plastic cover use (Plastic)</th>
<th>Sprayer leaks (LEAK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no (0)</td>
<td>yes (1)</td>
</tr>
<tr>
<td>no (0)</td>
<td>568 (76.1%)</td>
</tr>
<tr>
<td>yes (1)</td>
<td>178 (23.9%)</td>
</tr>
</tbody>
</table>

Pearson's $\chi^2$ test probability for independence = 0.19.

Footwear: The parameter estimate for footwear is practically zero (cf. Table 24). This is unexpected.

Masks: The parameter estimate of Mask is slightly positive. The studied "masks" are mostly improvised pieces of cloth covering the lower face. As mentioned, they are not expected to reduce health risks.

Trousers and shirts: Full-length trousers and long-sleeved shirts tend to reduce health risks, but the parameter estimate has a large standard error. Unexpectedly, the variable has a smaller parameter than overalls.

7.6 Simulation of prevention

Based on the estimated risk factors, we simulate behavioral changes, i.e., complete adoption of a selection of safety practices. The effect of complete adoption depends, of course, on the current level of adoption, which is highly specific to the study area. Therefore, results derived here can not be extrapolated to other regions without first assessing current practices there.

The incidences of adverse health effects per day of spray work are predicted under the following scenarios:

- all farmers avoid leaks (LEAK = 0)
- all farmers practice basic hygiene (BPREC = 1)
- all farmers use long trousers and shirts (TROUSERSHIRT = 1).
• all farmers avoid leaks, practice basic hygiene and use full-length trousers and shirts

The simulation procedure is as follows. Hypothetical practices are substituted for the respective values in the original data set. Subsequently, the health logits for each observation are calculated with the parameters of the model presented in Table 24, averaged and entered in the inverse logit function to obtain the simulated average incidence. This procedure is more accurate than evaluating the model at sample means due to the non-linearity of the logit function.

The average probabilities for contracting any adverse health effect in the different scenarios are reproduced in Table 28.

**Table 28: Health risks in different scenarios**

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current situation</td>
<td>12.0%</td>
</tr>
<tr>
<td>No leaks</td>
<td>10.3%</td>
</tr>
<tr>
<td>Basic hygiene</td>
<td>8.1%</td>
</tr>
<tr>
<td>Full-length trousers and long-sleeved shirts</td>
<td>7.1%</td>
</tr>
<tr>
<td>No leaks, hygiene, full-length trousers and long-sleeved shirts</td>
<td>3.9%</td>
</tr>
</tbody>
</table>

Basic hygiene would reduce the incidence of adverse health effects by 4 percent points (12% - 8.1%). Simple protective clothing would reduce the incidence by 5 percent points. Complete adoption of a set of simple safety practices would reduce average health risks to one third of current levels. The results give some clues as to what measures deserve priority in education programs. These are hygiene and maintenance of the appliance and working clothes. The priorities may differ between regions, since the simulation results are very specific to the project area.

The distribution of the individual, simulated health risks and logs of health risks (for better visualization of relative changes in risks) are presented in Figure 21.
Figure 21: Distribution of predicted health risks with different practices

A visual comparison of the risk distributions reveals that avoiding leaks reduces high risks (upper arrow), while hygiene measures yield the largest absolute effects in the range of current average risks and the highest relative
effects in the range of low risks (lower arrows). This signifies that farmers with leaking sprayers would be relatively unsafe users of PPA even if they fixed their sprayers. Hygiene, by contrast, is independent of other practices that affect health. The distribution effect of safe use education may thus depend on the predominantly recommended practices. Focusing extension on unsafe practices that tend to cluster, would yield desirable distributional effects.

7.7 Assessment of background health effects

Bearing in mind that farmers have been asked about health problems due to PPA, the health variables entail the farmers' assessments of the reasons for the problems. These assessments are potentially subject to error, because symptoms of PPA poisoning can be confused with symptoms of other illnesses. Two types of errors may occur: Symptoms of PPA poisoning may be wrongly attributed to other reasons and/or symptoms of other illnesses may be wrongly attributed to PPA. The health model allows inferences on the magnitude of the second kind of error. Simulating behavior that results in the lowest risks according to the models permits assessment of the incidence of adverse health effects at very low PPA exposures. These risks are not explained by the model and can be interpreted as upper limits of the shares of reported health problems that are not related to PPA. Because the model does not include all factors that affect health, some share of the estimated minimum incidence may nevertheless be due to PPA. It is unlikely, however, that health problems wrongly attributed to PPA exceed these "background" health problems.

Simulated "best" practices and the corresponding average risks are given in Table 29 and Figure 22. The calculations are based on the models for individual symptoms (cf. Table 23, p. 138). Simulated practices are those yielding the lowest risk in the respective models. STAGE is always set to its minimum value, corresponding to the earliest cropping stage, when exposure is expected to be lowest on a priori grounds. Due to the transformation of the variable STAGE (cf. p. 137), the earliest cropping stage takes the somewhat unintuitive value of -2.793.
Table 29: Background levels of health risks

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>ANY HEALTH PROBLEM</th>
<th>GIDDINESS OR NAUSEA</th>
<th>SKIN PROBLEMS</th>
<th>HEADACHE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PY</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BREAK</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BPREC</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>STAGE</td>
<td>-2.793</td>
<td>-2.793</td>
<td>-2.793</td>
<td>-2.793</td>
</tr>
<tr>
<td>ULV</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>LEAK</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OVERALL</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Results

"Background" level 2.0% 0.1% 0.5% 3.0%
Average reference risk 12.0% 2.9% 2.3% 4.9%

Figure 22: Estimated background and total health risks

The average reference risk is simply the health problem incidence. Of the symptoms giddiness or nausea, skin problems and headache, respectively, 0.1, 0.5 and 3.0 percent points cannot be explained by the model and might be due to reasons other than PPA. Put the other way round, 2.8, 1.8 and 1.9 percent points of the health risk are explained by the model and thus likely
to be due to PPA. Headache seems to be wrongly attributed to PPA use relatively often. This is also confirmed by the McFadden's $p^2$ values reported in Table 23 (p. 138) which show that the explanatory force of the headache model is worst.

7.8 Conclusions

Regression models have been estimated to reach conclusions on the health risks due to different PPA related practices and to simulate adoption of safety practices. The models gave many reasonable results, such as a risk reduction due to hygiene and risk increases associated with working time, cropping stage, leaks, and breaks. This is an indicator for the validity of the model. Conversely, overalls and other gear failed to prove effective in reducing health risks. The models and simulations allow the following conclusions to be drawn:

- Simple safety practices could contribute much to a reduction of adverse health effects. Promotion of safety should start with hygiene and maintenance of work clothes and appliances. A step-by-step approach seems to be the most suitable since the usefulness of protective gear remains questionable as long as proper maintenance is not ensured.

- Priority-setting in safe use education programs should be based on a local assessment of risk factors.

- Interview data may be used to elicit health and investigate the efficacy of protective devices and practices. PPA users are able to associate acute symptoms with their causes (related to PPA vs. unrelated to PPA) with considerable accuracy. When asked about health problems due to PPA, they do not report many diseases that are due to other reasons. However, the number of health problems that are due to PPA but not recognized as such is unknown.
8 Case study: Heterogeneity in health risks to PPA users

Information, education and training programs should be directed at and adapted to meet the needs of target groups defined and selected on the basis of socio-economic and psychological characteristics. The better a program is focused, the higher its expected benefit-cost ratio. In the context of PPA user safety, it would be helpful to know whether health risks concentrate in specific, identifiable segments of the population (UTSCH, 1991). In this study, we examine health risk heterogeneity within seemingly homogeneous populations. Heterogeneity is found significant among the Indian cotton growers but negligible among cotton farmers in Zimbabwe and Indian spraymen. The expected number of health problems due to PPA of the unsafest 25% of Indian farmers is around 90 times that of the safest 25%. We conclude that health risk heterogeneity is potentially important for the design of PPA safety programs. Further research is needed to evaluate the possibilities of identifying unsafe users and targeting communication efforts at them.
8.1 Introduction

Multiplicative risk models suggest that the absolute effect of a change in a practice is small when health risks are low and increase with rising health risks. Therefore, safe use extension should be directed predominantly at areas (crops, populations, etc.,) where health risks are considerable. The argument can be extended to subgroups of a population. If a population comprises relatively safe and unsafe PPA users, extension should focus on the latter. If populations are relatively homogenous in terms of health risks, such a differentiation might not be necessary. In this study, we quantify health risk heterogeneity in seemingly homogenous groups. The objective is to provide an overview of this potentially important aspect of health risk\(^{19}\).

The study is motivated by the author's casual observation that some Mexican farmers appear to handle PPA reasonably and carefully while others seem to be disturbingly unaware of preventive measures. Not that the former are using specific protective gear, they just seem to avoid spills and follow simple safety precautions such as maintaining the sprayers or washing their hands. We have also seen in Section 7.6 that certain unsafe practices tend to cluster, which suggests that some PPA users are systematically safer than others.

Obviously, health risks vary systematically between populations. Cotton and vegetable growers, for example, may be more at risk than maize farmers simply because PPA use levels and patterns vary between crops. Accordingly, safe use extension should be targeted at the former. However, this is not the topic here. Rather, we examine the risk distribution in populations that seem to be quite uniform at first sight, such as small-scale cotton farmers in Tamil Nadu, spraymen in the same area, and small-scale cotton farmers on communal lands in Zimbabwe.

Health risks vary between occasions for potential exposure because the variables that influence the health risk vary. The effects of these variations partly offset each other so that the risk of contracting some health effect for a large number of occasions varies less between subjects than the health risk on one occasion.\(^{19}\)Harper and Zilberman (1992) point out that health risk heterogeneity is potentially important also for regulation because some decision rules do not yield consistent policy implications with different health risk distributions.
single occasion. However, they do not completely offset each other. The health risk over a large period may thus show a variation between subjects even in a seemingly homogenous group.

The Chapter is organized as follows. In Section 8.2, we develop a model for health risk heterogeneity. The data and the estimation results are presented in Section 8.3. In Section 8.4, we examine whether heterogeneity in expected health impacts measured as labor loss is more accentuated than heterogeneity in health risks. Conclusions are offered in Section 8.5.

8.2 Model

PPA users are exposed to PPA at several occasions during a season or any other given time period. Such occasions may be sprayrounds or days of spray work. However, the precise definition of "one occasion" is not relevant for the following discussion. Each occasion is associated with a health risk. That is, on each occasion the user may or not contract an acute adverse health effect. Let \( y_{ij} \) be a binary variable that indicates whether individual \( i \) \((i = 1...n)\) contracts an adverse health effect \((y_{ij} = 1)\) or not \((y_{ij} = 0)\) on occasion \( j \) \((j = 1...m)\). The actual health outcome \( y_{ij} \) is stochastic and Bernoulli distributed with parameter, say, \( \pi_{ij} \). \( \pi_{ij} \) is the health risk to individual \( i \) on occasion \( j \).

Several sampling procedures are possible. The health state of individual \( i \) could be sampled on a number of randomly selected occasions. The resulting response variable \((y_{ij} | i)\) is Bernoulli distributed with \( E(y_{ij} | i) = E(\pi_{ij} | i) \). Alternatively, one could survey a number of individuals on one, randomly selected occasion \( j, j = k_i, \) each. The resulting response variable \((y_{ij} | j)\) is Bernoulli distributed with \( E(y_{ij} | j) = E(\pi_{ij}) \). An example for the latter sampling procedure is given in the previous chapter, where farmers were asked about their health state on a specific day of PPA application work. Thus, by surveying \((y_{ij} | i)\) or \((y_{ij} | j)\), we obtain binomial variables. Since the variance of binomial variables is a fixed function of the mean, it is impossible to estimate the risk variance between individuals with data on \((y_{ij} | i)\) or \((y_{ij} | j)\).

The risk variance between individuals \( \text{Var}[E(\pi_{ij} | i)] \) can be estimated only with information on different individuals and different occasions. The simplest data that contains this type of information are the counts \( Y_i \) \((i = 1...n)\) of positive health outcomes of a number of individuals \( i \) over a time period that
includes several \((m_i)\) occasions of potential exposure, \(Y_i = \sum_{j=m}^{m_i} y_{ij}\). When \(m_i\) is random and potentially unbound, hypothetical repeated random sampling of one individual produces Poisson distributed \(Y_i\). Moreover, sampling of different individuals produces Poisson distributed \(Y\) when the expected health risk does not vary between individuals, \(\text{Var}[E(\pi_{ij} | i)] = 0\). When the expected health risk varies between individuals, on the other hand, \(Y\) shows an overdispersed Poisson distribution. In that case, the distribution parameter of \(Y\), conditioned on the individual, has a variance between individuals. Let \(M = E(Y | i)\) and \(E(M) = \lambda\). Then (Agresti, 1990)

\[
E(Y) = E[E(Y | M)] = E[M] = \lambda \\
\text{Var}(Y) = E[\text{Var}(Y | M)] + \text{Var}[E(Y | M)] = \lambda + \text{Var}(M).
\]

Thus, when \((Y | M)\) has a Poisson distribution with mean \(M\), and \(M\) has a variance, \(Y\) has an overdispersed Poisson distribution, \(\text{Var}(Y) > E(Y)\).

The null-hypothesis is that expected health risks do not vary between individuals (homogenous risks). It can be tested by examining the goodness-of-fit of a Poisson distribution to \(Y\) with the Pearson statistic \(\chi^2 = \sum (n_Y - \hat{m}_Y)^2 / \hat{m}_Y\) (Agresti, 1990). \(n_Y\) and \(\hat{m}_Y\) are the observed and expected frequencies of given values of \(Y\). \(\chi^2\) has a chi-square distribution with \(N - 1\) degrees of freedom, where \(N\) is the number of different values of \(Y\). When the null-hypothesis of Poisson distributed \(Y\) cannot be rejected, we accept that the individuals' expected health risks are homogenous in the population.

When \(Y\) is not Poisson distributed, we obtain \(\text{Var}(M)\) by measuring the degree of overdispersion. We assume \(M\) Gamma distributed because this is a simple case to treat and leads to a reasonable negative binomial distribution of \(Y\). The probability density of \(M\) is then

\[
g(M) = \frac{1}{\Gamma(\alpha)} \beta^\alpha M^{\alpha-1} e^{-\beta M}.
\]

It follows that \(E(M) = \alpha / \beta\) and \(\text{Var}(M) = \alpha / \beta^2\). Hence,
\[
\text{Var}(Y) = E(M) + \text{Var}(M) = [E(Y)](1 + \beta)/\beta
\]

(Agresti, 1990). \( \phi = (1 + \beta)/\beta \) is a measure for overdispersion, \( \text{Var}(Y) = \phi E(Y) \). \( \phi = 1 \) for the Poisson distribution. Ehrenberg (1982) suggested estimating \( \alpha \) as \( \hat{\alpha} = \hat{\lambda}^2 / (\hat{\nu} - \hat{\lambda}) \), where \( \hat{\lambda} = \Sigma Y/n \) and \( \hat{\nu} = (n\Sigma Y^2 - \Sigma^2 Y)/n^2 \) are the estimated mean and variance of \( Y \), respectively\(^{20} \). This is equivalent to estimating \( \phi \) as \( \hat{\phi} = \hat{\nu} / \hat{\lambda} \). The goodness-of-fit of the negative binomial distribution can also be assessed with a \( \chi^2 \) test.

8.3 Results

8.3.1 Sample statistics

The following table gives the counts of adverse health effects suffered during one season in three groups, i.e., farmers in India and Zimbabwe, and spraymen in India.

\(^{20}\text{Agresti's } \alpha \text{ is called } k \text{ by Ehrenberg.} \)
Table 30: Number of health problems attributed to PPA in one cotton season

<table>
<thead>
<tr>
<th>Number of health problems attributed to PPA, Y</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>India</td>
<td>Zimbabwe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Farmers</td>
<td>Spraymen</td>
<td>Farmers</td>
</tr>
<tr>
<td>0</td>
<td>164 76.3%</td>
<td>15 29.4%</td>
<td>86 44.1%</td>
</tr>
<tr>
<td>1</td>
<td>28 13.0%</td>
<td>14 27.4%</td>
<td>57 29.2%</td>
</tr>
<tr>
<td>2</td>
<td>13 6.1%</td>
<td>8 15.7%</td>
<td>38 19.5%</td>
</tr>
<tr>
<td>3</td>
<td>7 3.3%</td>
<td>8 15.7%</td>
<td>12 6.2%</td>
</tr>
<tr>
<td>4</td>
<td>2 0.9%</td>
<td>6 11.8%</td>
<td>2 1.0%</td>
</tr>
<tr>
<td>5</td>
<td>1 0.5%</td>
<td>0 0.0%</td>
<td>0 0.0%</td>
</tr>
<tr>
<td>Sample size</td>
<td>215 100%</td>
<td>51 100%</td>
<td>195 100%</td>
</tr>
<tr>
<td>Total number of health problems</td>
<td>88</td>
<td>78</td>
<td>177</td>
</tr>
<tr>
<td>$\hat{\lambda}$, average number of health problems per respondent</td>
<td>0.409</td>
<td>1.529</td>
<td>0.908</td>
</tr>
</tbody>
</table>

Note: Indian data refers to the cotton season 94/95 (Coimbatore district), data from Zimbabwe to the cotton season 93/94 (Sanyati, Gokwe).

