UCD Department of Agricultural Economics

WORKING PAPER SERIES

Pesticides

University of California, Davis
Department of Agricultural Economics

A DYNAMIC ANALYSIS OF PRODUCTION EXTERNALITIES: PESTICIDE RESISTANCE IN CALIFORNIA COTTON

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Working Paper No. 86-3

1. INTRODUCTION

Productivity in agriculture has resulted largely from adoption of physically and biologically altering technology including chemical fertilizers, pesticides, and mechanical production processes. While it is clear that gains have occurred from technology, negative effects on the natural resource base from widespread adoption and cumulative use are also beginning to emerge. The buildup of salinity in soils from continuous irrigation and inadequate drainage, soil erosion, the development of resistance in pests to chemical pesticides, and depletion and contamination of aquifers from irrigation and fertilizer application are some of the more obvious examples.

Productivity analysis has not explicitly incorporated production externalities from adoption of particular production technology in the measurement of growth. These externalities are complex because of their dynamic and collective dimensions, complicating the design of policy to mitigate or reduce them.

The intertemporal and external effects of technology, along with the effects of mitigating environmental and resource policy, should be included in production analysis for several reasons: First, excluding production externalities can overstate (understate) productivity gains from technology since some resource costs (benefits) are not counted. Second, as public policy moves in the direction of requiring producers to bear more of the total costs of production and to "internalize" externalities, the total or social costs and benefits from technology must be ascertained. Third, as interest focuses on the long-run profitability of technology, the biological and physical "sustainability" of technology becomes critical. Fourth, potential inconsistencies between agricultural commodity programs and environmental policies provide yet another rationale for examining the effects of production externalities on productivity growth. Finally, evidence that existing regulatory policy has adversely affected productivity growth rates underscores the need for further analysis.

Models which explicitly incorporate externalities need to be developed in order to better measure and explain agricultural productivity. The objectives of this study are:

1. To develop a model of production that accurately captures the complex externalities that result from agriculture's reliance on physically and biologically altering technology (with pest resistance to chemical pesticides as an example.)
2. To define, in a control theoretic framework, dynamic productivity measures to compare the effects of alternative technology and environmental policy on future agricultural output, externality levels, bias in input use and overall welfare levels.
3. To estimate empirically the theoretic model examining the development of pest resistance in cotton production and the economics of nonchemical control technology with and without user costs incorporated.
4. To explore alternative policy approaches to achieve socially efficient sustainable technology choices that are consistent with private ownership of resources.

The outline of this report is as follows: the economic and policy framework for pesticide technology is presented in section 2, highlighting its importance in agricultural production, the potential for declining productivity and current policy constraints on pesticide use. The specific case of resistance in California cotton is developed. Section 3 models resistance as an unintended by-product of agricultural production and models socially efficient decisions on pesticide use using dynamic optimization theory and techniques. The theoretic model is solved empirically using dynamic programming in section 4. Rates of change in resistance are estimated econometrically as are other model parameters.

Analysis of the economics of pest control technology when resistance is incorporated is presented in section 5. Summary and conclusions are reported in section 6.

Previous Research

Empirical analyses of pesticide productivity conducted by Headley (1968), Lee and Langham (1973), and Talpaz and Frisbie (1975) showed positive short-run returns from pesticide use but, more importantly, highlighted the importance of including the intertemporal effects of chemical control technology in long-run productivity. Theoretical models of pesticide technology incorporating resistance have been developed. Hueth and Regev (1974) following Carlson and Castle (1972), likened pest resistance to a depletable natural resource in which the stock of pest "susceptibility" declines with cumulative pesticide use. Following Smith, (1969) dynamic first-order conditions for optimal pesticide use derived using optimal control theory show private decision making depletes the stock of susceptibility over time. Taylor and Headley (1975) incorporate a genetic model of pest resistance development to derive a dynamic optimal economic threshold. Feder and Regev (1975) similarly modeled pesticide use in a control framework including effects of use on prey-predator dynamics with residues as an externality. Theoretical results showed that centralized control achieves socially efficient resource use.

