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ECONOMICS OF AGRICULTURAL PESTICIDE RESISTANCE

by

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ECONOMICS OF AGRICULTURAL PESTICIDE RESISTANCE

Pesticide resistance poses a severe threat to agricultural productivity in the United States and in other areas of the world. And, this threat is increasing. Fueled by public concern over health and environmental effects of pesticide use, increased regulatory action is reducing the number of compounds available and increasing the threat of resistance to remaining compounds.

Reduction in pesticide efficacy from pest resistance has major economic, environmental, and human health implications. Understanding the economics of resistance at the farm level and beyond will allow us to achieve more optimal use of pesticides over time. Solutions to the resistance problem will require coordinated efforts among farmers, pest management firms, the chemical industry, government policymakers and regulators, and researchers.

My talk today will focus on four issues:

1. The nature of the economic impacts associated with pesticide resistance,
2. Implications of pesticide resistance for private and public sector actions,
3. Research needs with respect to pesticide resistance (from an economist's perspective),
4. A brief overview of a bioeconomic analysis of pesticide resistance currently underway at Virginia Tech.

My comments will be directed toward pesticide resistance in arthropods affecting crops, but most of the principles discussed hold for disease resistance as well.

ECONOMIC IMPACTS ASSOCIATED WITH PESTICIDE RESISTANCE

Pesticide resistance can influence pesticide costs and crop yields, affecting both the level and stability of farm income. Because of the mobility of pests, the pest-control actions of one farmer affect other farmers, and pest-control activities have significant environmental and distributional implications for society as a whole. Therefore, consideration of the economic impacts of pesticide resistance should encompass both field and farm level impacts as well as impacts beyond the farm gate.

Field or Farm Level Impacts -- For many years, increased insecticide usage appeared to be the least expensive means of insect control and a major source of productivity gains in agriculture. Increased resistance problems have raised the cost of pesticides (perhaps $100 million per year) both because a greater quantity of pesticides are needed to control pests, and because of a need to substitute newer and almost always higher priced insecticides to replace ineffective ones. If farmers react by reducing their insect control, then yields suffer. Increased use of insecticides due to resistance has magnified the development of secondary pest outbreaks and resurgences.

Management of tolerant or resistant arthropod natural enemies (predators and parasites of pest species) has allowed successful integration of biological and chemical control tactics and has thus reduced pesticide use and presumably the development of resistance in some cropping systems. For example, Hoyt has estimated that the use of predacious mites on apples in Washington state saves growers over $5 million per year on pesticides material and application costs.

Farm level decisions to apply insecticides are also influenced by the perceived income risk associated with alternative methods of pest control. The farmer's aversion to risk is a private incentive to overapply insecticides as a form of insurance, even though this overuse can exacerbate potential resistance problems.

Impacts Beyond the Farm Gate -- Pests are not confined to a single farm and consequently pest control can be considered a communal problem. Pests may move across several states or even national boundaries. Movement of resistant pests suggests that analysis of optimal pest control levels and means for implementing those levels must consider the possibilities for collective action within an agricultural region. That collective action may involve the agrochemical industry or groups of farmers themselves. Otherwise, individual farmers will not have an incentive to consider future resistance when they apply a pesticide.

Resistance management is complicated by the fact that pesticide use can result in water pollution, food residues, and damages to human health and non-target species, which can cause the socially optimum level of pesticide use to differ from the private optimum level. Private decisionmakers have limited incentives to include such environmental and social costs in their pesticide application decisions. If resistance increases pesticide use, then social costs will rise.

The environmental costs of pesticide use provide a rationale for pesticide regulatory action by environmental protection agencies. The divergence of social and private costs must be estimated if appropriate (from society's point of view) pesticide regulatory decisions are to be made. While measurement of this divergence is difficult, the analysis of regulatory actions is further complicated by the potential impact of pesticide regulations on the management of pesticide resistance. The use of a variety of pesticides is a promising tactic to combat developing resistance to any particular compound. Conversely, the banning of an effective pesticide may lead to more rapid development of resistance to the other chemicals and consequently to more pesticides being released in the environment.

Increased pesticide resistance also results in distributional effects. When yields decrease or costs increase, prices can be affected, and the net economic benefits on producers and consumers can differ. Also, producers in one region can benefit relative to those in another, depending on the effects on yield, costs, and prices in the different regions. The structure of the farm sector can be affected if costs or new technologies stimulated by pest resistance affect one size farm more than another or one commodity more than another. In addition, effects of resistance on agriculture have multiple effects on employment and income outside the farm sector, particularly on the chemical sector.