Under the hypothesis of homogenous risks, the cell counts have Poisson distributions with parameters 0.409, 1.529 and 0.908 for the respective populations. Figure 23 compares the actual counts with fitted Poisson distributions.
Figure 23: Overdispersion in counts of health problems attributed to PPA

a: Farmers, India

b: Spraymen, India
Visual examination of Figure 23 suggests that there is overdispersion in all three populations. Overdispersion seems to be particularly accentuated among the Indian farmers, where the observed number of farmers reporting to have suffered exactly one health problem is only about half the predicted number.

8.3.2 Estimation results

Table 31 reproduces the calculation of the Pearson $\chi^2$ statistics for the hypothesis that the counts of health problems are Poisson distributed. $n_Y$ and $\hat{m}_Y$ are the observed and predicted frequencies of health problem counts, respectively.
Table 31: Testing whether the counts of health problems attributed to PPA in one season are Poisson distributed

<table>
<thead>
<tr>
<th>Number of health problems, Y</th>
<th>India</th>
<th></th>
<th>Zimbabwe</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Farm</td>
<td>Spraymen</td>
<td>Farmers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$n_Y$</td>
<td>$\bar{n}_Y$</td>
<td>$n_Y$</td>
<td>$\bar{n}_Y$</td>
</tr>
<tr>
<td>0</td>
<td>164</td>
<td>142.78</td>
<td>15</td>
<td>11.05</td>
</tr>
<tr>
<td>1</td>
<td>28</td>
<td>58.44</td>
<td>14</td>
<td>16.90</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>11.96</td>
<td>8</td>
<td>12.92</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>1.63</td>
<td>8</td>
<td>6.59</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>0.17</td>
<td>6</td>
<td>2.52</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0.01</td>
<td>0</td>
<td>0.77</td>
</tr>
<tr>
<td>$\chi^2$ (5 degrees of freedom)</td>
<td>128.06</td>
<td>9.67</td>
<td>5.47</td>
<td></td>
</tr>
<tr>
<td>$P$</td>
<td>6.1 E-26</td>
<td>0.085</td>
<td>0.361</td>
<td></td>
</tr>
</tbody>
</table>

The $P$ value is the probability that sampling of a Poisson distributed random variable produces a poorer fit than the observed data. The null-hypothesis is rejected for the Indian farmers at any level of significance and accepted for the farmers in Zimbabwe. Health risks to spraymen appear heterogeneous at the 10% error level.

Since the data from the Indian farmers and spraymen does not support the Poisson model, we estimate the parameters of the alternative, negative binomial sampling model. Table 32 reproduces the estimated parameters of the distributions of $Y$ and $M$. For illustration, we also report the parameters for Zimbabwe, although overdispersion is not significant in that population.
Table 32: Estimated health risk distribution parameters in different populations

<table>
<thead>
<tr>
<th></th>
<th>India Farmers</th>
<th>India Spraymen</th>
<th>Zimbabwe Farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E(Y) = \lambda$</td>
<td>0.409</td>
<td>1.529</td>
<td>0.908</td>
</tr>
<tr>
<td>$\text{Var}(Y)$</td>
<td>0.763</td>
<td>1.857</td>
<td>0.966</td>
</tr>
<tr>
<td>$\phi$</td>
<td>1.863</td>
<td>1.214</td>
<td>1.064</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.474</td>
<td>7.141</td>
<td>14.17</td>
</tr>
<tr>
<td>$\beta$</td>
<td>1.158</td>
<td>4.669</td>
<td>15.61</td>
</tr>
<tr>
<td>$\text{Var}(M) = \alpha/\beta^2 = \text{Var}(Y) - E(Y)$</td>
<td>0.353</td>
<td>0.328</td>
<td>0.058</td>
</tr>
<tr>
<td>$P$ of Pearson $\chi^2$ statistic (4 df)</td>
<td>0.560</td>
<td>0.130</td>
<td>0.310</td>
</tr>
</tbody>
</table>

The degree of overdispersion $\phi$ exceeds 1 in all cases. The $P$ values are the probabilities that the data is drawn from a negative binomial distribution. They are larger than 0.1 and those of the Poisson model for the Indian farmers and spraymen, implying that the negative binomial model should be accepted. However, the value for spraymen is still low, suggesting that neither the Poisson nor the negative binomial distribution fits the data well. Figure 24 depicts the cumulative Gamma distributions of $M$ with the parameters reported in Table 32.
The expected number of health problems per season $M$ varies considerably among spraymen and farmers in India and slightly among farmers in Zimbabwe. A considerable proportion of the Indian farmers is at a very low risk. Table 33 gives a selection of quantiles of the distributions of $M$ in the three groups.
Table 33: Health risk quantiles

<table>
<thead>
<tr>
<th>Health risk quantiles</th>
<th>India Farmers</th>
<th>India Spraymen</th>
<th>Zimbabwe Farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25%</td>
<td>0.04</td>
<td>1.11</td>
<td>0.74</td>
</tr>
<tr>
<td>50%</td>
<td>0.18</td>
<td>1.46</td>
<td>0.89</td>
</tr>
<tr>
<td>75%</td>
<td>0.54</td>
<td>1.87</td>
<td>1.06</td>
</tr>
<tr>
<td>90%</td>
<td>1.12</td>
<td>2.29</td>
<td>1.23</td>
</tr>
<tr>
<td>Average M of safest 25%</td>
<td>0.01</td>
<td>0.89</td>
<td>0.63</td>
</tr>
<tr>
<td>Average M of unsafest 25%</td>
<td>1.13</td>
<td>2.27</td>
<td>1.22</td>
</tr>
<tr>
<td>M ratio between unsafest and safest 25%</td>
<td>90.3</td>
<td>2.55</td>
<td>1.93</td>
</tr>
</tbody>
</table>

In India, the average health risks faced by the unsafest 25% of farmers is around 90 times that of the safest 25%. The corresponding figures for Zimbabwe and the Indian spraymen are around 2.

8.4 Distribution of labor loss

The previous sections gave evidence with respect to the distribution of health risks. The concept "health risk" refers to a binary health variable (denoted \( y_{ij} \) above). Such a variable can give only a rough picture of health impacts because it does not account for the severity of health problems (cf. Section 5.4). This raises the question whether heterogeneity in expected health impacts from PPA would be more accentuated if we looked at a measure for the severity rather than the health risk itself. It is possible that relatively unsafe users are not only more likely to suffer a health problem on a given occasion of potential exposure, but are also overproportionally prone to face severe problems. The question is examined subsequently by analysis of the relationship between the frequency and the severity of health problems.

8.4.1 Labor loss vs. health risks

Labor loss, or absence from work due to adverse health effects of PPA, is a quantitative measure for the gravity of health effects. The labor loss is influ-
enced by such factors as pending farm work which must be dealt with, labor supply, attitudes, etc., in addition to the seriousness of a health problem. Thus, it cannot be more than a useful approximation to the health impacts. The variance of lost labor due to health effects of PPA in a given time period is a function of the variance in health risks between individuals, the variance of health risks between occasions, the variance of the function relating the labor loss to the health risk, and the corresponding covariances. By relating the average labor loss per health problem to the number of health problems due to PPA, we can draw conclusions concerning the covariance between the gravity of health problems and health risks. A positive covariance would imply that heterogeneity in health impacts measured as labor loss is more accentuated than heterogeneity in health risks.

8.4.2 Sample statistics

Table 34 reproduces the average labor losses per individual and season.

Table 34: Average labor loss attributed to PPA per individual and season

<table>
<thead>
<tr>
<th></th>
<th>India Farmers</th>
<th>India Spraymen</th>
<th>Zimbabwe Farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>215</td>
<td>51</td>
<td>195</td>
</tr>
<tr>
<td>Average number of health problems due to PPA per season (full sample)</td>
<td>0.409 (0.875)</td>
<td>1.529 (1.376)</td>
<td>0.908 (0.985)</td>
</tr>
<tr>
<td>Average labor loss due to PPA [days/season] (full sample)</td>
<td>1.000 (3.486)</td>
<td>4.314 (6.065)</td>
<td>0.708 (4.023)</td>
</tr>
<tr>
<td>Number of respondents with ≥ 1 health problem due to PPA in one season</td>
<td>51 (23.7%)</td>
<td>36 (70.6%)</td>
<td>109 (55.9%)</td>
</tr>
<tr>
<td>Average number of health problems due to PPA per season (respondents ≥ 1 health problem)</td>
<td>1.725 (0.981)</td>
<td>2.167 (1.134)</td>
<td>1.624 (0.755)</td>
</tr>
<tr>
<td>Average labor loss due to PPA [days/season] (respondents ≥ 1 health problem)</td>
<td>4.217 (6.177)</td>
<td>6.111 (6.422)</td>
<td>1.239 (5.324)</td>
</tr>
<tr>
<td>Number of respondents with labor loss &gt; 0 in one season</td>
<td>40 (18.6%)</td>
<td>26 (50.9%)</td>
<td>17 (8.7%)</td>
</tr>
<tr>
<td>Average number of health problems due to PPA per season (respondents with labor loss &gt; 0)</td>
<td>1.850 (1.051)</td>
<td>2.385 (1.134)</td>
<td>1.412 (0.712)</td>
</tr>
<tr>
<td>Average labor loss due to PPA [days/season] (respondents with labor loss &gt; 0)</td>
<td>5.377 (6.521)</td>
<td>8.462 (6.088)</td>
<td>8.118 (11.505)</td>
</tr>
</tbody>
</table>

Note: Figures in parenthesis are standard deviations or percent of sample.
The average labor loss per farmer due to PPA is around 1 day per season in both countries. Among spraymen, the average labor loss due to PPA is around 4 days per season. The average labor losses to respondents who suffered at least one health problem were 4.2, 1.2 and 6.1 days among the Indian farmers, the farmers from Zimbabwe and the spraymen, respectively. Among respondents who suffered any labor loss at all, the average labor loss is between 5.3 and 8.5 days per respondent. Figure 25 shows the cumulative distributions of labor loss in the three populations.

**Figure 25: Distribution of labor loss**

The figure shows that labor loss is very unevenly distributed among farmers and spraymen. While 24 and 56% of the farmers in India and Zimbabwe, respectively, report some health problem due to PPA, less than 20% account for the totality of labor loss (cf. Table 34). In the group of spraymen, the incidence of health problems due to PPA that entail labor loss is around 50% per season. Spraymen face PPA related health problems on a more regular
basis than farmers. Of course, the fact that spraymen spray more often partly explains this finding.

8.4.3 Estimation results

The following table reproduces the estimation results of OLS models relating the average labor loss per health problem to the number of health problems.

Table 35: Models for average labor loss per health problem due to PPA

<table>
<thead>
<tr>
<th></th>
<th>India Farmers</th>
<th>India Spraymen</th>
<th>Zimbabwe Farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.870 (1.157)</td>
<td>3.641 (1.366)</td>
<td>0.938 (0.780)</td>
</tr>
<tr>
<td>Health problems due to PPA</td>
<td>-0.187 (0.584)</td>
<td>-0.299 (0.560)</td>
<td>-0.089 (0.436)</td>
</tr>
<tr>
<td>R²</td>
<td>0.002</td>
<td>0.008</td>
<td>0.000</td>
</tr>
<tr>
<td>Model P</td>
<td>0.750</td>
<td>0.597</td>
<td>0.839</td>
</tr>
<tr>
<td>Pearson correlation coefficient</td>
<td>-0.046</td>
<td>-0.091</td>
<td>-0.020</td>
</tr>
</tbody>
</table>

Note: Estimated with respondents reporting at least 1 health problem due to PPA. Figures in parenthesis are standard errors.

The models show that the labor loss per health problem correlates negatively, but insignificantly, with the number of health problems due to PPA. The correlation coefficients are very small, suggesting that the severity and frequency of health problems are independent. Therefore, the variance in the labor loss per health problem does not accentuate the health impact heterogeneity.

8.5 Conclusions

We have examined the heterogeneity of health risks and impacts in seemingly homogenous populations by analysis of the distribution of health risks and labor loss. Heterogeneity was found considerable in India but negligible in Zimbabwe. The health risk to the unsafest 25% of the Indian farmers is 90 times the risk to the safest 25%. Surprisingly, the expected severity of health problems suffered by an individual, measured as average labor loss per health problem, is not correlated with the expected frequency of health problems suffered by that individual. The following conclusions are offered.
• Heterogeneity in health risks within seemingly homogenous groups may be considerable. This implies that groups of PPA operators may comprise subgroups of relatively safe and unsafe users. Therefore, it might be worthwhile to try to identify unsafe users and focus efforts to improve safety on that segment.

• For the main, most acute adverse health effects of PPA are minor problems of short duration. Operators are likely to have only limited experience with severe adverse health problems due to PPA. This implies that although they may have a subjective, quantitative notion about the frequency of adverse health effects, they may be unaware of the expected distribution of the quantitative aspects of health impacts. This conclusion corresponds well to the finding that the occurrence of considerable exposure is observable but not the actual mass of exposure (cf. Chapter 6).

• Safe use of PPA may have a different meaning to farmers and spraymen. To farmers, safe use has the character of an insurance against the relatively low probability of an accident. To spraymen, safe use signifies a reduction of regularly incurred costs.
Health costs of occupational exposure to PPA are estimated with the contingent valuation method. This method relies on the respondents' perceptions. We claim that PPA operators are aware of acute health risks. Hence, the contingent valuation includes values attributed to acute health risks. However, subjective estimates of chronic health risks and their accuracy are uncertain. Therefore, the extent to which the valuation includes chronic risks is also uncertain. Farmers and spraymen were asked to state the maximum that they were willing to pay (WTP) for health hazard-free PPA. An iterative bidding game was used to obtain a continuous WTP measure for hypothetical safe versions of different PPA brands. WTP regression models are estimated to examine internal consistency. A significant correlation between the oral toxicity of different PPA and the WTP for safe versions of these compounds suggests that the contingent valuations reflect preferences on a relative scale. However, validations with extra sample information shows that farmers overclaim health costs. The reported WTP is not correlated with the marginal value product of PPA, implying that stated preferences are in contrast to revealed preferences. The costs of hiring spray labor are considerably lower than the stated health costs, providing further evidence for overclaim. Twenty percent of the PPA value is a safe upper limit to the subjectively appreciated health costs and, hence, to the acute health costs of PPA.
9.1 Introduction

An assessment of health costs due to occupational exposure to PPA may prove useful in a number of contexts. First, it should give a better quantitative measure for health problems than health risk estimates. Second, economic measures for health reflect preferences and therefore allow an examination of the behavior of those who are knowingly at risk (Cropper, 1994). Third, health valuation may be normatively useful, allowing reconciliation of the conflicting objectives, income and health. In particular, it is an essential basis for the evaluation of efforts to prevent adverse health effects, such as regulation and extension.

There are many studies on the incidence of acute adverse health effects from PPA in developing countries, but only few have tried to value those health impacts. Cristman et al (1994) find that health costs which arise for Ecuadorian potato growers as a result of PPA use are considerable, but probably outweighed by the net production benefits of PPA. Antle and Pingali (1994, 1995) report that long-term health costs to Philippine rice farmers measured as labor productivity reductions exceed the direct income benefits of PPA. Zilberman and Castillo (1994) point out that this result is due mainly to a relatively low PPA productivity rather than to particularly high health costs.

Methods that yield monetary benefit measures are categorized as direct and indirect. Indirect methods develop models of choice and decision rules based on actual choices made by individuals of the population of interest. These constitute revealed preferences regarding goods, both market and non-market. Indirect health cost estimation requires the valuation of effects of health changes on productivity, leisure and the consumption of formal and informal health care services. Direct methods confront individuals with hypothetical choices. They are examples of stated preference techniques in that individuals do not actually make any behavioral changes, they only state that they would behave in a certain fashion (Adamowicz et al, 1994). The most prominent direct method is the contingent valuation method (CVM). Respondents are asked how much they would be willing to pay for an option, such as, for example, an improvement in health. The contingent valuation method is theoretically applicable to a broad variety of goods and services,
including private and public ones. It appears useful to value non-market goods which may be difficult or impossible to handle with indirect methods.

Both direct and indirect methods can be applied to value adverse health effects of PPA. For example, one might indirectly estimate the costs of illness by adding up the costs of lost labor, absence of daily duties, medication, health care services consumed, etc. Alternatively, one could examine the effects of toxicity on the demand for PPA and derive the demand for safety. We estimate the value of adverse health effects of PPA to operators with the contingent valuation method and compare the value obtained with indirect estimates. We also compare the farmers' stated preferences to actual choices of input allocation.

The contingent valuation relies on the preferences of the people affected. CROPPER (1994) argues that in valuing health it seems only appropriate to do so, rather than transferring values from developed countries to the developing country context.

The chapter is organized as follows. Section 9.2 introduces the basic concepts of economic health valuation. The demand for a production factor that affects both income and health is derived and the form (convexity vs. concavity) of the benefits of exposure reduction is discussed for later reference. Section 9.3 presents the contingent valuation method with emphasis on the controversy about its validity (Subsection 9.3.1). An overview of the NOAA (1993) guidelines is given in Subsection 9.3.2. Section 9.4 describes the application of the method. It includes a discussion of operator awareness of health risks due to PPA which is crucial to the interpretation of the WTP. Results are presented and subjected to a number of tests and comparisons with indirect estimates in Section 9.5. Conclusions are offered in Section 9.6.