Regev, Shalit, and Gutierrez (1977) modeled pesticide use, given resistance development, determining the optimal path of pesticide when an alternative or backstop technology is available showing that centralized decision making on pesticide use results in a lower level of resistance than private decision making. The authors suggest that, alternatively, a Pigouvian tax per unit of pesticide used, equivalent to the shadow value of resistance times the marginal contribution of pesticides to resistance over time, would also result in socially optimal solution.

Previous empirical studies of pesticide productivity incorporating resistance have been based on estimates of changing effectiveness over time as a function of cumulative pesticide use. Carlson (1977), econometrically estimated resistance effects on insecticide demand by state and major crop. Using secondary sources to identify the first time resistance appeared in specific regions and aggregate reports of organochlorines used by crop, Carlson estimated a resistance index as a function of lagged pounds of organochlorines used for control of the resistant species. He found that as resistance is increased substitute pesticides, specifically organophosphates, were employed.

Sarhan (1977) econometrically derived parameters for reducing mosquito populations with alternative pest control approaches and, in a linear programming model, examined the effects of governmental policy on chemical use and development of pest resistance. He concluded that over-reliance on available chemical methods leads to increased resistance. "Effectiveness functions," measures of the average percentage control attained, were used as approximations to resistance. The percentage of control (or kill) in the field was defined as the number out of 100 acres sprayed (or 100 locations treated) which did not require respraying.

Moffitt and Farnsworth (1981) estimated the effects of resistance development on aggregate U.S. pesticide demand. Their model permits an econometric assessment of the impact of pesticide use on resistance development with limited data. Resistance is expressed as a function of cumulative pesticide use and is mathematically characterized by a Weibull density function to approximate the biological dosage-response function. Using the mathematical properties of the distribution function and an initial estimate of resistance, selection pressure associated with cumulative pesticide applications was estimated. Aggregate U.S. pesticide data were used to estimate pesticide demand elasticities. This analysis must assume some initial level of effectiveness a critical parameter in the model.

Empirical estimates of the productivity of integrated pest control strategies have been made by Hall (1977) who showed that farms using pest control advisers reduced pesticide use per acre with no significant yield or profit effects. Grube (1978) estimated the productivity of pest control information finding that field scouting did not reduce insecticide use but had a marginal value well above costs.

Simulation models have been used to analyze the productivity of alternative pest control strategies concluding that integrated pest management technology can both reduce costs and increase yields (Reichelderfer and Bender, 1979). Pimental _et al_. (1979) used "best estimates" of costs and benefits to determine the effectiveness of alternative controls for reducing insecticides on cotton and corn.

Casey and Lacewell (1973) estimated the impact on cotton production of a ban on selected pesticides using actual production costs in combination with a Delphi procedure to determine pesticide demand elasticities. The effects of alternative pest strategies on yields and net revenue were simulated. Results showed that aggregate impacts from pesticide withdrawal on net revenue were minimal but regional effects were substantial. Yields or revenues from alternative, less environmentally damaging, production practices were not explored. Taylor, Lacewell, and Talpaz (1979) used a similar "hybrid" model to evaluate aggregate impacts of a toxephene ban on cotton. The econometric model employed engineering data to estimate supply response parameters under the regulated technology. Huang, Weislz, Willette, and Heady (1980) used the Iowa State CARD model to estimate the impact on output, price and interregional and intraregional pjroduction and income shifts. It combines the features of an econometric and a programming model, but is highly aggregate, ignores resistance, and is deterministic and static.

Following Hueth and Regev (1974), Lazarus and Swanson (1982) formulated a regional pest management model to examine the effects of cultural practices and pesticide use on the number of infested soybean fields and externality levels where externalities are mean numbers of pests using a control theoretic framework. A simulation model relying primarily on secondary data was used to estimate the effects of risk aversion on insect control choice.