What Types of Economic Analyses of Pesticide Resistance Have Been Conducted? -- Economic analysis of pesticide resistance (on and off farm effects) have been assessed both theoretically and empirically over the past 15 years. Many studies have explored the optimal use of pesticides in light of the dynamic nature of resistance. Others have examined the choice of alternative pest management strategies. Others have considered social and distributional effects.

Perhaps the most widely used method for evaluating alternative pest control strategies has been simple budgeting. Many examples are found in EPA and USDA studies evaluating the possible impacts of regulatory actions. However, most of these studies have used very crude or no estimates of resistance effects on pesticides use, cost, and effects.

Production function analysis, which involves the estimation of the productivity effects of pesticides through regression analysis, has been used to measure the effects of pesticide resistance on cotton production in the U.S. and in Louisiana (Carlson, 1977, 1979). Carlson measured substantial reductions in cotton yields due to resistance using this simple static approach.

Much of the literature on the economics of pesticide resistance includes dynamic optimizing models in which the optimal allocation of pesticides implies management of both the pest and its associated stock of susceptibility. Most of these models have been highly simplified and only theoretical. Dynamic models offer optimal actions (for example, pesticide application) given a set of state variables in the system, such as potential plant product, pest population density, and the stock of pest susceptibility. The problem is that of choosing time paths for control variables, which in turn imply, via a set of differential equations, time paths for the state variables. The time paths for the control variables are chosen to maximize a given function depending on the time paths of the control and state variables. The time paths can be both within seasons and across seasons. Empirically, the model can be solved using a dynamic programming or control theory approach.

The inherent complexity of the biological processes, and hence the mathematical complexity of the models, has constrained their use. Also, the models require good biological data for particular pest complexes on particular crops and these data have been scarce. Empirical use of these models has increased in recent years. Given the nature of the resistance problem, it is difficult to evaluate pest management strategies without a dynamic model.

Simulation has been used to help incorporate a risk effect or to generate data for use in the other models. A stochastic dynamic approach is preferred for in-depth analysis of both optimal pesticide use and the choice of pest management alternatives.

Consumer-producer surplus analysis is a means of calculating the effects of resistance at a societal level. It can be used to calculate distributional effects of resistance. The above discussion is an extremely brief summary of methods used for economic analysis of pesticide resistance. We will return to an example of a dynamic analysis of pesticide resistance below. First, however, let's consider the implications of pesticide resistance for private and public actions.

IMPLICATIONS OF PESTICIDE RESISTANCE FOR PRIVATE AND PUBLIC ACTIONS

The diversity of economic impacts of pesticide resistance, the dynamic nature of resistance, pest mobility, and environmental effects from pesticide use all have important implications for resistance management by the private sector. Public policies are needed to provide incentives for collective action to control the rate of depletion of the stock of pest susceptibility to pesticides.

Miranowski and Carlson have suggested a variety of conditions under which incentives exist within various elements of the private sector for managing the build-up of resistance. If pests have little mobility (and some do), if substitute controls are more costly, and if the crop has high value and is subject to serious pest damage in the absence of pest control, farmers have an incentive to seek to retard resistance. If pests are mobile but can be confined to a region, and if the costs of coordinating farms are relatively low, then incentives exist for multifarm collective action to help stem resistance. A single pesticide manufacturer has an incentive to manage resistance if it possesses a highly profitable pesticide with no actual or potential close substitute, if it can monitor the resistance at a relatively low cost, if it has a monopoly in marketing the pesticide, and if pests are mobile so that incentives for farm level management of resistance are noneconomic. Collective action on the part of chemical firms is also possible if resistance can be managed by mixtures of compounds owned by several firms, if resistance monitoring is valuable because of cross-resistance, and if coordinated rotation of compounds over time can reduce resistance.

If pests are mobile, pest management coordination among farms is costly, the market structure of the chemical industry discourages resistance management, and pest resistance is becoming, or is likely to become, a serious problem, public policies can be designed to provide incentives for resistance management. User charges or subsidies can be enacted to control the rate of use of a particular pesticide over time. Revenue generated from user charges could be used to develop a national program to finance resistance related research and the implementation of resistance management projects. Regulating agencies can restrict the use of current compounds and can allow special registration of new compounds for use in resistance management. Additional support can be provided to increase our understanding of the mechanisms through which pests develop resistance, to develop improved methods for monitoring resistance, and to discover ways of integrating field evaluations of resistance with economic models in designing optimal resistance strategies.