9.2 Value of health

9.2.1 Compensating and equivalent variation

The economic value of health is derived from the utility theory. Let \( U(Y,H) \) be utility as a function of income \( Y \) and health \( H \) (EVANS and VISCUSI, 1991). We can think of \( H \) as an index of all possible health states, where higher values indicate more preferred states. Thus, we ensure that the mar-
ginal utility of $H$ is always positive. The value of a change in health from $H_0$ to $H_1$ is defined alternatively as the change in income that compensates for a change in health or the change in income that is equivalent to a change in health. The former is the compensating variation $CV$, i.e. the solution of

\begin{equation}
U(Y,H_0) = U(Y - CV,H_1).
\end{equation}

The equivalent variation $EV$ solves

\begin{equation}
U(Y + EV,H_0) = U(Y,H_1).
\end{equation}

These measures have the following characteristics.

- Since utility is generally nonlinear, the compensating variation differs from the equivalent variation for the same change in health. For small changes in health, the difference is small if we assume the utility function smooth (namely, twice differentiable).

- The marginal utility of income may be zero at certain values of health. Therefore, economic measures do not necessarily exist for all changes in health. For example, there is no meaningful compensating or equivalent variation for death, since a dead person has no utility function. (Taking the utility concept to extremes, one might postulate that a dead person's utility is identical to 0 (EVANS and VISCUSI, 1991)).

- The utility maximizer is willing to give up the (positive) amount $CV$ of his income to ensure a gain in health or to accept an amount $CV$ as compensation for a health reduction. Similarly, the utility maximizer is willing to give up a (positive) amount $EV$ of his income to avoid a reduction in health or to accept the amount $EV$ as compensation for not realizing a gain in health. To summarize, the compensating variation corresponds to the willingness to pay to secure a benefit or the willingness to accept payment to tolerate a loss. The equivalent variation corresponds to the willingness to accept payment to sacrifice a benefit or the willingness to pay to prevent a loss (PEARCE and TURNER, 1990).
Table 36: Economic measures for benefits and costs

<table>
<thead>
<tr>
<th>Valued option</th>
<th>Benefit</th>
<th>Loss / damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compensating variation</td>
<td>WTP</td>
<td>WTA</td>
</tr>
<tr>
<td></td>
<td>to secure a benefit</td>
<td>to tolerate a loss</td>
</tr>
<tr>
<td>Equivalent variation</td>
<td>WTA</td>
<td>WTP</td>
</tr>
<tr>
<td></td>
<td>to forego a benefit</td>
<td>to prevent a loss</td>
</tr>
</tbody>
</table>

Source: after PEARCE and TURNER (1990)

This is the basis for the contingent valuation method. By asking respondents about their willingness to pay or willingness to accept, the researcher may directly elicit the compensating or equivalent variation and, hence, the value of a good.

9.2.2 Demand for health

In the following, we consider the compensating variation only, because our contingent valuation refers to the willingness to pay to secure a gain in health. Equation (19) implies that the compensating variation is a function of $Y, H_0$ and $H_1$. For simplicity, we suppress the subscript of $H_1$ and write $CV = CV(Y, H_0, H)$. Differentiating equation (19) with respect to $H$ and rearrangement yields

$$0 = -U_Y(Y - CV, H) CV_H(Y, H_0, H) + U_H(Y - CV, H).$$

Transformation yields

$$CV_H(Y, H_0, H) = \frac{U_H(Y - CV, H)}{U_Y(Y - CV, H)}$$

$CV_H$ is the marginal willingness to pay for health given that actual health and income are $H_0$ and $Y$. Jointly, the right hand side of (21) and equation (19) imply that $CV_H$ refers to constant utility but to different contributions of $Y$ and $H$ to utility. By keeping $Y$ and $H_0$ constant, we may write $CV_H = CV_H(H)$. The inverse of this function is the Hicks compensated demand for health. It is the demand for a good in function of prices conditioned on constant utility. The integral of $CV_H$ between $H_0$ and $H$ is $CV$, i.e. the willingness-
ness to pay to secure a gain in health \((H > H_0)\) or the willingness to accept a reduction in health \((H < H_0)\). To illustrate the difference between the Hicks compensated demand and the uncompensated demand (at variable utility), assume health could be bought and sold at a price \(p\). Utility is then \(U = U(Y - p(H - H_0), H)\), where \(H\) is a choice variable. The first order condition for utility maximization implies

\[
p(Y, H_0, H) = \frac{U_H(Y - p(H - H_0), H)}{U_Y(Y - p(H - H_0), H)}.
\]

Note that (21) and (22) are equivalent at \(H = H_0\). It can be shown that \(p_H < 0\) implies \(CV_{HH} < p_H\) and, hence,

\[
WTP = CV < \int_{H_0}^{H} p \, dH,
\]

as depicted in Figure 26.

**Figure 26:** Hicks compensated demand and willingness to pay
9.2.3 Uncertainty

A change in health is typically stochastic. For instance, the use of PPA may cause a large number of different health effects, each with a certain probability. Denoting the possible health effects with \( h \) and their probabilities with \( \pi \), the expected value of (the change in) health is \( E(H) = h'\pi \). Denote the compensating variations of \( h \) with \( c \). Due to the nonlinearity of the compensating variation, \( CV(E(H)) = CV(h'\pi) \neq c'\pi = E(CV(H)) \). That is, the economic value of expected health is generally not equal to the expected economic value of health. This implies that the willingness to pay for a stochastic change in health is a function of the change in expected health and the change in the probability distribution of health. Typically, a change in health realized with certainty (\( \pi = [\pi_1, \pi_2, ..., \pi_n] = [0, ..., 0, 1, 0, ..., 0] \)) is preferred to a stochastic change in health with the same expected value. That is, uncertainty about health represents a cost.

These considerations may be relevant for the interpretation of the willingness to pay to avoid adverse health effects of PPA. Let \( h \) be the possible effects with element \( h_1 \) representing no effect. Think of \( \pi \) as probabilities of these effects in function of PPA use, way of use, etc. The willingness to pay to avoid adverse health effects of PPA is then the willingness to pay for changing \( \pi \) from some current distribution \( \pi^1 \) to the singular distribution \( \pi^0 \) where many elements of \( \pi^1 \) are positive while only the first element of \( \pi^0 \) is positive, \( \pi^0_1 = 1 \). The change from \( \pi^1 \) to \( \pi^0 \) affects the expected value of health and the probability distribution of health. Therefore, the willingness to pay to avoid ill health is composed of a willingness to pay for an improvement of expected health plus the willingness to pay for a reduction of uncertainty about health.

9.2.4 Demand for PPA under health risks

The demand for PPA is derived for the cases of certainty and uncertainty about health effects. Consider first the hypothetical case of certain health effects of PPA. PPA affect both health and income. We may thus write \( U = U(Y(x), H(x)) \), where \( x \) are PPA. Total income is composed of profits from agricultural production \( \Pi = pq(x) - wx \) and other income \( Y_0 \): \( Y(x) = Y_0 + pq(x) - wx \), where \( p \) is the product price, \( q(x) \) is a production function, and \( w \) is the price of PPA. The demand for PPA is given by the first order condition for utility maximization with respect to \( x \) which establishes \( U_Y \cdot (pq_x - \)
w) + U_HHx = 0. At the margin, \( U_{H}/U_{Y} = CV_{H} \). Hence \( pq_{x} = w - CV_{H}H_{x} \). (\( H_{x} < 0, CV_{H} > 0 \)). In words, the marginal value product of PPA, \( pq_{x} \), equals the marginal costs of PPA composed of a marginal expense \( w \) and marginal health costs \(-CV_{H}H_{x}\). This determines the demand for PPA on the condition that the decision-maker has accurate information about health costs and that health costs are certain.

Now consider the case of uncertain health effects. Assuming separability, we may think of \( H \) as expected health and denote the variance of, or uncertainty about health with \( V \). Utility is then \( U = U(Y(x),H(x),V(x)) \) and the demand for PPA is given by \( pq_{x} = w - U_{H}/U_{Y} H_{x} - U_{V}/U_{Y} V_{x} \). (\( H_{x} < 0, V_{x} < 0 \)).

### 9.2.5 Costs of expected health and uncertainty

Let \( C \) be the sum of the cost of expected health and uncertainty about health so that \( C_{x} = -U_{H}/U_{Y} H_{x} - U_{V}/U_{Y} V_{x} \). The form of this expression in \( x \) is of particular interest. Assuming \( U_{H}/U_{Y} \) and \( U_{V}/U_{Y} \) approximately constant in relation to minor changes in health, differentiation with respect to \( x \) yields \( C_{xx} = -U_{H}/U_{Y} H_{xx} - U_{V}/U_{Y} V_{xx} \). Typically, epidemiologists and toxicologists assume constant or increasing marginal expected health responses to toxic substances, while health risks are not high. Since the response has the opposite sign of the implied change in health, \( H_{xx} \leq 0 \). The sign of \( V_{xx} \) is less certain. In particular, a small increase in \( x \) from 0 to \( x_{1} \) implies a change from certainty (\( \pi = [1,0,\ldots,0] \)) to uncertainty, an effect which might be more significant than the increase in uncertainty associated with a change from \( x_{1} \) to \( 2x_{1} \). This would imply \( V_{xx} > 0 \) and, if uncertainty \( V \) dominates \( C \), \( C_{xx} < 0 \). The health costs \( C \), composed of the cost of expected health and uncertainty may thus be convex or concave with respect to PPA use levels (and other variables that increase exposure), depending on the form and relative importance of the two cost elements. The possibility \( C_{xx} < 0 \) implies that the marginal benefits of exposure reduction (prevention) may be increasing.

EOM (1994) elicits consumer preferences for reductions in the health risks due to PPA residues in food. He finds that both technical risk information and risk perceptions inadequately explain the price premiums consumers claimed to be willing to pay for safer produce. The author concludes that "perhaps what [the respondents] evaluated in the [contingent behavior] question was the difference in 'food safety' implied by the two produce types rather than changes in 'risk' per se. Therefore, high price premiums may simply reflect consumers' desires to assure that the food they eat is safe.
rather than reflect particular amounts of risk reduction". This implies that the value of a risk reduction increases overproportionally as certainty is approached. Thus, EOM's study suggests that the benefits of health risk prevention may indeed be convex.

9.3 Contingent valuation: Discussion

The contingent valuation method has been widely applied, namely to value environmental assets and damage. However, the widespread use, and the amount of money at stake in some cases (e.g. CARSON et al, 1992, quoted in HARRISON and LESLEY, 1996), lead to a controversy which we summarize below drawing principally on DIAMOND and HAUSMAN (1993 and 1994) and HANEMANN (1994). The controversy is largely concerned with nonuse values (existence values, off-site values) of public goods because those cannot be measured with indirect methods.

9.3.1 Controversy about reliability

*Philosophical arguments*

HANEMANN (1994) and others point out that nonuse values of public goods can only be measured by asking the individuals who hold these values, i.e., the public. Expert assessments of environmental damage is of little or no help when public valuation is the object of measurement. DIAMOND and HAUSMAN (1994) find this a poor argument and call it the some-number-is-better-than-no-number fallacy, meaning that being the only method does not imply that it is a valid method. On the other hand, if rejecting a contingent valuation measure as unreliable means the value is not taken into account, the actual valuation is also just a number, zero.

In some cases, the controversy concerns the burden of proof rather than the actual advantages and drawbacks of the method. DIAMOND and HAUSMAN (1994) argue that in establishing guidelines for contingent valuation studies, NOAA (1993) should have provided reasons for reaching the conclusion that studies meeting the guidelines are "reliable enough to be the starting point of a judicial process of damage abatement". Thus, they assign the burden of proof to the proponents. HANEMANN (1994) assigns it to the critics as he mentions that "contingent valuation is now used around the world [...], both by government agencies and the World Bank" and that "nobody has
stopped using data from the Current Population Survey, Consumer Expenditure Survey [...] because there are response effects in such surveys. The same should apply to contingent valuation surveys". Of course, the magnitude of the error is important, not the error per se.

Validity and reliability

Turning to the more technical arguments, Shavell (1993) divides criticism of contingent valuation into six claims: "that individuals sometimes do not have adequate understanding of what they are asked to evaluate; that they may have motives to misrepresent their opinions; that they may have poor incentives to answer questions carefully; that their answers may reflect something different from valuation; that their answers may depend substantially on the form in which questions are posed; that [...] contingent valuation estimates have been highly variable." These claims are discussed subsequently.

1. Individuals sometimes do not have adequate understanding of what they are asked to evaluate. Responses to contingent valuation surveys may reflect derived preferences. For example, the value attributed to saving a part of a bird population may be derived from the desire to save the species from extinction. Thus, the answers depend then on the respondent's belief about the biological relationship between population size and risk of extinction which may be prone to substantial errors (Diamond and Hausman, 1994). Mitchell and Carson (1989) call this type of error amenity misspecification bias due to part-whole confusion: The respondent includes a broader (or narrower) range of benefits when valuing a good than intended by the researcher.

2. Individuals may have motives to misrepresent their opinions. Respondents may believe that contingent valuation results will influence public or private decisions. In that case, they might possibly exaggerate or diminish the apparent importance of an issue (Shavell, 1993). This results in so-called strategic bias. Evidence for non-existence of such biases is largely drawn from experimental economics. However, Cummings and Harrison (1994) claim that experimental and survey settings differ too much to allow such conclusions.

3. Individuals may have poor incentives to answer questions carefully. Unlike market transactions, contingent valuations do not imply that indi-
individuals bear the consequences of their choices. Therefore, respondents tend to simplify the mental effort of evaluation, in particular when valuing an unfamiliar good. In the extreme case, answers are no better than simple guesses (SCHKADE and PAYNE, 1993).

4. Answers to contingent valuation questions may reflect something different from valuation of the good of interest to the researcher. This claim includes (at least) three groups of arguments.

a) Contingent valuations may reflect the respondent's desire to do good in the world (independently of the provision of the good of interest), a desire to please, duty, the willingness to bear a fair share of the costs of a project—these are sometimes summarized as "warm glow", the willingness to pay for the environment in general rather than the good under examination, and altruism21 (DAUM, 1993). This implies that the willingness to pay relates to a coalescence of values attributed to a variety of concepts. The value of the good of interest cannot be identified.

b) Respondents may express values attributed to actions rather than states of the environment. This implies that the valuation of a resource that is not at risk is different from (namely lower than) the value attributed to the same resource that was at risk but then saved. Thus, the action of saving the resource is assigned a value of its own. The valuation of actions may imply that damage caused by man is attributed a higher value than similar damage that occurred naturally. This raises a number of issues some of which concern the very foundations of economic theory according to DIAMOND (1996).

c) Individuals may be describing what they think is good for the country, in a sort of casual cost-benefit analysis. Answers then reflect how much respondents think people generally care about an issue rather than their own preferences (DIAMOND and HAUSMAN, 1994). This creates aggregation and interpretation problems. Moreover, if the claimed willingness to pay is just the result of a

---

21Altruism exists if individuals attribute values to the well-being or welfare of others.
casual cost-benefit analysis, it appears preferable to conduct an expert analysis.

5. Answers may depend substantially on the form in which questions are posed. The way the contingent valuation question is asked and the information provided to the respondents prior to the question may strongly influence answers. Awareness of substitutes (Hausman et al, 1993) and budget constraints (Kemp and Maxwell, 1993) seem to be particularly important.

6. Contingent valuation estimates have been highly variable. The results of different studies intended to value the same good have sometimes varied by several orders of magnitude (Carson, 1991, quoted in Shavell, 1993).

Proponents recognize these objections but put them into perspective by examination of the circumstances in which they apply. They propose three classes of arguments. The first deals with the communication between the researcher and the respondent. The second concerns the nature of preferences and the third defines the factors that should be allowed to influence responses and be included in willingness to pay measures.

- **Communication.** Like any survey, contingent valuation is a communication process between researchers and informants, i.e., respondents. Results depend essentially on how questions are asked and what information is given and/or available to the respondents. According to proponents, asking the right questions in the right way rules out problems of misunderstandings (objection 1), strategic bias (objection 2), "warm glow" (objection 4a), and casual cost-benefit analysis (objection 4c) (e.g. Hanemann, 1994 and Mitchell and Carson, 1985). Results of contingent valuations have varied widely (objection 5) because, according to proponents, some researchers asked the wrong questions.

- **Nature of preferences.** Confronted with objection 3, and the criticism that respondents "are not easily in touch with underlying preferences," (Diamond and Hausman, 1994), Hanemann (1994) argues that people make up decision rules and preferences in a heuristic manner at the moment they need them rather than having some set of rules stored in their minds. He points out that these psychological processes are pertinent to both hypothetical and real trade-offs and that therefore contingent valuation does not differ from market transactions and/or voting in this respect.
Components of values (objections 4a and 4b).

- Should valuations include altruism? JOHANSSON (1994) finds that aggregation of individual willingness to pay yields consistent welfare measures if the hypothetical option in the contingent valuation scenario is defined in such a way that the respondent assumes that other individuals stay at their initial utility levels. Applied to public goods, this signifies that respondents should be asked about their willingness to pay on condition that everybody else also pays thus remaining at their initial levels of utility. Whether this is practicable, given that the utility derived from public goods varies across subjects, remains to be answered.

- Defendants and opponents (DIAMOND and HAUSMAN, 1994) seem to agree that contingent valuations include values attributed to actions (objection 4b). They disagree on what should be included in economic analysis. Should the willingness to pay include a valuation of actions or just of states of the world? DIAMOND (1996) argues that values attributed to actions are valid expressions of preferences but that including them into welfare measures creates a number of problems. For instance, when a resource saved is valued more than the mere existence of the same resource, proposing and subsequently abandoning a destructive project would create welfare. Thus "if we are not willing to restrict analysis to preferences defined over the state of the environment, rather than also including the process resulting in that state, then we need a new welfare economics to make use of such preferences" (DIAMOND, 1996).