2. THE ECONOMIC AND POLICY FRAMEWORK

Pesticides contribute significantly to agricultural productivity reducing damage to world food crops and supplies. It is estimated that for every dollar spent on pesticides between \$2.00 and \$4.00 of crop value is returned (Headley, 1968; Doyle, 1985) yet pesticide use also creates many well-chronicled unwanted negative side effects such as risks to workers and residues in food products. Others are only recently recognized as critical problems including pollution of underground water stocks, serious disruption of insect population dynamics, and development of resistance to chemical pesticides. The long-run economic productivity of chemical pesticides depends critically upon the rate at which insects develop resistance to them. Currently, the pace of resistance development is thought to be accelerating at the same time discovery of new control mechanisms has slowed. The number of resistant insect species doubled in the 10 yeras between 1970 and 1980 from 224 to 428 (<u>Technology</u>, Nov.-Dec. 1985). A 1981 survey classified nearly 60 percent of resistant pests as agricultural pests (Georgiou, 1981). Eight percent of resistant agricultural pests are now resistant to the four main classes of insecticides.

Insecticides that are losing effectiveness are not being replaced. In part this reflects the high costs of development due to regulatory testing requirements and registration procedures (Comins, 1978). Costs of registering new materials have reduced the number of materials being manufactured and

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[3] Pounds of active ingredients of insecticides used in the United States increased by 20 million pounds between 1964 and and 1971, but then declined slightly only to rise to nearly 170 million pounds in 1980 (Eichers, 1981).

turned the focus toward broad spectrum chemicals increasing the opportunity for resistance development. At one time alternative chemical compounds were routinely available to combat major pests, but the lines of defense have become thinned and the problem of increasing resistance is masked in many cases because a tenuous chemical control continues to be achieved (CAST, 1983) although with much higher use levels.

Resistance of agricultural insects to current chemical insecticides is an important economic and public policy issue. The economic implications for agriculture include: (1) crop losses from resistant insect damage; (2) higher costs to producers of pest control as chemical effectiveness declines; and (3) adjustments in cropping and land use when control costs exceed returns in other activities. Social costs of resistance include: (1) an increased chemical load in the environment; (2) greater selection pressure on susceptible, nontaraget insect populations; and (3) potentially higher food costs. The opportunity costs to society of resources devoted to development of new control methods and regulatory program costs must be considered as well.

Continued increases in the total amounts of materials used (Table 2.1), observed increases in pest control costs, slow rate of adoption of alternative technology and increasing constraints on the use of particular chemicals prompt economic analysis of changes in the productivity of chemical compounds over time, the economic feasibility of alternative less damaging technology embodied in integrated pest management (IPM) techniques, and the role of environmental policy in achieving socially efficient use.

Table 2.1--National Trends in U.S. Insecticide Use, 1966-1980

Year	Pounds of Active Ingredients (millions)
1966	147.3
1971	167.9
1976	165.0
1980	169.2

Source: Adapted from Eichers, T. R. "Farm Pestiacide Economic Evaluation, 1981," Agricultural Economic Report Number 464, U.S.D.A. Economics and Statistics Service, Washington, D.C., March 1981, Tables 4 and 6.

Pesticide Use in Cotton and Resistance Development

Cotton production in all areas of the world suffers serious economic losses from pests and chemical insecticides have become critical to continued profitability. Continued reliance on chemical pesticides is leading to development of genetic resistance of pests resulting in greater use levels and vastly reduced cotton acreages. Table 2.2 indicates the shift in the type of insecticide compounds used to combat cotton pests. Use of organochlorines has declined nationally due to the removal of DDT from use. Many cotton pests had demonstrated tolerance prior to its removal (NRC, 1981). Organophosphate use on cotton doubled between 1964-1976. Carbamate use declined substantially, largely due to loss of effectiveness. Synthetic pyrethroids which did not come into widespread use until about 1978 are now the dominant insecticide for control of cotton pests (USDA, 1985).

Total pounds of insecticide used on cotton (without synthetic pyrethroids) declined between 1964 and 1976. However, 68 million pounds of active insecticide ingredients were used on cotton in 1980 (Eichers, 1981) indicating that total pounds of insecticides applied to cotton increased over 1976 levels in the past five years. A more striking statistic is the trend in per acre insecticide use. From Table 2.3 it is evident that use rates per acre have increased substantially. Organochlorine use per acre nearly doubled between 1964 and 1976. Organophosphate use per acre increased 25 percent in this same period.