RESEARCH NEEDS WITH RESPECT TO PESTICIDE RESISTANCE MANAGEMENT (FROM AN ECONOMIST'S PERSPECTIVE)

Research of several types is needed. First, additional studies on the genetics, biochemistry, physiology, and population biology of resistant organisms; and development and field evaluation of improved methods to detect, monitor, prevent, and slow resistance are needed. These studies, while biological in nature, can provide information for subsequent economic analysis. Second, economic assessment of alternative resistance management strategies for individual farmers, groups of farmers, and agrochemical companies, given the pest mobility, pest and crop dynamics, and industry structure associated with particular pesticides is needed. Third, assessment of the economic impacts associated with pesticide resistance that would result from alternative regulatory actions by public agencies, such as EPA, is needed. Fourth, assessment of environmental implications of pesticide use, given the projected increases in pesticide resistance, is needed. Fifth, assessment of interregional and international economic and environmental implications associated with differential resistance control activities by region and commodity is needed.

These analyses would help to design institutional arrangements to stimulate resistance management by farmers and agrochemical companies, would assist public agencies to design appropriate regulations in light of resistance, and would help design national and international policies to control resistance development.

OVERVIEW OF A BIOECONOMIC ANALYSIS OF PESTICIDE RESISTANCE CURRENTLY UNDERWAY AT VIRGINIA TECH

A study is currently underway in the agricultural economics department at Virginia Tech to develop a procedure for analyzing the dynamic economic effects of pesticide regulatory action and the subsequent potential development of pest resistance. This study, funded by EPA, focuses on the tufted apple bud moth, European red mite, black ladybird beetle pest-predator complex in apples. This study, which Rich Kazmierczak is undertaking for his Ph.D. dissertation, has three major sub-objectives:

1. to develop a dynamic economic model of apple production that includes the potential effects of pest control measure on emerging pest resistance,
2. to combine the economic model with a biological simulation model capable of tracking the development of pest resistance through time, and
3. to use the bioeconomic model to describe the economic effects of various regulatory actions on pesticides used in apple production.

Recent regulatory pressures on pesticides have diminished the number of chemicals available, thereby increasing the use of remaining chemicals which then decline in efficacy due to resistance. For example, tufted apple bud moth resistance to organophosphates leads to the use of alternative pesticides. Unfortunately, the predator black ladybird beetle tends to be less tolerant of the alternatives, leading to an increase in European red mites. European red mite populations rapidly develop resistance to many pesticides.

One of the key questions considered in this study is how EPA can regulate the use of pesticides without hastening the development of resistance to remaining chemicals; and how EPA can help preserve pest susceptibility to pesticides while at the same time maintaining grower profits.

Because pesticide use in one period affects the biological system for many years, a dynamic economic model is needed which maximizes economic benefits to producers and consumers over time subject to the time varying interactions of pest densities, predator densities, pest susceptibility to pesticides, predator susceptibility to pesticides, immigration of susceptible pests and predators, environmental carrying capacities, and crop yield.

The biological part of the model is a simulation model called SERA, "Simulating the Evolution of Resistance of Arthropods" developed by Tabashnik and Croft and later modified by Knight. SERA combines user specified life history parameters, population genetic characteristics, migration patterns, and pesticide mortality functions for a pest-predator complex. From this information, SERA generates the time path of resistance under user specified pesticide application regimes (figure 1). SERA is parameterized for the study using experimental field data from Pennsylvania.

The economic and biological models are regional in geographic scope and are linked in a bioeconomic control theory model. The dynamic relationships embodied in the SERA model are constraints in the economic model along with the effects of pests on crop yield, market supply and demand relationships, and the social discount rate.

Constraints can be placed on the range of permitted control variables, thereby allowing the examination of different regulatory policy options. Subject to satisfying feasibility conditions, the solution to the control model will yield a set of partial differential equations that describe the optimal trajectory of the decision variables (pest control and non-pest control inputs) through time for any initial and/or terminal conditions.