There is a consensus that contingent valuations should be validated with results from indirect methods or with internal consistency tests (e.g. NOAA, 1993; DESVOUSGES et al, 1993). The controversy concerns which tests truly assess validity and whether such validations generally fail or not. The best validation would be a comparison with results from indirect valuation methods. However, in many cases indirect methods cannot be applied. The researcher must then resort to internal consistency tests. MITCHELL and CARSON (1989) suggest investigating whether the willingness to pay depends in a plausible manner on potential explanatory variables. For example, the willingness to pay for the environment should increase with income. DIAMOND and HAUSMAN (1994) argue that such tests are not decisive because they would produce similar results independently of whether the will-
ingness to pay relates to relative preferences or to warm glow, etc. Moreover, they point out that, when tested, contingent valuations often fail the tests.

Confronted with this criticism, Hanemann (1994) follows three lines of arguments. First he claims that results obtained from conscientiously conducted contingent valuations passed testing by comparison with direct estimates. "[O]verall, the contingent valuation estimates are slightly lower than the revealed preference estimates and highly correlated with them". This contrasts with Mitchell and Carson (1989), who noticed that market researchers estimating the demands for private goods prior to market release, commonly face the need to calibrate hypothetical responses, i.e. to reduce contingent valuation measures by factors of 1.5 to 10 (Duffield and Patterson, 1992, and Seip and Strand, 1992, quoted in Diamond and Hausman, 1994). Hanemann also recognizes that surveys of purchase intentions may not be accurate predictors of subsequent purchase behavior. Second, Hanemann points out that comparisons with actual behavior corroborate contingent valuation measures. However, in one of the studies he quotes as being supportive (Cummings et al, 1993), contingent valuation measures and actual behavior appear to have been comparable only after the former had been corrected by incorporating information from the latter. Third, Hanemann argues that contingent valuation surveys are comparable to surveys of voting intentions which have produced reliable results according to Kelley and Mirer (1974, quoted in Hanemann). Researchers conducting contingent valuation studies generally recognize the potential of unreliable or incredible results by removing extreme willingness-to-pay responses (outliers and/or zero values) from the data set (Diamond and Hausman, 1994).

To conclude this discussion, it is obvious that there are many potential sources of error in contingent valuations. Adhering to guidelines is recommendable but cannot eliminate skepticism in absence of validations with results obtained from indirect estimates. We agree with NOAA (1993) that "some form of internal consistency is the least we would need to feel some confidence that the verbal answers correspond to some reality". There seems to be a consensus that hypothetical surveys tend to overestimate the demand for private goods.
9.3.2 Guidelines for conducting reliable contingent valuation surveys

NOAA (1993) proposed a number of guidelines for the design of contingent valuation studies. General guidelines concern the sampling procedure, the minimization of non-responses, the pretesting for interviewer effects in major studies, and reporting. Specific guidelines for value elicitation surveys are summarized in Table 37.

Table 37: NOAA guidelines for contingent valuation surveys

- **Conservative design**: When aspects of the survey design are ambiguous, the option that tends to underestimate willingness to pay is preferred.

- **Elicitation format**: Asking about the willingness to pay to secure a benefit or avoid a loss is thought to provide more reliable answers than asking about the willingness to accept compensation for a loss incurred.

- **Referendum format**: The valuation question should be posed as a vote on a referendum.

- **Accurate description of the program or policy**

- **Pretesting of photographs**

- **Reminder of substitutes**: "Respondents must be reminded of substitute commodities. [...] This reminder should be introduced forcefully and directly prior to the main valuation question to assure that respondents have the alternatives clearly in mind."

- **Adequate time lapse**: Concerns the valuation of damage that actually occurred. The time lapse between occurrence of the damage and the survey should be sufficient that respondents regard the scenario of complete restoration as plausible.

- **Temporal averaging**: In eliciting time-dependent values, appropriate weights should be attributed to values at different times.

- **No-answer option**: A no-answer option should be explicitly allowed on the main valuation question.

- **Yes/no follow-ups**: "Yes and no responses should be followed up by the open-ended question: 'Why did you vote yes/no?'"

- **Cross-tabulations**: The survey should include a variety of other questions that help to interpret the responses to the primary valuation question.

- **Checks on understanding and acceptance**: The questionnaire must be kept sufficiently simple.

Source: NOAA (1993)

NOAA further mentions a number of goals for value elicitation surveys: Respondents should be reminded of alternative expenditure possibilities; the survey should allow identification of the effects of "warm glow"; the re-
spondents' capacity of distinguishing temporal from permanent losses and to adequately allow for the timing of the restoration process should be investigated.

9.3.3 Contingent valuation studies about health risks due to PPA

The contingent valuation method has been applied previously to value health risks due to PPA. Most studies are concerned with the values consumers attribute to PPA residue-free produce (e.g. BUZBY et al, 1995; EOM, 1994; HUANG, 1993; MISRA et al, 1991; OTT, 1990).

We are aware of only one contingent valuation of occupational health risks due to PPA: HIGHLEY and WINTERSTEEN (1992) elicit US farmers' ranking of different environmental risks due to PPA, including acute and chronic health risks. They used open-ended questions to estimate the values attributed to the prevention of those risks. Respondents were provided with information about the magnitude of the risks ("no risk", "low risk", "middle risk", "high risk"). The rankings and contingent valuation measures were used to estimate environmental and health costs of PPA. The average willingness to pay to avoid health risks are 1.6 and 3.5 US$ per acre and spray-round for "low" and "high" acute and chronic health risks respectively. This corresponds to 10-25% of the PPA costs. Open-ended questions are commonly thought to bias estimates upwards (e.g. HANEMANN, 1994) and therefore the actual health costs are likely to be lower than 25% of PPA costs.\(^{22}\)

\(^{22}\)Besides HIGHLEY and WINTERSTEEN (1992), there is a study by WARBURTON et al (1995) who do not value health, but assess the willingness to pay for protective gear in the Philippines. A sample of farmers were given gloves and masks free of charge for one season and could buy the gear at the end of the season. Adoption rates were low. Unfortunately, they are not reported quantitatively. Therefore, we cannot estimate the willingness to pay for protective gear with the information provided by WARBURTON et al.
9.4 Contingent valuation: Application

9.4.1 Operator awareness of health risks due to PPA

The contingent valuation method is based on the assumption that—under certain conditions—responses on a hypothetical scenario reflect true preferences. This presupposes that the respondents have a clear qualitative and quantitative idea of the implications of the scenario, i.e., that they are "familiar" with the good or service in question (Mitchell and Carson, 1989; Diamond and Hausman, 1994). In the context of PPA safety, this signifies that the respondents should be aware of the potential health consequences of PPA use. If operators do not understand the link between PPA and health, other methods must be used to value the health effects of PPA, e.g. a combination of epidemiological dose-response models and a valuation of health as such (Cropper, 1994).

There seems to be a consensus in the literature that PPA operators in developing countries are aware of acute health effects of PPA. Crissman et al (1994) report that 60% of the population (non-farmers as well as farmers) in a region of high fungicide and insecticide use "thought many people in the region experienced illness from pesticide exposure" and "about 40% knew people who stopped working with pesticides because of health problems they attributed to pesticide use." Partly based on that evidence, Cropper (1994) concludes "applicators are almost surely aware of acute poisoning". Antle and Capalbo (1994) write that "farmers and farm workers are aware of the risks of poisoning but less aware of longer term, chronic risks."

Similar, but more anecdotal evidence, can be derived from the personal experiences of the author in the Mexican project area. When I first arrived in the Fraylesca, I used to explain my research topic to villagers and in farmer trainings. I was surprised to find that one or two sentences were usually sufficient to express the basic idea. Virtually everyone, including non-farmers, immediately recalled one or several incidences of PPA poisoning. In many cases they referred to suicide attempts rather than occupational accidents. Nevertheless, the general population was clearly aware of health risks due to using or misusing PPA. A number of qualitative surveys (focus group discussions) conducted for the project confirm that. Note that awareness of health risks does not imply that the general population or the farmers are very knowledgeable about the technical aspects of exposure. For instance, a
common erroneous belief is that the main hazard relates to respiratory rather than dermal exposure (e.g. Warburton et al, 1995).

The incidence of adverse health effects from occupational exposure to PPA is relatively low in the Mexican area (cf. Chapter 6). In areas where the incidence is higher, as in the Indian and Zimbabwe project areas, it would seem reasonable to assume an awareness of acute health risks. During one season, a farmer or a sprayman may be exposed to PPA many times. Each time, he may, or may not suffer an acute health problem. The resulting, relatively large number of "trials" is expected to improve the efficiency of the subjective health risk estimate. That is, we postulate Bayesian learning about probabilities of suffering health damage due to PPA. Of course, the accuracy of an estimate depends not only on the number of trials (the sample size, so to speak) but also on the variance of the random variable which is large in the case of health effects. That is, subjective estimates of health risks of minor, relatively frequent symptoms are likely to be more accurate than risk estimates of serious, infrequent effects that have an "accident" character.

As shown in Chapter 7, operators have considerable ability to associate acute health problems with their causes (PPA related or not). This is in accordance to Utsch (1991), who points out that although Sri Lanka farmers did not spontaneously report symptoms of PPA poisoning, they turned out to be highly aware of possible symptoms when asked specifically whether a certain symptom could be due to PPA or not. Chapter 8 showed that spray operators report a considerable number of acute health problems that do not cause any labor loss. Hence, operators consciously perceive and remember even minor acute health problems and it seems plausible to presume high awareness of more severe effects experienced.

Further evidence comes from the fact that some operators use protective gear such as masks. Although the gear used might not provide significant protection, operators apparently believe it does and thus reveal awareness of health risks. Warburton et al (1995) reports farmers to consciously practice several methods of avoiding PPA contamination in the field. Crissman et al (1994) find that 56% of farmers know home remedies to PPA poisoning. Independently of whether those methods and remedies are indicated, they testify awareness of health risks.

Warburton et al (1995) asked farmers, their spouses, and laborers to rank hazards to humans of different PPA brands. The rankings correlate signifi-
cantly with the WHO hazard classes and hardly vary by gender and occupation, although involvement in PPA handling does. Apparently, the rural population's experience and knowledge of acute health effects is sufficient to allow differentiated risk estimates.

In conclusion, it must be assumed that operators are aware of acute health risks. Moreover, operators are "familiar" with the problem, suggesting that the contingent valuation method should not be rejected on the grounds of a lack or awareness or familiarity.

Awareness of chronic effects is a different matter for several reasons (cf. e.g. Antle and Pingali, 1995). First, Bayesian learning does not apply to long-term health outcomes. The operator's "sample size" for chronic effects is just one, making it impossible to estimate chronic risks based on own experience. Second, chronic health effects are multifactorial and health deteriorates slowly, reducing the possibilities of identifying the cause of the problem and of estimating risks. It is thus improbable that operators have a consistent subjective probability estimate of chronic effects. Farmers who believe that chronic effects exist face uncertainty, defined as the absence of quantitative risk estimates, rather than subjective risk. Operators are not "familiar" with chronic effects, reducing the usefulness of the contingent valuation method for valuation of chronic effects.

To conclude this discussion, and taking into account that uncertainty may be valued, the willingness to pay for prevention must be assumed to reflect the following values:

1. The full cost of expected acute health effects.

2. The cost of uncertainty about acute effects.

3. The cost of expected chronic effects as subjectively appreciated by the respondent. As far as chronic effects are concerned, the subjective cost estimate may differ considerably from the true cost because one cannot presume respondents to estimate chronic effects with any degree of accuracy. ("True costs" of chronic effects is understood here as the costs respondents would attribute to chronic health risks if their experience would allow their evaluation.)

4. The cost of uncertainty about chronic effects as subjectively appreciated by the respondent.
The total willingness to pay measures the respondent's subjective health cost estimate. Since items #3 and #4 are non-negative, it is not less than the true costs of acute health risks (sum of #1 and #2).

9.4.2 Survey design

Data is gathered from cotton growers and spraymen in the Indian project area. (See also Chapter 3 where data of the same survey is used.) The spraymen include professional contractors (entrepreneurs) and rural (day) laborers. The PPA under examination are exclusively insecticides. The contingent valuation surveys were used to collect data on health and production to investigate the effects of the subjectively appreciated marginal health costs on the demand for PPA. The data refers to the cotton season 1994/95. Since yield data was to be collected, the surveys were conducted after harvest, from April to June 1995.

Face-to-face interviews were used due to the obvious limitations of carrying out mail or phone surveys among rural farmers, spraymen, and laborers around Coimbatore. For each village in the study area, a target number of interviews with farmers and spraymen was fixed in proportion to the total number of farmers and spraymen. The latter information was provided by the local project administration. Some interviewers were professionals from the research institute, others agricultural students trained by the institute. They went to the villages where they selected respondents on a first contact basis until they had completed the target number of interviews.

Respondents were eligible if they grew cotton in the 94/95 season, sprayed pesticides for a fee or wage, or met both criteria.

9.4.3 Hypothetical scenario

The hypothetical option might be any form of prevention, such as substitution of safe (health neutral) plant protection techniques for the currently used toxic PPA, the (effective) use of protective gear, or other protective practices. Theoretically, one could design valuation scenarios based on any of these means of prevention. In practice, however, some are more suitable than others because some affect productivity as well as health and some lead to highly abstract scenarios. The adoption of health neutral plant protection techniques, such as biological control affects both health and productivity. Hence, the willingness to pay for such techniques would reflect the value of
the changes in health, changes in productivity and the costs of adoption. It would then be necessary to quantify the latter two in order to estimate the former. However, this is impossible because the production effects of safe plant protection practices are not truly known, either. Similarly, the willingness to pay for protective gear is the difference between the WTP for the subjectively estimated preventive effect minus the willingness to adopt the habit of wearing the gear. To summarize, the willingness to pay for these forms of prevention reflect the WTP to avoid ill health, minus the unknown costs of adopting the respective forms of prevention.

In order to create a scenario that differs from the actual situation with regard to health costs only, we use valuation questions which refer to hypothetical, completely safe PPA, i.e. PPA that are absolutely harmless to human health, but otherwise equally effective as existing PPA, as suggested by Cropper (1994). Farmers were asked about their willingness to pay for safe PPA by means of a price premium. Spraymen were asked about their willingness to pay for spraying safe PPA by means of reduced fees.

To ensure that the current situation and the hypothetical option differ in health costs and familiarity of the respondent with the option, the hypothetical safe brand should control pests just as effectively as some existing toxic PPA that is used by the respondent. Therefore, we asked farmers about the brands they use, selected one of those, and asked about the willingness to pay for a safe version of that brand. Since the brands used vary across farmers, the reference brands had to be selected during the interviews and the individual willingness to pay values refer to different brands.

We also differentiated between farmers who reported having suffered an adverse health effect of PPA during the season and those who did not. This allows us to examine whether, and how experience affects the subjective health cost estimates. Farmers who suffered a health problem due to a specific PPA brand were asked about their willingness to pay for a safe version of that brand (or the brand that caused the worst health problem in cases where there were several). Farmers who had not were asked about their willingness to pay for a safe version of the brand they used in the last spray-round prior to the interview. (Cf. questionnaire extracts reproduced in Appendix A.)
9.4.4 Elicitation method

Contingent valuation elicitation methods are categorized into methods that give discrete indicators and methods that give continuous measures of the willingness to pay. We preferred the latter, because sample sizes had to be kept small, implying that the loss of information entailed by the use of discrete indicators (Mitchell and Carson, 1989) could not be compensated. Moreover, the effect of the reference brand had to be identified statistically, which is difficult with small samples and discrete WTP measures. (Sample sizes were kept small to limit the probability of interviewing the same farmer repeatedly, given the limited population in the project area and the considerable number of surveys conducted for the project.)

We used an iterative bidding game with fixed starting bids (fixed proportions of the reference price), although it is generally recognized that random starting bids are methodologically superior (Mitchell and Carson, 1989). The reason for this choice was that starting bids had to be determined during the interview and that selecting random bids of a predetermined distribution in function of run-time information was too complex a procedure under the prevailing conditions.

The pretests indicated that the average willingness to pay for safe PPA was around 20% of the PPA price. The spraymen's average willingness to pay to spray harmless PPA was around 15% of the fee. Iterative bid tables were set up with starting bids between 115 and 133% of the PPA price (corresponding to price premiums between 15 and 33%) and 95-80% of the fee for farmers and spraymen, respectively. Starting bids are fixed proportions of rounded reference prices (fees) and, hence, slightly variable proportions of the actual reference prices (fees). For example, for reference brand prices between 61 and 70 Rs, the starting bid was always 81 Rs, corresponding to price premiums between 33 and 16% (cf. Appendix A).

9.4.5 Compliance with NOAA guidelines

The NOAA guidelines (NOAA, 1993) were developed for nonuse values. However, many of them should apply also to valuations of private goods. Compliance with the guidelines is discussed in Table 38.
Table 38: Compliance with NOAA guidelines

**Guidelines: Discussion**

- **Conservative design:** As mentioned, the willingness to pay is not less than the costs of acute effects and an estimate for the average cost of subjectively appreciated total (acute and chronic) effects. That is, we did not attempt to be conservative. A conservative estimate of health costs is the cost of illness.

- **Elicitation format:** In accordance with the guideline, we asked about the willingness to pay for an improvement in health rather than the willingness to accept compensation for a reduction in health.

- **Referendum format:** The referendum format was used iteratively.