Table 2.2--Trends in Insecticide Use on Cotton in the United States by Major Category, 1964-1976

Insecticide	Pounds of Active Ingredients (millions) 1964	1976
Organochlorines		
DDT	55.8	27.3
Endrin	23.6	0
Toxaphene	1.9	1.0
Other	26.9	28.1
Organophosphates		
Malathion	15.2	31.0
Methyl Parathion	8.8	0
Parathion	1.6	.68
EPN	0	6.1
Disulfoton	.6	1.8
Monocrotophos	0	1.5
Carbamates	4.5	1.4
Chlordimeform	0	4.4
Total	78.0	64.1

Source: Adapted from Committee on Cotton Insect Management, Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council "Cotton Boll Weevil: An Evaluation of USDA Programs." National Academy Press, Washington, D.C., 1981, Table 2.2.

Table 2.3--Pounds per Acre of Active Ingredients of Insecticides on U.S. Cotton 1964, 1976

	Pounds of Active Ingredients per Acre Treated	
	1964	1976
Organochlorines	3.9	7.3
Organophosphates	1.9	2.4
Carbamates	4.5	1.3

Source: Adapted from Committee on Cotton Insect Management, Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council "Cotton Boll Weevil: An Evaluation of USDA Programs." National Academy Press, Washington, D.C., 1981. Table 2.2.

Examination of trends in cotton insecticide use demonstrates clearly the effects of continual pesticide use on natural selection of resistant strains of cotton insects. One research has estimated that cumulative cotton insecticide use since 1950 approximates 200 pounds per acre of cotton (NRC, 1981). There are now many cotton insects which have shown evidence of resistance to more than one chemical compound.[7] At least 21 species have developed resistance to one or more insecticides (NRC, 1981). The boll weevil is resistant to some insecticides in 10 of 11 states (Brazzel, 1961). Cotton bollworms (Heliothis zea) and tobacco budworms (Heliothis virescens), two key cotton pests, have developed resistance to many types of insecticides. There is now evidence the tobacco budworm is resistant to some synthetic pyrethroids (permethrin)--

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[7] Cotton insects are not the only pests where evidence of resistance is building. Georghiou's (1981) recent survey of pest resistance to insecticides classifies nearly 60 percent (over 400) of these as agricultural pests; 8 percent of resistant agricultural pests are resistant to the four main classes of insecticides and about 4 percent have demonstrated some resistance to synthetic pyrethroids.

presently the last line of defense against budworm in many areas--which did not even have conditional EPA approval until 1979 (NRC, 1981; Reynolds, 1983). Thus, not only are cotton pests showing cross-resistance to nearly all chemical compounds, but resistance development is occurring at a much faster pace.[8] New technology or policy which husbands chemicals is essential to continued profitability of cotton, and more generally to assure the sustainability of chemical pest control.

Alternative Technology

Integrated Pest Management (IPM), the application of economic principles to pest control problems, has emerged as a technological alternative to sole reliance on chemical pest control. Integrated pest management has been defined as: a pest management system that in the context of the associated environment and population dynamics of the pest species utilizes all suitable techniques and methods in as compatible manner as possible, and maintains the pest population at levels below those causing economic injury (Entomological Society of America, ESA, 1975).

This broad definition is translated into specific elements:

1. Scouting or Field Checking: regular assessment of pest population levels, usually by sampling fields.

2. Economic Threshold to Guide Decisions: use of chemical pesticides only when marginal costs of control are less than or equal to economic damage caused by pests (Headley, 1972).

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[8] Pests can become resistant to other forms of control but development of chemical resistance has been much more rapid. Georghiou (1965) refers to this as "accelerated microevolution."

3. Alternative control Measures: use of a variety or "integration" of pest control techniques including biological controls, mechanical and/or physical controls, cultural controls and autocidal methods.