INPUTS TO THE SERA MODEL:

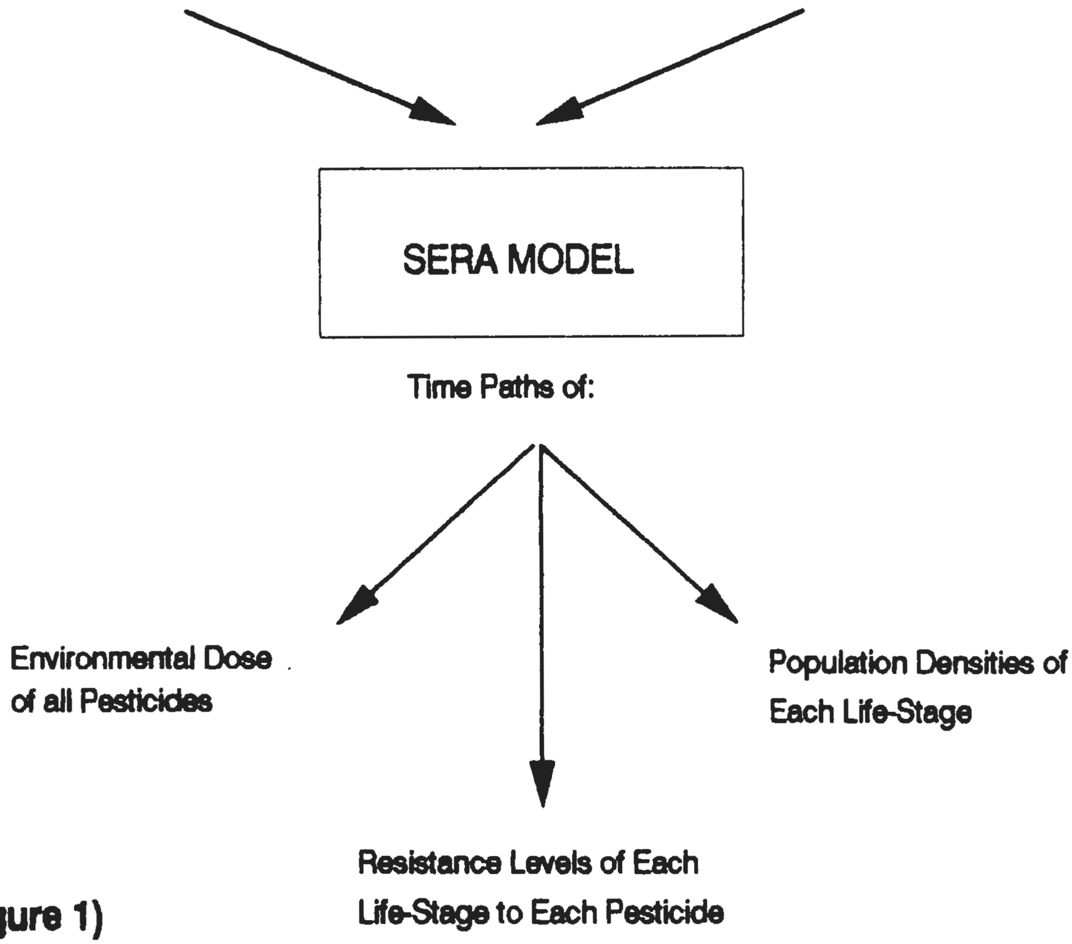
FOR EACH ORGANISM IN THE MODEL

LIFE HISTORY PARAMETERS

1) growth rates
2) fecundity
3) daily and winter mortality
4) age structure
5) potential predator/prey interactions
6) initial densities/carrying capacities
7) immigration rates from:
   a) woods
   b) other apple orchards
   c) other fruit orchards

PESTICIDE PARAMETERS

1) number of controls
2) application dosages
3) spray schedules
4) potential cross-resistant linkages
5) initial resistance levels
6) relative susceptability to each control by age class
7) extent of refugia from control
8) fitness effects of resistant gene
9) pesticide half life's in environment