- **Accurate description of the program or policy:** The decision to ask about the willingness to pay for safe versions of existing brands is made to keep the scenario simple. Referring to safe versions of known brands rules out any confusion between productivity and safety as far as possible. We asked about the willingness to pay a certain price rather than the willingness to pay a certain percentage premium. This also reduces the complexity of the evaluation process.

- **Pretesting of photographs:** Does not apply.

- **Reminder of substitutes:** We did not refer to available substitutes. We felt that respondents are sufficiently familiar with PPA and the associated health risks to understand the possibilities of reducing health effects by reducing PPA use or employing spray labor.

- **Adequate time lapse:** Does not apply.

- **Temporal averaging:** Does not apply.

- **No-answer option:** The respondents were not explicitly informed about their no-answer option. However, interviewers were instructed not to insist on a yes/no-answer when respondents appeared not to have understood the question.

- **Yes/no follow-ups:** After the iterative referendum questions, respondents were asked about their reasons for not stating higher willingness to pay. Answers included economical constraints and the assertion that health problems were not severe. These answers suggest that respondents understood the question.

- **Cross-tabulations:** Instead of cross-tabulations, we use a regression model to examine whether the answers depend reasonably on a number of explanatory variables (Subsection 9.5.2).

- **Checks on understanding and acceptance:** Understanding and acceptance was not thought to pose major problems, since respondents are familiar with PPA and the health risks incurred. Chronic problems represent an exception. However, due to the lack of epidemiological risk estimates of long-term health effects of PPA, no information about chronic effects could be included in the scenario without running the risk of distorting answers rather than avoiding biases.
In conclusion from Table 38, we comply with most NOAA guidelines. However, it is possible that we should have informed the respondents more comprehensively about available substitutes. Potential long-term health outcomes pose a problem which is inherent not to the method but to the nature of such effects.

9.4.6 Interpretation

Willingness to pay an amount vs. willingness to pay a price

Typical contingent valuations refer to a good or service that is hypothetically offered in a given quantity and quality, e.g. a discrete, well-defined improvement of the environment. Alternatively, the valuation may refer to a change in the price of a good or service. The respondent is thought to evaluate the current and the hypothetical option in terms of his compensating (or equivalent) variation and to answer accordingly. The reported willingness to pay is an amount of money corresponding to the shaded area in Figure 26 (p. 170).

The scenario employed here is different in that it refers to the mere availability of safe PPA rather than a discrete change in prices or supplies. The farmer is free to choose hypothetical usage levels of the safe PPA. Recall that we asked farmers about the maximum price premium they would be willing to pay for safe PPA rather than for the amount they would be willing to pay for making safe PPA available. It is important that the significance of this difference is fully recognized. The willingness to pay is an amount of money, depicted as an area. The maximum price premium, by contrast, is an amount of money per unit of safe PPA. In price-quantity diagrams, this corresponds to a vertical distance.

Interpretation of the maximum price premium for safe PPA

As mentioned in Section 9.2, the benefits of exposure reduction are composed of the value of the improvement in expected health and the value of the reduction in uncertainty. They may be convex, linear or concave in exposure reduction (prevention). Convex benefits of prevention suggest that relatively high values are attributed to uncertainty. The interpretation of the maximum price premium for safe PPA under different curvatures of the
benefits are discussed subsequently. Moreover, we distinguish two hypotheses about the respondents' interpretations of the hypothetical option.

Let $x$ and $b$ be the hypothetical usage of, and price premium for safe PPA respectively. The benefits $B$ of using the safe brand consist of the improvement of health. Consider the case of decreasing marginal benefits, $MB$, from the use of the safe PPA, depicted in Figure 27. It can be seen that the maximum price premium at which the safe PPA is used at all is the premium at which the smallest available unit of $x$ is demanded. This is $b_1$ and corresponds to a cost ray through $O$ with the slope of $B$ at $x = 0$. Therefore, when marginal benefits of the use of a safe PPA are decreasing, the maximum premium should reflect the marginal benefits of its usage in a small amount.

**Figure 27:** Maximum price premium with decreasing marginal benefits of the use of safe PPA

If this interpretation is correct, farmers would report a positive premium but, conversely, the hypothetical usage of safe PPA would be the smallest unit of $x$ available.

A reviewer found it implausible that farmers implicitly make this evaluation. He suggested that respondents consider using a substantial amount of safe PPA even though that amount exceeds the quantity demanded when the theoretical maximum premium is paid. For example, a farmer might hypothetically substitute the safe PPA completely for its toxic counterpart. Figure 28 shows how to interpret the price premium in this case.
Let $J$ be the share of the reference brand in total PPA usage. The farmer restricts his choice of $x$ to $J$ for the above-mentioned reasons. The maximum price premium he may pay for $x$ without decreasing his level of utility is the average benefit $b_3$ derived from using $J$ of the safe brand. That is, when farmers report the maximum premium at which using $J$ of the safe brand does not reduce utility, the premium is interpreted as $b_3$. However, when the premium is $b_3$, usage $x = J$ is overoptimal. The premium at which $J$ is optimal is $b_2$, suggesting the alternative interpretation that farmers report $b_2$. Note that a hypothetical surplus results at $b_2$ and $x = J$.

It seems quite impossible to determine whether $b_2$ or $b_3$ is the relevant premium when respondents restrict the hypothetical input choice. However, we can test whether they do in fact restrict the input choice as follows. Under the joint hypotheses that respondents restrict the input choice to $J$, or some increasing function of $J$, and that marginal benefits of safe PPA are decreasing, the reported price premium is decreasing in $J$. Alternatively, when farmers hypothetically use only marginal quantities of the safe PPA, the price premiums reflect marginal benefits at $x \approx 0$ which are independent of $J$. Thus, by examination of the relationship between $J$ and the reported price premiums we can infer on input restrictions in the farmer's reasoning.

A different situation arises when marginal benefits of prevention are increasing at $x = 0$, as depicted in Figure 29.
Benefits are not convex over an infinite range. Rather they are convex near \( x = 0 \) and concave in an upper range, as depicted. The bold line represents the demand for safe PPA in function of the premium \( b \). As safe PPA become available and \( b \) decreases, demand is zero first and jumps to \( x^* \) as costs fall below benefits at \( x^* \). Therefore, the maximum costs at which non-negative net benefits result correspond to the ray \( C \), i.e., the tangent to the benefit curve \( B \) through \( O \). The maximum price premium at which a positive quantity is demanded is \( b^* \). Thus, when marginal benefits of safe PPA are increasing near 0, the maximum price premium farmers are willing to pay equals average benefits at some unknown quantity \( x^* \).

Note that the pest control productivity of the hypothetical safe PPA equals that of its existing toxic counterpart. Therefore, it is reasonable to assume that farmers would substitute the safe brand for its toxic counterpart while \( x^* < J \). When \( x^* > J \), however, the safe brand is substituted for other brands or the total PPA usage (toxic and safe brands) increases. In this case, the productive effects of substituting safe PPA cease to be zero. This gradually results in a decrease in marginal benefits, as depicted above. Hence, \( x^* \) is likely to correlate positively with \( J \), even if farmers do not restrict the hypothetical usage of the safe brand to \( J \). Therefore, the hypothesis of restricted input choice cannot be tested when benefits are convex near \( x = 0 \). In any
case, convex benefits imply that the price premium increases with \( J \), while concave benefits imply that the premium is non-increasing in \( J \).

Linear benefits represent a further possibility. Marginal and average benefits are then constant and equal and the maximum price premium is independent of \( J \).

To summarize, the safe brand's usage may or not be restricted in the respondent's reasoning and its benefits may be concave, linear, or convex, producing six combinations as shown in Table 39. We can draw conclusions on the curvature of the benefits by examining the relationship between \( J \) and the willingness to pay a price premium.

**Table 39: Hypotheses on the interpretation of the maximum price premium**

<table>
<thead>
<tr>
<th>Hypothetical input choice</th>
<th>Curvature of benefits derived from substituting safe for toxic PPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>Concave</td>
</tr>
<tr>
<td></td>
<td>i) Price premium reflects marginal benefits at ( x = 0 ) and is independent of ( J ).</td>
</tr>
<tr>
<td></td>
<td>ii) Price premium reflects average and marginal benefits which are equal and constant. It is independent of ( J ).</td>
</tr>
<tr>
<td></td>
<td>iii) Price premium reflects average benefits at an unknown positive quantity ( x^* ) and increases with ( J ).</td>
</tr>
<tr>
<td>Restricted to an increasing function of ( J )</td>
<td>iv) Price premium reflects average benefits at an unknown positive quantity and decreases with ( J ).</td>
</tr>
<tr>
<td></td>
<td>v) Price premium reflects average and marginal benefits which are equal and constant. It is independent of ( J ).</td>
</tr>
<tr>
<td></td>
<td>vi) Price premium reflects average benefits at an unknown positive quantity ( x^* ) and increases with ( J ).</td>
</tr>
</tbody>
</table>

Table 39 shows that the curvature of the benefits of safe PPA is crucial to the interpretation of the price premium. Since the production effects of substitution are zero at low usage of the safe PPA, benefits equal health costs in that range. When health costs are convex (concave) in the usage of and exposure to toxic PPA in the current range, the benefits of exposure reduction are concave (convex) in the use of safe PPA.
The total costs of expected health and uncertainty about health (the compensating variation for the change in the subjectively appreciated distribution of stochastic health) is estimated basically as follows:

- If benefits of prevention are linear (cases (ii) and (v)), the price premium reflects constant average health costs. Total health costs are estimated at the price premium times the current PPA usage.

- If the price premium reflects marginal benefits of prevention at current use levels of PPA and benefits of prevention are concave (case (i)), total health costs cannot be calculated directly. Examination of the relationship between the price premium and current PPA usage might allow the estimation of a function whose integral equals health costs. Marginal health costs per PPA expenditure are estimated at the price premium.

- If the price premium reflects average benefits of prevention and depends on \( J \) (cases (iii), (iv) and (vi)), a health cost function of \( J \) can be estimated. Total health costs are the predicted value of this function for \( J = 1 \).

9.5 Results and validation

9.5.1 Overview

Excluding incomplete and inconsistent answers, 85 to 88% of the surveyed farmers and spraymen are eligible for the analysis as shown in Table 40.
Table 40: Willingness to pay to avoid ill health due to PPA

<table>
<thead>
<tr>
<th></th>
<th>Spraymen</th>
<th>Farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>51</td>
<td>215</td>
</tr>
<tr>
<td>Inconsistent, incomplete or no answer</td>
<td>6</td>
<td>33</td>
</tr>
<tr>
<td>Complete, consistent answer</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Mean WTP, % fee reduction</td>
<td>11.3</td>
<td>(10.6)</td>
</tr>
<tr>
<td>Median WTP, % fee reduction</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Mean WTP, % price premium</td>
<td>38.9</td>
<td>(17.8)</td>
</tr>
<tr>
<td>Median WTP, % price premium</td>
<td>50.0</td>
<td></td>
</tr>
<tr>
<td>Willingness to pay &gt; 0</td>
<td>34</td>
<td>76%</td>
</tr>
<tr>
<td>(Farmers)</td>
<td>180</td>
<td>99%</td>
</tr>
</tbody>
</table>

Notes: The willingness to pay as percent spraying fee reduction cannot be interpreted in the same way as the willingness to pay as percent PPA price premium. Figures in parenthesis are standard deviations.

The maximum price premium farmers are willing to pay is around 40% on average. The median price premium is 50%. Spraymen claim to be willing to work for about 89% of the normal gross fee when spraying a safe PPA. The average willingness to pay is thus around 11% of the fee. Figure 30 reproduces the distribution of the maximum price premiums and fee reductions.

Figure 30: Histograms of willingness to pay for safe PPA

a: Farmers  

b: Spraymen  

Note: The farmers' values are the hypothetical price premiums for safe PPA in percent of the price for the corresponding toxic PPA. The spraymen's values are the hypothetical fee reductions accepted for spraying safe PPA in percent of the normal gross fees.
The farmers' answers cluster around 50% of the reference price. Note that the highest price premium in the bid table was between 50 and 66%.

Six different comparisons and tests are performed to examine validity and reliability. First, we evaluate the internal consistency of the price premiums with a regression model (Subsection 9.5.2). The spraymen's willingness to pay could not be subjected to such a test due to the small sample size. Second, we compare the farmers' stated and revealed preferences by estimation of the effect of stated marginal health costs on the demand for toxic PPA (Subsection 9.5.3). Third, we compare the contingent valuation with a rough estimate of the costs of illness (Subsection 9.5.4). This test is conducted for both farmers and spraymen. Fourth, we compare the farmers' contingent valuations with the cost of avoiding health problems by hiring spray labor (Subsection 9.5.5). Fifth, we compare the valuations of farmers and spraymen (Subsection 9.5.6). Sixth, we compare the spraymen's valuations with actual wages paid for spraying PPA of different toxicities (Subsection 9.5.7). We convert health cost estimates into values per Rupee spent for PPA to obtain comparability.

9.5.2 Internal consistency

A regression model for the reported price premium is estimated in order to examine internal consistency and the hypotheses about the form of the health cost function and the farmer's reasoning with respect to the hypothetical usage of safe PPA.

The dependent variable is the reported maximum price premium for hazard-free PPA expressed as proportion of the reference price. Explanatory variables are the following:

- **Age**: Elderly respondents are expected to care more for health than younger farmers. This would result in a positive parameter estimate. On the other hand, it is easier for elder farmers to delegate spray work to younger family members. This would result in a negative parameter, insofar farmers value their own health more than that of their family members, or in a parameter around zero, if they do not.

- **Wealth**: Income is thought to positively effect the demand for health. Since income depends on input use, it is endogenous to the willingness to
pay. To limit simultaneity, we use a wealth score that codes for ownership of household items such as radio, motorbike, etc.

- **PPA quantity**: If health costs are convex in exposure, the PPA quantity (coded in LogPPA as $\log_{10}$ of PPA expenses in Rupees per acre) has a positive effect on marginal health costs. However, the marginal health costs are a component of the marginal PPA application costs and, hence, expected to reduce total PPA usage. The relationship between the willingness to pay and the PPA quantity is thus potentially simultaneous.

- **Cotton acreage**: The variable ACREAGE gives the cotton acreage. We set the maximum acreage to 10, in order to reduce the influence of a few farmers with very large acreage. A positive parameter of ACREAGE is expected because income and acreage are likely to be correlated positively. However, like LogPPA, ACREAGE is endogenous to the willingness to pay: Cotton requires more PPA per acre than many other crops and causes relatively high exposures because the operator passes along narrow plant rows. Therefore, cotton production is likely to involve larger health risks than other major crops grown in Coimbatore district. Farmers with a high health costs estimate might thus simply reduce the cotton acreage.

- **Employment of spray labor**: The variable HIRESALL codes 1 for farmers who have all spraying done by hired labor. The variable is endogenous since farmers with a high willingness to pay are expected to employ more (non-family) spray labor. On the other hand, hiring spray labor reduces the potential exposure of the farmer and—if health costs are convex in exposure—the price premium. The effect may thus take either sign.

- **Substitutes to safe PPA**: The willingness to pay for safe PPA depends mainly on available substitutes. Hired labor is one substitute we have already considered. We asked farmers whether they considered that health problems with PPA could be avoided in order to elicit their awareness of further substitutes. Answers are coded in the dummy AVOIDABLE ($0 = \text{no}; 1 = \text{yes}$). The variable is expected to reduce the willingness to pay.

- **Adverse experiences with reference brand**: Farmers who suffered health problems in the reference season due to a brand whose name they recalled were asked about the willingness to pay for a safe version of that brand. They are coded 1 in the dummy variable CVREF. The remainder of farmers were asked about the PPA they used on the last occasion of spraying
prior to the interview and are coded 0 in CVREF. The parameter of CVREF is expected to be positive.

- **Any health problems ever suffered:** Farmers who report having experienced health effects of PPA prior to the season of data collection are coded 1 in the variable EVERINTOX. The variable is expected to have a positive effect on the willingness to pay for safety.

- **Share of the reference brand in total PPA use:** The share of the reference brand in total PPA use is used to infer on the hypotheses summarized in Table 39. A positive sign of its parameter would indicate that health costs are concave in exposure, corresponding to convex benefits of exposure reduction (hypotheses (iii) or (vi)). A negative sign would suggest that health costs are convex and that farmers consider substituting considerable amounts of the safe PPA (iv). A value around 0 implies that health costs are approximately linear in exposure ((iii) or (v)), or that health costs are convex and that farmers consider substituting only small quantities (i).

- **Reference brand:** The variable LOGLD50 is the log10 of the oral LD50 of the reference brand's active ingredient. High values represent low human toxicity. Since the benefits of safety are a positive function of the current hazards, the variable is expected to reduce the willingness to pay. Some farmers did not recall the brand name (but still remembered the price of the brand). In order not to exclude these observations, we introduce the dummy NOBRAND. Farmers who did not recall the reference brand name are coded 1 in NOBRAND and 0 in LOGLD50. Thus, the parameter of NOBRAND measures the farmers' perceptions of the toxicities of the brands that were not reported.

- **Scenario variables:** Two variables are introduced to examine how answers depend on the contingent valuation questions.
  
  - **STARTINGBID** is the starting price premium expressed as a proportion of the reference price. As mentioned, we did not intend varying the starting bid. However, since PPA prices are continuous, while the starting bids were calculated as functions of rounded prices, a small variance is introduced in the variable STARTINGBID.