IPM systems have demonstrated positive effects on crop productivity and have shown great adaptability in their application (Pimental, 1978). Ennis has demonstrated a 30-50 percent reduction in crop losses with IPM pest control strategies (Ennis et al., 1985). However, in 1980, only 16 million acres, or 4 percent of U.S. cropland, were in "IPM" programs. These "crop protection systems" require a thorough understanding of the dynamic interaction of weeds, water, and pests. Since problems are very specific to crop and location, systems must be developed and tested locally under a variety of stress conditions.

They also work best with regional cooperation or "pest management" organizations that monitor pest populations over a given area, make decisions on economic thresholds and control the timing of pesticide applications. However, private pest control advisors do provide these services on a fee per acre basis. It has been pointed out (Pimental, 1978) that the institutional arrangements may be more difficult than the biological principles involved.

Environmental Policy

Current regulatory policies to reduce or eliminate negative effects from pesticide use are designed to reduce the persistence of chemicals in the environment, protect worker health and safety, and control pesticide use practices to reduce economic losses to nontargeted crops.

Environmental policy covers all aspects of pesticide use: chemical production, distribution, advertising and sales, handling, and application of materials establishing limits on crop residues and monitoring actual levels. The primary mechanisms by which pesticides are controlled are:

1. Registration of Materials: materials are licensed by the government based on scientific assessment of benefits and risks.

2. Restricting Use: chemicals are restricted to certain crops.

3. Specifying Re-entry and Harvest Intervals: regulates when workers can return to treated fields and time intervals from treatment to harvest.

4. Setting Tolerances on Food Residues: sets legal limits on the quantity of materials allowed to remain on food crops.

5. Requiring Protective Clothing: specifies the nature of protective clothing to be worn and under what conditions to help reduce exposure of workers to chemicals.

6. Providing Information to Users: product labels assure registration, specify appropriate uses and provide first aid information.

Resistance has not been explicitly addressed by environmental policy. Effective policy must recognize the fundamental biological dynamics and the difficulties in internalizing externalities which arise from the collective aspects of pesticide use. Resistance is a collectively produced externality--it is the cumulative use of chemical technology over a broad geographic region which alters pest population dynamics. Because pests are considered a common property resource, there are no incentives for individuals to husband pesticide use today such that resistance is lower in future periods.

Such collective, intertemporal externalities theoretically require collective action or other institutional arrangements not presently in use by government. Taxes, pollution charges, and subsidy schemes that force producers to face the total costs of production or provide economic incentives to adopt alternative technology are feasible policy options.

A Disaggregate Approach

Models that incorporate externality effects should reflect a significant degree of disaggregation as well as have the capability for integrating the biological, physical, and economic processes. Analysis needs to be disaggregate, specific to a sector or commodity. This is true for both the agricultural and nonagricultural sectors as noted by Kopp and Smith (1981). Fortunately, microproduction data are often available at the regional or commodity level, facilitating estimation of externality functions from historical production and regulatory data.

Although federal environmental regulations are uniform for all regions, environmental problems often are location-specific. Thus analyses and policies are likely to be targeted to specific regional externality problems such as the selenium contamination of the Kesterson reservoir in California. Evidence indicates that the emergence of pesticide resistance is restricted to selected regions, crops, and even specific insects. The specificity of these issues makes them no less interesting nor important; however, it does have implications for how production relationships are modeled and how policies are designed.

THE EMPIRICAL SETTING : PESTCIDE USE IN COTTON ON PRODUCTION IN IMPERIAL VALLEY

The Imperial Valley is located in the southern desert region of California adjacent to the border with Mexico. About 600,000 acres are cultivated annually.[9] Average rainfall is under three inches per year (1915-1979) with most of the rain occurring between August and March. Irrigation water, essential for crop production, is transported from the Colorado River to the Valley through the All American Canal. Water is highly saline constraining cropping patterns. Cotton, a relatively salt tolerant plant, produces high yields in Imperial's saline soils although rising water tables and excessive underground salt accumulations necessitate drainage and careful irrigation management. Soils in the Valley are primarily silty clay deposited by flood waters from the Colorado River. Only 2 percent of soils rated as Class I and 25 percent as Class II by the USDA Land Capability Classification System with over 70 percent rated as relatively poor (Class III and VI).