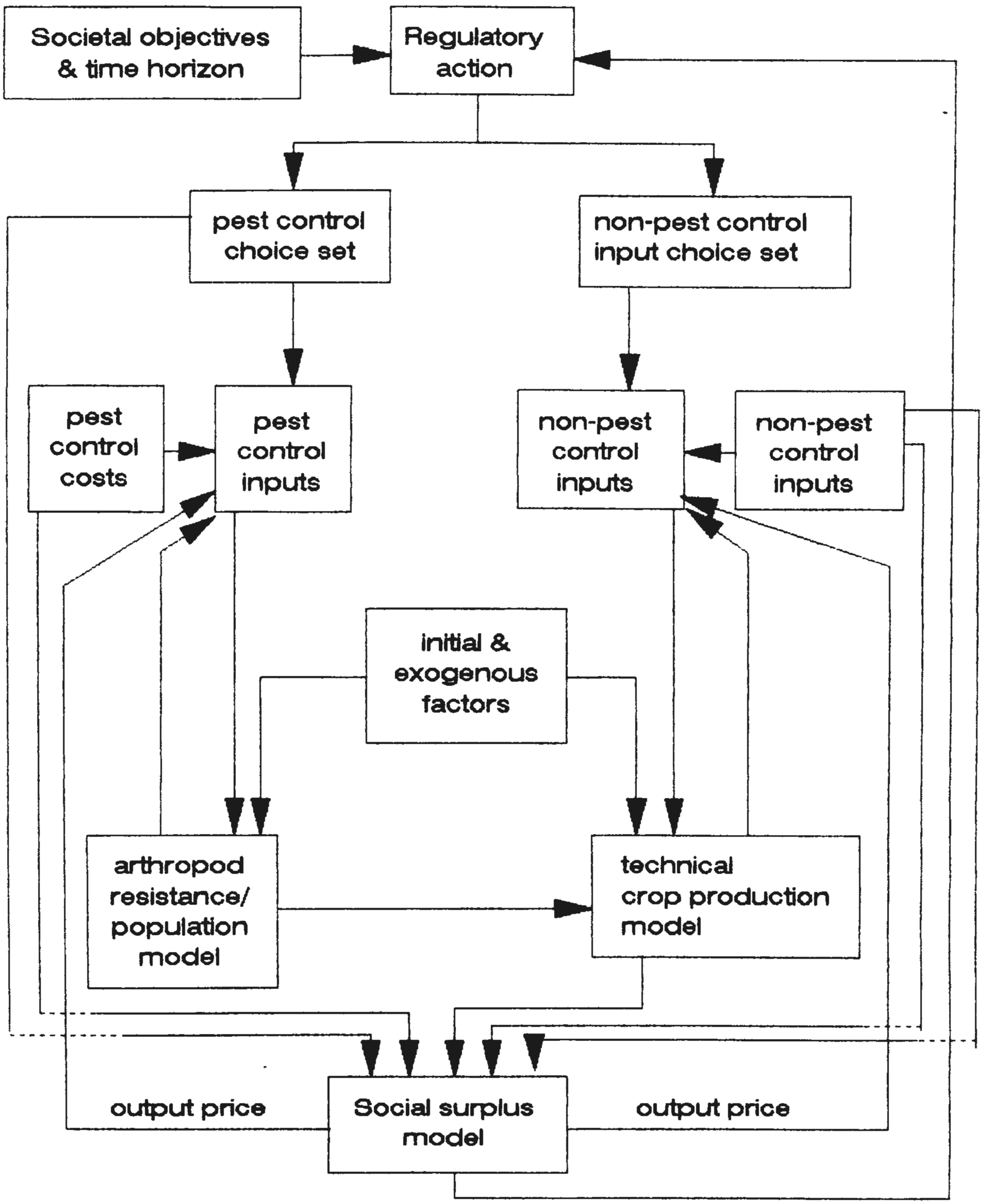
(figure 1)

A diagrammatic version of the control model is found in figure 2. Mathematical details are found in Kazmierczak, chapter 4.

Hence, the study will provide, for a particular pest-complex on apples, (1) the optimal time-path for pesticide use, (2) estimated short, intermediate, and long run effect of pesticide use on profits, consumer benefits, and resistance, and (3) simulation of both the resistance and the economic effects of alternative regulatory policies with respect to the pesticides studied. The model can be easily modified to analyze other pest complexes and/or pesticide alternatives.

CONCLUSIONS

A variety of economic issues are associated with pesticide resistance. Analysis of many of these issues requires relatively complex and dynamic bio-economic models. Interdisciplinary work is needed because realistic information and modeling is required of both the biological processes and the economic impacts associated with pesticide resistance.


Societal objectives & time horizon
Regulatory action
pest control choice set
non-pest control input choice set
pest control costs
pest control inputs
non-pest control inputs
non-pest control inputs
initial & exogenous factors
arthropod resistance/ population model
technical crop production model
output price
Social surplus model
output price

(figure 2)

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