  - Besides, the absolute price premiums vary because they are multiples of variable reference prices. For example, for reference prices
of 80 and 800 Rs, the starting bids (price plus premium) were 92 and 920 Rs, respectively. Theoretically, this should not make a difference because the prices refer to different PPA and quantities. However, in practice, farmers might be more reluctant to accept paying a high absolute price premium. Examination of the influence of the absolute price premium is possible due to inclusion of the variable LOGREFPRICE, defined as the log_{10} of the reference price.

Table 41 reproduces the sample statistics.

Table 41: Sample statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>Variable</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTP (price premium)</td>
<td>0.389(0.178)</td>
<td>J</td>
<td>0.340(0.294)</td>
</tr>
<tr>
<td>AGE</td>
<td>41.38(13.24)</td>
<td>LOGLD50</td>
<td>1.847(1.402)</td>
</tr>
<tr>
<td>WEALTH</td>
<td>2.534(1.581)</td>
<td>NOBRAND</td>
<td>0.264</td>
</tr>
<tr>
<td>HIRESALL</td>
<td>0.022</td>
<td>ACREAGE</td>
<td>2.920(2.128)</td>
</tr>
<tr>
<td>EVERINTOX</td>
<td>0.152</td>
<td>LOGPPA</td>
<td>2.936(0.429)</td>
</tr>
<tr>
<td>AVOIDABLE</td>
<td>0.719</td>
<td>STARTINGBID</td>
<td>0.168(0.023)</td>
</tr>
<tr>
<td>CVREF</td>
<td>0.202</td>
<td>LOGREFPRICE</td>
<td>0.000(0.206)</td>
</tr>
</tbody>
</table>

Note: Standard deviations (SD) are reported for continuous variables, only. Sample size is 178 (complete records).

Only 2.2% of the farmers hire all spray labor. Fifteen percent of the farmers report ever having suffered a health problem due to PPA before the season of data collection. This is lower than the percentage of farmers who report health problems due to specific brands in the season 1994/95 (CVREF; 20.2%) and indicates that the propensity for reporting and/or capacity to recall health effects decreases with time. Probably, mild effects are reported only when they are relatively recent, suggesting that EVERINTOX codes relatively severe health effects. The reference brands account for 34% of the PPA expenses on average (J). Twenty-six percent of the farmers could not recall the reference brand name (NOBRAND). The starting bid was 16.8% above the reference price on average. The sample average of LOGREFPRICE is 0 because this variable was transformed to zero mean.

Table 42 reproduces the results of the regression model.
Table 42: Regression results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.145</td>
<td>(0.166)</td>
<td>0.383</td>
</tr>
<tr>
<td>AGE</td>
<td>0.001</td>
<td>(0.001)</td>
<td>0.600</td>
</tr>
<tr>
<td>WEALTH</td>
<td>-0.012</td>
<td>(0.009)</td>
<td>0.166</td>
</tr>
<tr>
<td>ACREAGE</td>
<td>* 0.019</td>
<td>(0.007)</td>
<td>0.011</td>
</tr>
<tr>
<td>LOGPPA</td>
<td>* 0.090</td>
<td>(0.037)</td>
<td>0.015</td>
</tr>
<tr>
<td>HIRESALL</td>
<td>* -0.164</td>
<td>(0.089)</td>
<td>0.067</td>
</tr>
<tr>
<td>AVOIDABLE</td>
<td>* -0.057</td>
<td>(0.033)</td>
<td>0.081</td>
</tr>
<tr>
<td>AVOIDABLE * CVREF</td>
<td>* 0.197</td>
<td>(0.075)</td>
<td>0.009</td>
</tr>
<tr>
<td>CVREF</td>
<td>* -0.137</td>
<td>(0.066)</td>
<td>0.040</td>
</tr>
<tr>
<td>EVERINTOX</td>
<td>* 0.071</td>
<td>(0.038)</td>
<td>0.068</td>
</tr>
<tr>
<td>J</td>
<td>-0.031</td>
<td>(0.050)</td>
<td>0.536</td>
</tr>
<tr>
<td>LOGLD50</td>
<td>* -0.026</td>
<td>(0.016)</td>
<td>0.099</td>
</tr>
<tr>
<td>NOBRAND</td>
<td>-0.064</td>
<td>(0.049)</td>
<td>0.199</td>
</tr>
<tr>
<td>STARTINGBID</td>
<td>0.232</td>
<td>(0.578)</td>
<td>0.688</td>
</tr>
<tr>
<td>LOGREFPRICE</td>
<td>* -1.009</td>
<td>(0.443)</td>
<td>0.024</td>
</tr>
<tr>
<td>STARTINGBID * LOGREFPRICE</td>
<td>* 5.565</td>
<td>(2.591)</td>
<td>0.033</td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.165</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected R²</td>
<td>0.087</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall P</td>
<td>0.011</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Figures in parenthesis are standard errors. N = 178. * = significant at 10% error level.

The corrected $R^2$ of less than 0.1 is very low. However, the model as a whole is significant. We suppose that attitude variables would considerably improve the fit. However, there are no such variables in the data, with exception of AVOIDABLE which yielded significant estimates.

WEALTH and AGE have virtually no effect on the willingness to pay. Given the standard deviation of the wealth scoring variable of 1.58, the standard effect of wealth is ± 1.9 percent points. The negative sign of wealth is unexpected, but might be explained by the fact that rich farmers tend to employ more spray labor.

ACREAGE and LOGPPA yield significant positive parameter estimates.
Farmers who hire all spray labor (HiresAll = 1) are willing to pay 16 percent points less for safe PPA than those who spray personally. The parameter is significant at the 10% error level.

At average levels of AVOIDABLE (0.719), the effect of CVREF is only 0.46 percent points. This signifies that health problems suffered in the season of data collection do not influence the willingness to pay. This is reasonable if farmers are familiar with acute health problems due to PPA, because then a single occurrence of a health problem hardly alters the experience based health risk estimate. At average levels of CVREF (0.202), the effect of AVOIDABLE is −1.7 percent points. That is, farmers who find health problems avoidable report lower price premiums as expected. However, the effect of AVOIDABLE is large and positive (14.0 percent points) among farmers who suffered a health problem in the season (CVREF = 1). Stated the other way round, farmers who suffered health problems and find that these cannot be avoided report lower price premiums. An explanation for this unexpected result might be that these farmers do not believe that the hypothetical PPA is really safe. If this interpretation is correct, the positive parameter estimate of AVOIDABLE * CVREF reflects lack of confidence in, or understanding of, the contingent valuation question rather than the value of health.

The parameter of EVERINTOX is positive, as expected, and significant at the 10% error level. That is, farmers having suffered severe health effects of PPA are willing to pay higher safety premiums. The effect is 7.1 percent points.

The parameter estimate of J is negative but small and not significant. The 95% confidence interval is [−0.139 .. 0.067]. The magnitude of the upper limit implies that benefits of exposure reduction are not (very) convex and that health costs are not (very) concave in exposure. Uncertainty does not appear to play a major role. This leaves the hypotheses (i), (ii), (iv) and (v) about the form of the benefits and the evaluation process (Table 39, p.192): Health costs of PPA are either linear or convex. If health costs are linear, the maximum price premium refers to average health costs. If health costs are convex, the premium refers to marginal health costs and is an upper limit for the average health costs. Thus, by multiplying the price premium with PPA use we obtain either the health costs (linear case) or an upper limit to the health costs (convex case).
The parameter of LOGLD50 has borderline significance at the 10% error level and the expected negative sign. This signifies that farmers discriminate PPA by toxicity. However, the absolute effect is small. A change of ±1 WHO hazard class corresponds to a change of ±1 in LOGLD50. This has an effect on the price premium of ±2.6 percent points only. This implies that the willingness to pay for safe PPA is large even when the reference brand is relatively safe. This might be due to the fact that pyrethroids—which are generally of low toxicity—may cause disturbing symptoms that are poorly predicted by the oral LD50. Nevertheless, we would have expected a lower willingness to pay for substituting completely safe for relatively safe PPA.

The parameter estimate of NOBRAND measures the effect of setting LOGLD50 = 0 for farmers who did not report a brand name. The predicted geometric mean LD50 value of non-reported brands is \(10^{(-0.064/-0.026)} = 289\) mg/kg—a reasonable value in the range of the LD50's of common insecticides.

At the geometric mean of the reference prices (LOGRefPrice = 0), the starting bid has a small, insignificant effect on the reported price premiums as indicated by the parameter of STARTINGBID. A variation of the starting bid of ±10 percent points would affect the reported price premiums by ±2.3 percent points only. We may quite safely conclude that the reported price premiums are not subject to considerable starting bid bias. HERRIGES and SHOGREN (1996) suggested that the observed willingness to pay WTPobs might be biased towards the starting bid \(b\) according to WTPobs = WTPtrue + \(\alpha(b - WTP_{true})\). \(\alpha\) is the parameter of STARTINGBID. Transformation gives an equation for the true willingness to pay, WTPtrue = \(b + (WTP_{obs} - b)/(1 - \alpha)\) which yields WTPtrue = 0.46 at average levels of \(b\) and WTPobs, i.e., an estimate 7 percent points above WTPobs.

At average starting bids (STARTINGBID = 0.168), the marginal effect of LOGRefPrice is -1.009 + 0.168 \(\cdot\) 5.565 = -0.074. A variation of LOGRefPrice by ±1 standard deviation (±0.206) causes a negligible variation in the price premium by ±1.5 percent points.

Results so far suggest that the reported price premiums vary reasonably with a number of potential explanatory variables, namely the toxicity of the reference brand, the health problems experienced, and the employment of spray labor. An exception is the effect of AVOIDABLE in the group of farmers who suffered adverse health effects in the reference season. The contingent
valuation questions affect the reported values slightly, but the internal consistency test provides no evidence that would make us reject the estimates.

9.5.3 Stated preferences for safe PPA versus revealed preferences for PPA use reduction

Marginal health costs detract from the demand for toxic PPA (cf. Subsection 9.2.4). Figure 31 illustrates this effect. With large marginal health costs $MHC_2$, the demand for PPA is $X_2$ which is lower than the demand $X_1$ that results of small marginal health costs $MHC_1$. It is also lower than $X_0$ which results if health costs are zero. The negative demand effect of the marginal health costs is due to the fact that marginal profits $M\Pi$ decrease with $X$ and does not depend on the form of the health costs.

**Figure 31: Effect of marginal health costs on demand for toxic PPA**

The price premiums reflect marginal health costs under hypotheses (i), (ii) and (v) of Table 39 (p. 192). (In cases (ii) and (v), average and marginal health costs are equal.) Note that the price premiums refer to current PPA use levels. They correspond to $b_1$ and $b_2$ in Figure 31. Hence, the price premiums are expected to reduce the PPA demand under the above-mentioned hypotheses. Under hypothesis (iv), they reflect average health costs at some unknown hypothetical usage of safe PPA. Average health costs can be assumed to correlate positively with marginal health costs.
Hence, under hypothesis (iv), the price premiums should also reduce the PPA demand.

The marginal cost of using PPA is the PPA price, plus marginal application costs, plus marginal health costs. We may thus test the hypothesis that the price premiums reflect health costs by adapting the PPA demand model from Chapter 3 to include the price premium. Marginal costs $W$ of using PPA are then not $w$ but $W = w(1 + k / 1.32) = w(1 + k')$, where $k$ is the price premium expressed as a proportion of the marginal PPA use costs $w$ and $k' = k / 1.32$. (Note that $w$ is composed of the PPA price, the marginal application costs and the marginal capital costs. $w$ was estimated to 1.32 per Rs of PPA in Chapter 3.) The alternative hypothesis is that farmers do not take health costs into account when allocating inputs, or that the reported price premiums do not reflect health costs. The null and alternative hypotheses are nested by specifying $W = w(1 + k')\Omega$, where $\Omega$ is an estimation parameter. $\Omega = 1$ implies that farmers maximize utility composed of profits and health. $\Omega = 0$ implies that farmers maximize profits without considering health costs, or that the reported price premiums do not reflect marginal health costs. $1 > \Omega > 0$ suggests that the reported price premiums reflect health costs on a relative scale with $\Omega$ being a scaling factor. Substituting $W$ for $w$ in the input demand model developed in Chapter 3, and disregarding the differences in PPA use strategies yields the demand function

$$X = \frac{1}{\lambda} \left[ \ln \left( \frac{\gamma \lambda}{w(1 + k')^\Omega} \right) + \frac{w(1 + k')^\Omega}{q \gamma \lambda} + \ln \delta \right] + u.$$  

(Refer to Chapter 3 for a description of the variables.) (23) is estimated in the form $X = 1/\lambda \left[ \ln \beta_1 - \Omega \ln(1 + k') + \ln q + \ln \lambda + 1/(\beta_1(1 + k')^\Omega q \lambda) + \beta_2 \right] + u$, where $\beta_1 = \gamma / w$, $\beta_2 = \ln \delta$.

The variance in the reported price premium is partly due to a variance in the scenario, i.e., in the "measuring device". That effect should be eliminated before we use the answers in the estimation model. Explanatory variables that reflect the measuring device rather than differences in the subjective health cost estimates are LOGLD50, $J$, STARTINGBID and LOGREFPRICE. $k$ is the price premium corrected for the effects of these variables, i.e., the predicted premium for LOGLD50 = sample average; $J = 0$; STARTINGBID = sample average; LOGREFPRICE = sample average. Thus,
\[ k = \text{WTP} \]
\[ + 0.026 \cdot (\log \text{LD50} - 1.847) \]
\[ + 0.031 \cdot j \]
\[ - 0.232 \cdot (\text{StartingBid} - 0.168) \]
\[ + 1.009 \cdot (\log \text{RefPrice}) \]
\[ - 5.565 \cdot (\text{StartingBid} \cdot \log \text{RefPrice}) \]
\[ - \text{avg} (\text{StartingBid} \cdot \log \text{RefPrice}) \].

(k has a sample mean of 0.399 and a standard deviation of 0.263. \( k' \) has a sample mean of 0.302 and a standard deviation of 0.199.) Alternatively, we use \( k' = \text{WTP} / 1.32 \). Table 43 reproduces the results of the PPA demand models.

Table 43: PPA demand effect of stated marginal health costs

<table>
<thead>
<tr>
<th></th>
<th>Profit maximization</th>
<th>Utility maximization</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k' )</td>
<td>( \lambda )</td>
<td>( \rho y / w )</td>
</tr>
<tr>
<td></td>
<td>( \ln \delta )</td>
<td>( \Omega )</td>
</tr>
<tr>
<td></td>
<td>Corrected WTP</td>
<td>Reported WTP</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>0.738 (0.143)</td>
<td>0.765 (0.157)</td>
</tr>
<tr>
<td>( \rho y / w )</td>
<td>0.823 (0.134)</td>
<td>0.775 (0.160)</td>
</tr>
<tr>
<td>( \ln \delta )</td>
<td>-0.709 (0.135)</td>
<td>-0.706 (0.141)</td>
</tr>
<tr>
<td>( \Omega )</td>
<td>-0.352 (0.496)</td>
<td>-0.547 (0.706)</td>
</tr>
</tbody>
</table>

95\% upper limit of \( \Omega \) 0.464 0.614

Raw \( R^2 \) 0.687 0.688 0.689

Corr \( R^2 \) 0.217 0.219 0.220

Note: \( N = 171 \) (complete records). Figures in parenthesis are standard errors. * denotes significant differences from 0 at the 5\% error level.

\( \Omega \) is not significant and has an unexpected negative sign. However, it is significantly smaller than 1 in both models. The hypothesis that the price premiums reflect marginal health costs must be rejected. The null hypothesis of profit maximization cannot be rejected. The claimed willingness to pay correlates poorly with revealed preferences. The contingent valuation is not compatible with revealed preferences.
An upper limit of revealed marginal health costs can be estimated as follows. The 95% upper limit of $\Omega$ in the model with the corrected WTP is 0.464. Therefore, the 95% upper limit of $W$ is $w(1 + k')^{0.464}$. Evaluated at average $k'$, this is $1.13w$. The upper limit of the marginal health costs expressed as proportion of the PPA expenses is then $0.13w = 17\%$. That is, there is a 95% probability that marginal health costs do not exceed 17% of the PPA value.

9.5.4 Contingent valuation versus costs of illness

In Table 44, the price premium is translated into a willingness to pay in Rupees per season and compared with the farmers' valued labor loss due to PPA. Labor should be valued at its opportunity cost. It seems reasonable to calculate with a figure in the range of the fees paid to laborers, because labor loss due to PPA occurs when farmers are spraying. For these calculations, we assume that the price premium reflects average health costs (hypotheses (ii), (iv) or (v)). Should the price premium reflect marginal health costs and benefits of exposure reduction be concave (i), the willingness to pay estimated at the premium times the PPA usage is an upper limit of the health costs.

Table 44: Direct and indirect health cost estimates, farmers

<table>
<thead>
<tr>
<th>Based on contingent valuation and other sample data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Expenses for PPA per acre (cotton only)</td>
<td>1296 Rs</td>
</tr>
<tr>
<td>Cotton acreage</td>
<td>3.2</td>
</tr>
<tr>
<td>Expenses for PPA per farm (cotton only)</td>
<td>4147 Rs</td>
</tr>
<tr>
<td>Price premium (contingent valuation)</td>
<td>39%</td>
</tr>
<tr>
<td>WTP per season</td>
<td>1617 Rs</td>
</tr>
<tr>
<td>Actual labor loss due to PPA per season (days)</td>
<td>1.00</td>
</tr>
<tr>
<td>Implicit value of 1 day labor lost and associated disutility</td>
<td>1617 Rs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indirect valuation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate opportunity cost of labor (1 day)</td>
<td>100 Rs</td>
</tr>
<tr>
<td>Valued labor loss</td>
<td>100 Rs</td>
</tr>
</tbody>
</table>

Ratio direct - indirect valuation                   | 16.2    |

Note: All figures are averages.