California's Imperial Valley is a particularly suitable location to investigate empirically the long-run effectiveness of pesticide technology and the role of public policy in reducing environmental externalities. Imperial Valley cotton yields are well above the California state average which is almost twice the national average. Approximately 40 percent of all restricted pesticides used on cotton in the state are applied in the Imperial Valley although it produces less than 8 percent of the State's cotton (CDFA, I978). Imperial County ranks as number one or two among California counties in pounds of restricted pesticides applied per acre. The Valley's desert climate produces unique and expensive pest management problems; its stable climate reduces the effects of variable weather patterns on insect populations and plant growth; its high agricultural productivity, especially in cotton, has been

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[9] This largely constitutes the service area of the Imperial Irrigation District.

very dependent upon high levels of insecticides and other technical inputs such as irrigation, drainage, fertilizers, insecticides and equipment. Any policies which affect the availability, quality or prices of these inputs can have immediate consequences for production patterns and practices.

The "Insecticide Treadmill"

Imperial Valley first grew cotton consistently with profit following World War II in the late 1940's when DDT and other synthetic organic compounds came into commercial use. Prior to this, insect pests made cotton production risky. Pesticide use increased until the early 1960s when DDT residues were found in alfalfa hay sold to dairies in the Los Angeles milkshed (Dunning, 1973). At that time an integrated pest management program, which included scouting and judicious use of selective chemicals, was introduced greatly reducing growers' dependence on insecticides (Reynolds, 1975). Pests could be controlled with three or four chemical applications. However, the southern desert valleys, including Imperial, began to rely heavily on chemical pest control again in the mid-1960s when the pink bollworm (Pectinophorm gossypiella) migrated from New Mexico to the Valley. By 1968 the average number of chemical pesticide applications per season was estimated by the County Agricultural Commissioner to be about 15 (Calexico Chronicle, 1982). In 1969, cost of production studies placed the number of recommended insecticide applications at 18 (Cooperative Extension, 1969). Farmers were spraying regularly from July through October in their efforts to control pink bollworm populations and yields declined to less than two bales per acre remaining at this lower level for several years. Losses were due, in part, to the cotton leaf perforator (Bucculatric thurbeiella), a secondary pest which emerged and proved difficult to control, but also to declining effectiveness of organochlorines and organophosphates in controlling pink bollworm populations.

Yields remained relatively stable from 1972 through 1976, but data on recommended pesticide applications and control costs suggest clearly that use of pesticides to control cotton pests was increasing. Pesticide spray programs became critical to production with several applications of broad spectrum chemicals per season routine. By the mid-1970s insect control in cotton was more costly and less efficient than at any previous time (Reynolds, 1975).

Heavy reliance on chemicals disrupted the national pest population dynamics in the Valley. Both targeted pests and non-targeted beneficial insects were being killed and without the presence of natural enemies new pests flourished, affecting not only cotton but sugar beets, melons, lettuce, and carrots. The most serious, economically damaging secondary pest to result from the control of pink bollworm was Heliothis virescens (tobacco budworm) which appeared in the Imperial Valley in 1972 (Sharma, I977). Tobacco budworm had been a serious economic pest in the southern states many years earlier. Prior to widespread use of chemical control for pink bollworm, tobacco budworm populations were held in check in Imperial Valley by beneficial insects. Thus, what was under normal conditions not an economic pest became a primary target of control (Toscano, N.C., V, Sevacherian, R.A. VanSteenwyk, 1970).

By the time the tobacco budworm arrived in California it had already developed a high tolerance to chemical insecticides, making control difficult as well as costly. Chlordimeform was effective against budworm but was withdrawn in California in 1977 because of its alleged carcinogenic properties. In 1977 tobacco budworm losses in cotton were estimated to be 50 million dollars or 40 percent of the Imperial Valley cotton crop (Sharma, 1977). Yield losses were in evidence during the period 1976-1978, but it is difficult to separate the effects of removal of chlordimeform, large infestations of both pink bollworm and tobacco budworm and two years of hurricanes which prevented pesticide treatments late in the season when pest populations were peaking (Burrows et al., 1882). In 1978, synthetic pyrethroids were first used to control tobacco budworm but early evidence showed some cross resistance to DDT (Eichers, I982).