The value of labor loss and associated disutility implicit in the contingent valuation is extremely large and exceeds the opportunity cost of labor loss.
by a factor of 16.2. While the contingent valuation results suggest that health costs are around 40% of the PPA expenses, the indirectly valued labor loss is only 2.4% of the PPA expenses. Note, however, that the valued labor loss is a lower limit to total health costs.

In Table 45, the spraymen’s willingness to pay as percent fee reduction is translated into a willingness to pay in Rupees per season and compared with valued labor loss due to PPA. Some spraymen are paid on a per tank basis, others on per day basis. The former are professional contractors who own the equipment, while the latter are day laborers who work with the equipment provided by the employer. Thus, equipment costs to contractors have to be accounted for in estimating revenues and the costs of lost labor.

<table>
<thead>
<tr>
<th>Table 45: Direct and indirect health cost estimates, spraymen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contractors</strong></td>
</tr>
<tr>
<td><strong>Based on contingent valuation and other sample data</strong></td>
</tr>
<tr>
<td>• Gross earnings per day</td>
</tr>
<tr>
<td>• Approx. costs of equipment and fuel</td>
</tr>
<tr>
<td>• Net earnings per day</td>
</tr>
<tr>
<td>• Spraying days per week</td>
</tr>
<tr>
<td>• Spraying weeks per cotton season</td>
</tr>
<tr>
<td>• Net earnings per season</td>
</tr>
<tr>
<td>• WTP (% gross fee reduction)</td>
</tr>
<tr>
<td><strong>Indirect valuation</strong></td>
</tr>
<tr>
<td>• Actual labor loss due to PPA per season (days)</td>
</tr>
<tr>
<td>• Valued labor loss per season</td>
</tr>
<tr>
<td><strong>Ratio direct - indirect valuation</strong></td>
</tr>
</tbody>
</table>

Note: All figures are averages.

The willingness to pay per season is around 5.7 times larger among contractors than among day laborers. It is about 3.6 and 1.8 times the cost of lost labor for the respective groups. Considering that the indirect valuation does not account for uncertainty, the psychic value of health, medical expenses and costs of health care, and that the average labor loss is sensitive to few observations of large labor loss (small sample size), these differences between direct and indirect health cost estimates appear reasonable. In the
case of spraymen, the indirect valuation appears to validate the contingent valuation.

The indirect valuation of the contractors is transformed into a value per Rupee spent for PPA as follows. The valued labor loss of 430 Rs corresponds to 5.7% of the total labor value per season of 7600 Rs. Since spray labor costs are around 20% of the PPA costs (cf. Chapter 3), labor loss due to PPA is estimated at $5.7 \times 20\% = 1.1\%$ of the PPA expenses. This figure is based on costs of illness and represents a lower limit to the true health costs.

### 9.5.5 Farmers' contingent valuation versus hiring spray labor

Farmers can avoid health problems due to PPA almost completely by hiring spray labor. The cost of spray labor was estimated previously to 20% of the PPA value. The costs of hiring all spray labor are thus around Rs 830 per season. Since hired spray labor is only minimally less effective than family spray labor (cf. Chapter 3), this is an upper limit to the farmers' health costs. Moreover, it is a safe upper limit, since the opportunity cost of the farmers' labor is not zero. However, it is only half the health costs implied by the farmers' claimed willingness to pay of around Rs 1600. In other words, if health costs to farmers are truly Rs 1600, it is not plausible why any farmer would spray personally instead of hiring labor. The farmers' claimed willingness to pay exceeds the health costs implied by revealed preferences by a factor of at least two.

### 9.5.6 Farmers' versus spraymen's contingent valuations

The willingness to pay exhibited by the farmers and spraymen can be compared when expressed as proportions of the labor cost of PPA use. The farmers' average willingness to pay of 40% of the PPA value correspond to roughly 200% of the labor value. The spraymen's willingness to pay, by contrast, is only about 12% of the labor value. That is, the farmers' willingness to pay measures are around 16 times larger than those of the spraymen. This is a very large difference, even if we take into account the generally higher income of farmers, the possibly larger subjective uncertainty and higher shadow wages of farmers, and allow for some differences in preventive practices between farmers and spraymen.

By way of illustration, accept for a moment that the spraymen's willingness to pay approximates true health costs as suggested by the comparison with
the indirect valuation. Contractors are willing to pay 13% of their gross revenue to avoid ill health from PPA. Since application costs are around 20% of PPA costs, the predicted health costs of farmers who do all the spraying personally is $13\% \cdot 20\% = 2.6\%$ of PPA costs, or $4147 \cdot 2.6\% = 107$ Rs / season. This figure is in a range that could be expected from the indirect valuation of the farmers' health costs. We conclude that the farmers' and spraymen's contingent valuations are contradictory.

9.5.7 Contingent valuation versus wage rates

Spraymen should charge higher fees (hazard premiums) when spraying relatively toxic PPA, unless the demand for spray labor is infinitely price elastic. Only one of 51 interviewed spraymen claimed that some contractors or laborers charge higher fees for spraying particularly hazardous PPA. Only five farmers (4% of those hiring spraymen) reported that some spraymen charge higher fees when spraying particularly harmful PPA. Three farmers (2%) reported ever having paid a higher fee (cf. Table 46).

<table>
<thead>
<tr>
<th>Table 46: Frequency of hazard premiums according to farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number and % of farmers</strong></td>
</tr>
<tr>
<td>Claim that some spraymen charge higher fees</td>
</tr>
<tr>
<td>when spraying particularly harmful PPA</td>
</tr>
<tr>
<td>Have ever paid a hazard premium</td>
</tr>
</tbody>
</table>

Base: 133 farmers who hired spraymen

There are two explanations for the low frequency of hazard premiums paid in the labor market: (a) the true willingness to pay or health costs might be lower than the reported health costs, and (b) the demand for spray labor might be highly elastic. It is not possible to determine which explanation is more appropriate based on the data available.

Details of the five cases in which farmers report that hazard premiums were paid to spraymen are reproduced in the following table. The results are to be interpreted with due care since these cases do not constitute a representative sample.
Table 47: Hazard premiums on the spray labor market

<table>
<thead>
<tr>
<th>Source of information</th>
<th>Normal fee</th>
<th>Special fee</th>
<th>Hazard premium [% of normal fee]</th>
<th>Active ingredients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own experience</td>
<td>40 Rs</td>
<td>45 Rs</td>
<td>13%</td>
<td>cypermethrin</td>
</tr>
<tr>
<td>Own experience</td>
<td>40 Rs</td>
<td>75 Rs</td>
<td>88%</td>
<td>monocrotophos</td>
</tr>
<tr>
<td>Own experience</td>
<td>70 Rs</td>
<td>90 Rs</td>
<td>29%</td>
<td>N/A</td>
</tr>
<tr>
<td>Hearsay</td>
<td>50 Rs</td>
<td>70 Rs</td>
<td>40%</td>
<td>N/A</td>
</tr>
<tr>
<td>Hearsay</td>
<td>50 Rs</td>
<td>70 Rs</td>
<td>40%</td>
<td>N/A</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>42%</td>
<td></td>
</tr>
</tbody>
</table>

Notes: "Own experience" denotes cases where the respondent actually paid the premium as contrasted with "hearsay". N/A = not available

Note that these hazard premiums are paid for spraying a specific toxic PPA rather than a PPA of average toxicity, given that all PPA used in the Indian project area are considerably toxic. Therefore, the premiums compensate for a fraction of the health costs only. Moreover, the price premium is the joint effect of a reduction in labor supply due to increased health costs and the price elasticity of labor demand. In view of that, the hazard premiums actually paid are large compared to the spraymen's average willingness to pay. On the other hand, a 40% wage premium is equivalent to an 8% PPA price premium.

9.5.8 Consolidation

Results of the above tests are summarized in Figure 32.
By consolidating the figures, health costs can be safely assumed to be below 20% of the PPA expenses and are likely between 5 and 10% of these expenses. Note that these estimates include the unknown but non-negative costs respondents attribute to chronic effects. Hence, they exceed the costs of acute health effects.

The farmers' willingness to pay overestimates health costs by a factor of more than two. The spraymen's willingness to pay is in the range of the indirect estimates.

What are the reasons behind the large differences between the farmers' stated and revealed preferences on the one hand, and between the direct and indirect valuations on the other?

- Could the differences be due to biases introduced by the elicitation method? As argued above, the relative and absolute starting price premi-
ums have only small effects on the willingness to pay. Starting bid bias is present but small. Iterative bidding games as used here are generally believed to produce less reliable results than dichotomous choice scenarios (referenda). However, the first step of the iterative game corresponds exactly to a referendum. Eighty percent of the respondents accepted the first bid, implying that a referendum would have yielded average or median willingness to pay measures above (probably well above) the starting bid of around 17%. Thus, the elicitation method does not explain the results.

- Farmers are thought to value uncertainty. The (negative) value of uncertainty is not accounted for by the indirect valuation. Since farmers suffer health problems less frequently than spraymen, they might be more uncertain about expected health effects. This might partly explain the difference in valuations between farmers and spraymen. However, it does not explain the differences between stated and revealed preferences. Moreover, if uncertainty plays a major role, we expect convex benefits of exposure reduction. No evidence for this was found.

- We did not explicitly provide the respondents with any reasons to refuse to pay for (applying) safe PPA. After all, spraying for lower fees or buying more expensive PPA has very direct income effects with which respondents are familiar. However, spraymen might have been more aware of their budget constraints than farmers because they were asked to work for lower fees while farmers were asked to spend more money. This might partly explain the discrepancies between the valuations of the two groups.

- Farmers might have experienced that new PPA are more effective than older products. Therefore, they might presume that the hypothetical safe PPA is more effective than its existing toxic equivalent. In this case, the willingness to pay includes a hypothetical productivity benefit as well as the value of health. This would explain the differences between the farmers' stated and revealed preferences and between direct and indirect valuations. However, it also implies that respondents did not truly understand the valuation scenario and that there is amenity misspecification bias.
9.6 Conclusions

Health costs from operator exposure to PPA were estimated with the contingent valuation method. Farmers were asked about their maximum willingness to pay for safe (non-toxic, health hazard-free) PPA by means of pesticide price premiums. The average reported premium is 40%. It varies reasonably with a number of factors that should affect the willingness to pay, in particular the toxicity of the reference brand and adverse health effects experienced. Moreover, it is hardly influenced by factors that should have no effects, such as the starting bid and the price of the reference PPA. However, the upper limit to the effect of the claimed willingness to pay on PPA demand is only around half the expected effect, implying that health costs are lower than claimed. This conclusion is supported by the fact that a 40% price premium exceeds the costs of prevention by employment of spray labor by a factor of at least two. Moreover, the claimed willingness to pay for safety exceeds the cost of illness (valued labor loss) by a large factor. Based on these considerations, we reject the farmers' contingent health valuation.

Spraymen were asked about their willingness to pay for spraying safe rather than toxic PPA in terms of reduced fees. They are willing to give up 11% of their fees (wages) to avoid ill health from PPA. This figure is not in contradiction with other health cost estimates obtained.

The indirectly estimated health costs refer to acute effects only. The estimates based on stated and revealed preferences include the costs of acute effects and an unknown, but non-negative cost of chronic effects as subjectively appreciated by the respondent.

The following conclusions are offered.

- The farmers' health costs due to PPA are lower than the claimed willingness to pay for safe PPA. They can be safely assumed not to exceed 20% of the PPA value.

- PPA operators are aware of the acute health risks of PPA, as expected. Otherwise, the reported willingness to pay would not be a multiple of valued labor loss.

- Farmers and spraymen discriminate PPA by hazard. This is evident from the positive correlation between toxicities and willingness to pay for safe
versions of different brands (and the fact that some, although few, spray-
men charge hazard premiums for spraying particularly toxic PPA.)
10 Conclusions

The evidence provided in the previous chapters is evaluated with respect to the questions posed in the introduction: Do PPA users trade-off health against income? At what rate do they do so? Could health and income be improved? (Sections 10.1 to 10.3). Conclusions concerning methodological issues are presented in Section 10.4. Section 10.5 suggests future research topics.

10.1 Trade-off between health and income

Three conditions must be met to affirm the existence of a trade-off. First, PPA must be used productively. Second, PPA must entail health costs to users. Third, PPA users must account for both profits and health in their allocative decisions. Chapter 3 showed that PPA are used productively in the Indian project area. In Part II, acute adverse health effects were found considerable in India and Zimbabwe and non-negligible in Mexico.

We argued in Chapters 2 and 3 that farmers take expected profits into account in input allocation. We found that PPA usage varies widely and that price factors do not explain this variation. The transformed model derived from the structural equation system yielded reasonable results. As expected, estimated productivity increased when the model included factors which might influence pest pressure. This suggests that farmers observe crop reactions to input use and follow sequential decision rules. It does not imply, however, that farmers are pure profit maximizers and does not allow allocative efficiency to be measured.
In Chapters 7 and 9, we argued that PPA operators are aware of *acute* health effects of occupational exposure to PPA. Operators recall minor acute health effects that are relatively recent and do not appear to hold PPA responsible for many health effects that are due to other causes. Moreover, farmers and spraymen are able to discriminate PPA by hazard, at least where health effects are relatively frequent. Literature suggests that some operators attempt to protect themselves from exposure to PPA. This provides further evidence of awareness.

Chronic health risks are a very different problem. Some studies suggest the existence of considerable chronic health effects of PPA use in developing countries. The significance of these effects is poorly documented, however, partly due to the difficulties involved in assessing exposure patterns of the past. The users' perceptions and beliefs about such effects are unclear (Chapter 9).

Productive PPA use and awareness of acute effects suggest that operators trade-off health against income. The claimed willingness to pay to avoid adverse health effects was found to be positive among both Indian farmers and spraymen. We also provided direct evidence for the trade-off: Occasionally, hazard premiums are paid to spraymen for applying particularly harmful PPA. Farmers employing third party spray labor exhibit a lower willingness to pay for safe PPA. However, we could not support the hypothesis that farmers who claim to anticipate high health risks reduce PPA use. The finding is probably due to methodological problems of our contingent valuation study (Chapter 9).

Results on the rate of the trade-off (Chapter 9) show that health costs are less than 20% of PPA expenditure in the Indian study area. The probable range is between 5 and 10% of the PPA value. Since it must be assumed that operators are aware of acute health risks, these figures include the costs of acute health effects. Moreover, they may include subjectively appreciated costs of chronic effects if respondents think such effects exist. The subjective health costs are less than the productivity benefits derived from PPA use in the same area. The latter are between 38 and 74% of the total PPA application costs, which is equivalent to 50-100% of the PPA expenditure (Chapter 3). Health costs to spraymen are high in comparison to their income (about 10%). In Mexico, the incidence of acute adverse health effects is less than 3% per day of spraying, suggesting that health costs in that area are lower than in India or Zimbabwe.
10.2 Improving health

The technical case studies presented in Chapters 6 and 7 suggest that exposure to spills is responsible for a major share of the health problems. However, it is unlikely that farmers are truly aware of this. Therefore, it should be possible to reduce such exposure by enhancing knowledge, and promoting carefulness and hygiene. Safe appliances, PPA packages and formulations may also play a major role. Relatively simple survey techniques may facilitate the local identification of major exposure sources (Chapter 6).

Protective gear is not a panacea to health risks due to PPA. An important reason for this is that most exposure is due to spills on the hands and they are not protected by any gear except gloves. However, gloves are very problematic (Chapter 6). Moreover, spills from leaking sprayers soak protective clothing and thereby reduce its usefulness. Experiments, on the other hand, have demonstrated the protective effect of properly maintained gear in cases of exposure from spray mist or minor spills. Therefore, the recommendation for protective clothing must be accompanied by educational efforts to achieve proper maintenance and a reduction of spills.

Protective clothing entails expenses and inconveniences of usage and maintenance. The time needed for proper maintenance is not known. However, given that clothing should be washed after each day of spray work, it might well be in the range of, or exceed, the average labor loss due to acute health effects, i.e. around 1 day per season in India and Zimbabwe. Moreover, protective gear provides only limited protection. Therefore, the willingness to pay for protective gear must be assumed to be considerably lower than the health costs. In the Indian study area, this signifies that the willingness to pay for protective gear is unlikely to exceed a few percent of the PPA expenses. In Mexico, the willingness to pay for protective gear is certainly even lower because health effects are far less frequent.

A low willingness to pay for protective gear implies a low readiness to adopt the gear and has important implications for safe use programs. Farmers must be motivated for safety with other benefits than just improvements in health. For example, one might stress that fixing the sprayer not only prevents spillage on the body, but also losses of PPA. Hygiene at working breaks is a further practice which not only reduces adverse health effects of PPA, but might also directly increase well-being during the spraying operation.
10.3 Improving PPA productivity

We should stop thinking of IPM as a categorical concept. Chapter 3 showed that the extent to which farmers observe pests is a continuous variable. Hence, step-by-step improvements of PPA use strategies are possible. Just as safety cannot be implemented at once, approaching the objective of IPM is a process during which a number of technical issues have to be addressed (cf. Chapter 4).

Occasionally, improvements of PPA productivity increase the demand for PPA and may thus imply larger health risks. However, in such cases, PPA usage is likely to drop after some time, as skills in using PPA continue to increase (Chapter 4).

Non-chemical and chemical plant protection techniques are not pure substitutes. The benefits of non-chemical techniques may partly consist in reducing the adverse side-effects of synthetic PPA (Chapter 4).

10.4 Methodological aspects

10.4.1 Production analysis

A major problem in pesticide productivity estimation is that data on the destructive capacity of pests in absence of control (potential damage) is not normally available. Farmers must be assumed to take this capacity into account, even if they do not follow formal scouting schemes. Therefore, pest pressure affects both production and input allocation and its omission from the model causes simultaneous-equation bias. One solution is to use specifically collected data, from on-farm research, for instance (Chapter 2). This implies that PPA productivity should be assessed on a case-by-case basis—a view which is supported by FAO (GIVELET, 1986, quoted in WEBER, 1996).

In Chapter 2, we argued that production function estimation is not normally justified with cross-section data because identification of such models requires that inputs vary due to variables that do not appear in the production function. However, such variables are typically prices which do not normally vary in cross-section data. We suggested three potential solutions to this problem.
• On-farm research allows the introduction of a controlled (exogenous) variance in some input variables and thus contributes to the identification of the production function.

• Variances in marginal transaction costs may be responsible for a major share of the input variance and so identify the simultaneous-equation system of technical and behavioral relationships.

• Non-linear restrictions imposed on the production function may allow identification of transformations of the structural model. For example, in the context of damage control, multiplicative abatement terms are common and allow construction of identified models by division of the production function into the demand equation of the damage control agent (Chapters 2 and 3).

Historical estimates of marginal pesticide productivity are highly variable. It is likely that this variance is the result of missing data, misspecifications, and underidentified production models as well as variations in the true marginal productivity across crops, regions and time (Chapter 2).

10.4.2 Epidemiological health risk assessment

Acute adverse health effects of PPA can be elicited quite reliably with interviews. PPA operators are generally aware of such effects and report even minor symptoms insofar the time period between the survey and the health effect is not too long. Exposure assessment is more problematic. Protective practices explained only a small share of the total variance of health effects in the case study presented in Chapter 7. The reason is suspected to be that spills account for most of the exposure variance. However, the occurrence of spills can hardly be elicited with interviews.

It is extremely difficult to elicit the variables needed for epidemiological models of long-term health outcomes. While health states can be assessed with medical tests, elicitation of past exposure presents tremendous problems. Reliance on the farmers' memory alone dilutes the exposure variable. This leads to conservative estimates of health risk factors (Chapter 5).
10.5 Suggestions for future research

10.5.1 Production analysis

In absence of price variables, identification of the production function requires that the error terms of the factor demand and the production function are independent. Most econometricians assume independence implicitly or explicitly. However, little is known about the factors that cause the residual variance in PPA usage. More detailed input demand models should be estimated to achieve better understanding of the farmers' behavior and input allocation. In doing so, the researcher may soon face a need to formulate dynamic models since the decision-maker observes and considers crop reactions to inputs and environmental factors during the season. Besides observations of the crop and the environment, preconceived ideas and marginal transaction costs are candidates of variables that influence input allocation.

Econometric models of plant protection should include (initial) pest pressure as a variable or as a function. Few such models have been estimated in the past and the pest pressure variable is typically defined in an ad-hoc manner. It should prove useful to systematically evaluate different pest pressure variables or functions with respect to their suitability for data collection and production analysis.

10.5.2 Health effects of PPA on operators

The elicitation of past exposure is difficult with interviews. First, it is hardly possible to discriminate between single active ingredients or even groups of chemical compounds. Second, the exposure variance is mainly due to spills whose past occurrence is impossible to assess. Prospective studies might help to solve these problems.

Operator perceptions about chronic effects may be an interesting research topic. Their elicitation would allow definition of their role in input allocation. However, as long as the epidemiological evidence for chronic effects is not appropriately documented, any study on farmers' perceptions will be unsatisfactory because, in absence of such evidence, perceptions can only be compared to health risks extrapolated from the animal model. Since exposure typically shows a large variance, such extrapolations are highly variable
and unlikely to allow determination whether farmers over- or underestimate chronic health risks or costs.

10.5.3 Safe use of PPA

More field-level studies are needed on the health effects of protective gear and practices. Important explanatory variables of models for health risks are spills, the condition (maintenance) of equipment and clothing and more detailed variables for hygiene. Large samples are required because the response and many explanatory variables are typically binary.

It would be interesting to estimate simultaneous-equation systems composed of a function for the health risk and behavioral equations that capture the farmer's short-term reactions to health effects experienced or noticeable exposure.

Chapter 7 showed that practices, such as maintenance of equipment and hygiene, reduce acute adverse effects considerably. We called these practices "simple". Are they truly simple? Little is known about the cost of protection and the farmers' readiness to adopt safer practices. Protective equipment might account for only a small fraction of the total cost of prevention. Therefore, it might prove useful to investigate the behavioral changes that are needed to achieve safer use. Finally, the costs and benefits of safe use extension should be assessed.
Appendix A: Contingent valuation questions

Questionnaire extracts are presented on the following pages. The questionnaires were designed by the author, translated to Tamil, pretested and applied by Indian Market Research Bureau, New Delhi.
53. Instruction: Look up how many cases of health problems there are with 'yes' in column D of table 1 (reported to be partly or fully due to pesticides.)  
   - none ............ 0 cont. with Q. 55.
   - one ............. 1 cont. with Q. 54.
   - two or more .... 2 cont. with Q. 54.

54. In that case (refer to worst/only case due to pesticides by date, symptoms or any other characteristic), what pesticide were you using?  
   - If farmer can't say or doesn't know (CS/DK), code as 'Z' and continue with Q. 55.
   - If respondent can tell pesticide, code correspondingly and continue with Instruction 56.

55. What pesticide brand did you use the last time you sprayed?  

56. Instruction: Write brand reported in Q. 54 or Q. 55 here (full text):  

57. How much did ... (mention brand name reported at instruction 56) cost? ................. Rs.  

58. What quantity did this price refer to?  

59. INSTRUCTIONS FOR USE OF TABLE A:  
   1. Look up in the leftmost column of table A the price reported in Q. 57. If exact price is not indicated, take next higher price of the same column.
      Report that price here ................. Rs.
   2. Mark that row of TABLE A for your later reference.
   3. Move to the right in that row to the column marked "start here". This is the price to start with in Q. 60.
4. Then ask:

Assume, there is a... (state brand of Instruction 56)
- which could not cause any harm or health problems to humans at all
- and which would otherwise be as good as the... (state brand of Instruction 56) you bought,...

60. would you buy this pesticide if it cost Rs.... (state price looked up in table A)? If necessary make clear that this price refers to the quantity as in Q. 58.

Farmer would buy:
ask Q. 60 again with next higher price of the same row (moving to the right)
Farmer would not buy:
ask Q. 60 again with next lower price of the same row (moving to the left).
Farmer can't believe such a pesticide exists:
make sure farmer understands that the hypothetical pesticide would kill the pest as well as the currently used brand does, and ask again.
Farmer cannot say whether he would buy or not after repetition of the explanation: continue with Instruction 61.

Continue to do so, till you find the highest price the farmer would be willing to pay or until no higher or lower prices are left in the row.

61. Instruction: Report whether farmer finally would agree to buy the harmless pesticide.
Code as appropriate .......... □
Farmer agrees to buy ..... 1 report highest price farmer would pay:
Farmer does not agree .... 2
Can't say, doesn't know .. 3 cont. at Q. 63
<table>
<thead>
<tr>
<th>Orig. price [Rs]</th>
<th>Hypothetical prices to use in Q. 60 [Rs]</th>
<th>If not accepted, move this way</th>
<th>Start here</th>
<th>If price accepted, move this way</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>61 63 66</td>
<td>69</td>
<td>72 78 90</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>71 74 77</td>
<td>81</td>
<td>84 91 105</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>82 84 88</td>
<td>92</td>
<td>96 104 120</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>92 95 99</td>
<td>104</td>
<td>108 117 135</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>102 105 110</td>
<td>115</td>
<td>120 130 150</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>112 116 121</td>
<td>127</td>
<td>132 143 165</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>122 126 132</td>
<td>138</td>
<td>144 156 180</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>133 137 143</td>
<td>150</td>
<td>156 169 195</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>143 147 154</td>
<td>161</td>
<td>168 182 210</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>153 158 165</td>
<td>173</td>
<td>180 195 225</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>163 168 176</td>
<td>184</td>
<td>192 208 240</td>
<td></td>
</tr>
<tr>
<td>170</td>
<td>173 179 187</td>
<td>196</td>
<td>204 221 255</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>184 189 198</td>
<td>207</td>
<td>216 234 270</td>
<td></td>
</tr>
<tr>
<td>190</td>
<td>194 200 209</td>
<td>219</td>
<td>228 247 285</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>204 210 220</td>
<td>230</td>
<td>240 260 300</td>
<td></td>
</tr>
<tr>
<td>220</td>
<td>224 231 242</td>
<td>253</td>
<td>264 286 330</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>245 252 264</td>
<td>276</td>
<td>288 312 360</td>
<td></td>
</tr>
<tr>
<td>260</td>
<td>265 273 286</td>
<td>299</td>
<td>312 338 390</td>
<td></td>
</tr>
<tr>
<td>280</td>
<td>286 294 308</td>
<td>322</td>
<td>336 364 420</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>306 315 330</td>
<td>345</td>
<td>360 390 450</td>
<td></td>
</tr>
<tr>
<td>320</td>
<td>326 336 352</td>
<td>368</td>
<td>384 416 480</td>
<td></td>
</tr>
<tr>
<td>340</td>
<td>347 357 374</td>
<td>391</td>
<td>408 442 510</td>
<td></td>
</tr>
<tr>
<td>360</td>
<td>367 378 396</td>
<td>414</td>
<td>432 468 540</td>
<td></td>
</tr>
<tr>
<td>380</td>
<td>388 399 418</td>
<td>437</td>
<td>456 494 570</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>408 420 440</td>
<td>460</td>
<td>480 520 600</td>
<td></td>
</tr>
<tr>
<td>440</td>
<td>449 462 484</td>
<td>506</td>
<td>528 572 660</td>
<td></td>
</tr>
<tr>
<td>480</td>
<td>490 504 528</td>
<td>552</td>
<td>576 624 720</td>
<td></td>
</tr>
<tr>
<td>520</td>
<td>530 546 572</td>
<td>598</td>
<td>624 676 780</td>
<td></td>
</tr>
<tr>
<td>560</td>
<td>571 588 616</td>
<td>644</td>
<td>672 728 840</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>612 630 660</td>
<td>690</td>
<td>720 780 900</td>
<td></td>
</tr>
<tr>
<td>650</td>
<td>663 683 715</td>
<td>748</td>
<td>780 845 975</td>
<td></td>
</tr>
<tr>
<td>700</td>
<td>714 735 770</td>
<td>805</td>
<td>840 910 1050</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td>765 788 825</td>
<td>863</td>
<td>900 975 1125</td>
<td></td>
</tr>
<tr>
<td>800</td>
<td>816 840 880</td>
<td>920</td>
<td>960 1040 1200</td>
<td></td>
</tr>
<tr>
<td>900</td>
<td>918 945 990</td>
<td>1035</td>
<td>1080 1170 1350</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>1020 1050 1100</td>
<td>1150</td>
<td>1200 1300 1500</td>
<td></td>
</tr>
<tr>
<td>1100</td>
<td>1122 1155 1210</td>
<td>1265</td>
<td>1320 1430 1650</td>
<td></td>
</tr>
</tbody>
</table>
A2 Spraymen

64. **On what basis do you (usually) charge the fees for spraying pesticides?**

65. **How much do you (usually) charge per...** (as in Q. 64)?

66. **Instructions for use of table B:**

Assume there is a pesticide that could not harm your health nor cause any sickness or health problems at all...

67. **Would you accept to work for a fee of say...** (state fee looked up in table B) **when spraying this pesticide?**

Spraymen would accept:
- ask Q. 67 again with next lower fee of the marked row in table B (moving to the right).

Spraymen would not accept:
- ask Q. 67 again with next higher fee of the marked row in table B (moving to the left).

Spraymen can't believe such a pesticide exists:
- make sure he understands that the hypothetical pesticide would kill pests as well as existing brands do and ask Q. 67 again.

Spraymen cannot say whether he would accept or not after repetition of the explanation:
- continue with Instruction 68.

Continue to do so, until you find the lowest fee the spraymen would be willing to work for or until no higher or lower fees are left in the row.

68. **Instruction:** Report whether spraymen would finally accept to work for a lower fee when spraying a harmless pesticide

- Would accept ..... 1 report lowest accepted fee ........... Rs.
- Wouldn't accept .. 2 continue (Q. 69)
- CS/DK ............ 3 continue at Q. 70
Table B: Hypothetical fees for spraymen [Rs]

<table>
<thead>
<tr>
<th>Original fee [Rs]</th>
<th>Hypothetical fees to use in Q. 67</th>
</tr>
</thead>
<tbody>
<tr>
<td>If spraymen rejects fee, move this way</td>
<td>Start here</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td>40</td>
<td>38</td>
</tr>
<tr>
<td>50</td>
<td>48</td>
</tr>
<tr>
<td>60</td>
<td>57</td>
</tr>
<tr>
<td>70</td>
<td>67</td>
</tr>
<tr>
<td>80</td>
<td>76</td>
</tr>
<tr>
<td>90</td>
<td>86</td>
</tr>
</tbody>
</table>
Appendix B: Interpretation of logit model results

Response variables of binary logit models take one of only two values, e.g. sick or healthy, or suffering a certain symptom or not. The distribution of individuals over the two states may be described by a proportion \( \pi \) (e.g. 20% unhealthy, \( \pi = 0.2 \)) or by the odds \( \Omega \) (e.g. 20% unhealthy by 80% healthy, \( \Omega = \pi/(1 - \pi) = 0.25 \)). A simple measure to compare two proportions \( \pi_1 \) and \( \pi_2 \) is the difference \( \pi_1 - \pi_2 \). However, the difference of proportions is sometimes not very meaningful. For instance, the difference of 4% between 1% and 5% may be more significant than the difference between 26% and 30%. In such cases, the ratio between proportions may be a useful measure. The ratio \( \pi_1/\pi_2 \) is the relative risk. Proportions may also be compared in terms of the odds ratio \( \theta = \Omega_1/\Omega_2 = \{\pi_1(1 - \pi_2)\} / \{\pi_2(1 - \pi_1)\} \). The odds ratio is 1 if \( \pi_1 = \pi_2 \). Two odds ratios represent the same level of association, but in opposite directions, when one value is the inverse of the other. At low risks, the relative risk and the odds ratio are mutual approximations, because \( 1 - \pi_1 \approx 1 - \pi_2 \).

The \( \log_e \) of the odds is the logit. Parameters of logit models give the marginal effects on the logit of the response variable. A positive parameter represents a positive association. The magnitude of the association is easiest to interpret in terms of the odds ratio or relative risk. A parameter estimate \( \beta \) of 1, for example, corresponds to an odds ratio of \( \exp(\beta) = \exp(1) \approx 2.7 \) and—if the probability of the health effect is small—a relative risk of approximately 2.7. (The partial derivative of the risk with respect to the explanatory variable is \( \pi_x = \beta \pi(1 - \pi) \).)
Example: The variable LEAK yielded a parameter estimate of 1.012 in one model in Chapter 7. The odds ratio of the health risk between farmers with leaks and without leaks is thus $\exp(1.012) = 2.75$ implying that leaks multiply risks by approximately 2.75 while risks are small.

Two statistics for the model as a whole are generally reported, the Model $P$ and McFadden's $\rho^2$. They are both derived from the likelihood ratio statistic testing the hypothesis that all coefficients except the constant are zero. The Model $P$ is the error level of a $\chi^2$ test with degrees of freedom equal to the number of covariates in the model not including the constant. McFadden's $\rho^2$ is a transformation of the likelihood ratio statistic intended to mimic an $R^2$. It lies between 0 and 1 and a higher $\rho^2$ denotes more significant results. However, $\rho^2$ tends to be much lower than $R^2$, and a low number does not necessarily imply a poor fit. Values between 0.20 and 0.40 are considered highly satisfactory (HENSHER and JOHNSON, 1981, quoted in STEINBERG and COLL, 1991).
References


AMIPFAC, Asociación Mexicana de la Industria de Plaguicidas y Fertilizantes, n.d. *Diagnóstico y Tratamiento de la Intoxicación Aguda por Plaguicidas*. AMIPFAC, Mexico City.


ICAR. 1989. *Technology for Increasing Cotton Production in India*. All India Coordinated Cotton Improvement Project, Central Institute for Cotton Research, Coimbatore, Tamil Nadu, India.


Recursos Naturales en La Fraylesca, Chiapas: un Diagnóstico. CIMMYT, Mexico-City.


Curriculum vitae

Beda, son of Eugen and Pia Angehrn-Alpiger, was born January 14, 1966, in St. Gallen, Switzerland. He graduated from the Grammar School of the Canton St. Gallen in 1984 and received his degree as an Agricultural Economist from the Swiss Federal Institute of Technology (ETH) at Zurich in 1991. In 1992, he worked in extension and teaching in Rheineck, SG. He has been with the Institute of Agricultural Economics at ETH since 1993 and until 1995 was deployed in Villaflores, Chiapas, Mexico on behalf of the Ciba-Geigy Foundation for Cooperation with Developing Countries.

Publications