Use of these broad spectrum synthetic organic insecticides altered cotton field ecosystems turning minor pests into major economic pests (NRC, 1981). Unlike the situation in the Imperial Valley during the 1950s, growers now had to routinely control pink bollworm, tobacco budworm, spider mites, lygus, leafhopper, whitefly, and cotton leaf perforator. Control costs were high and by 1980, control of pink bollworm and tobacco budworm was only achieved with chemical applications every 4-5 days beginning in June. In 1981,the white fly (Trialeurodes abutilonea) appeared in the Valley as an economically important pest. The costs of pest control reached a new high that year with some cotton growers spending in excess of $350 per acre for pest control. Some fields were treated as many as 20 times resulting in record levels of insecticide use. The large white fly infestations damaged cotton crops but the virus carried by the whitefly virtually ruined fall melons and severely damaged the winter lettuce crops.

It was obvious that the Imperial Valley was on what has been referred to by entomologists as the "insecticide treadmill." Use of chemicals to control one or two pests leads over time to destruction of natural prey-predator relationships which in turn lead to emergence of new crop damaging pests, which themselves require control. In addition, continuous exposure of pests to chemicals leads to development of increased tolerance in insect populations requiring greater amounts and types of chemicals.

Integrated Pest Management Practices

This experience with chemical control has led in the past 15 years to the search for alternative approaches to pest management. Adoption rates for specific IPM practices in the Imperial Valley are shown in Table 2.4. They appear to be higher than those estimated in USDA's delphi analysis (1982). Results indicated that although IPM practices have been adopted cultural controls such as specified planting, harvesting and stalk destruction dates are not widespread in Imperial Valley. These are the most controversial of the IPM recommendations among Imperial Valley growers, as the historically high cotton yields result in large part from the "top" set or "second" set of cotton bolls which is possible because of the extra long growing season. The major problems with this management practice are that:

(1) pest populations increase with each generation during the season and a longer season implies more potential damage requiring greater amounts of pesticides; greater exposure of pests to pesticides increases their tolerance and speeds the development of resistance.

Table 2.4--Rates of Adoption of Cotton Insect Control Technology, Imperial Valley, California, 1982

Technology	Percent of Growers Using Technology		USDAs Optimal Rates of Adoption[b]
	Sample[a]	USDA Delphi Estimates[b]	
Recommended cotton varieties	100	100	100
Insect traps for monitoring and recommendation	63	30	95
Field scouting and reports	88	50	90
Treatment recommendations as basis of economic threshold	n.a.	30	95
Pheromone control of pink bollworm	100[c]	--	--[d]
Biological control of heliothis complex	31	5	95
Pest and plant development prediction systems	0	0	100
Post harvest stalk destruction	n.a.	71	75
Recommended planting and harvest dates	n.a.	2	75

[a] Results of questionnaire administered to a random sample of Imperial Valley Cotton Growers. See Appendix A and B.

[b] Adopted from USDA-ERS-NRED, "Western Delphi: Insecticide Use and Lint Yields in Weevil-Free Areas of the Cotton Belt" (Washington, D.C., May 1982), included Imperial and Riverside Counties, CA, and Yuma and Mohave Counties, AZ. Table 1.

[c] 1982 mandatory pheromone program.

[d] Goals not recommended by extension because technology not yet proven. If proven effective, recommend utilization by 100 percent of growers.

(2) because a source of food is always available, insects survive to enter diapause; warm winters allow them to "overwinter" in the soil waiting to emerge the next year.[10]

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[10] There are three available methods to reduce overwintering: (1) planting a winter grain crop, (2) shredding stalks and disking them under, and (3) terminating one season's cotton crop early and planting late the following season. Enforcing an early harvest date for cotton is difficult as growers maintain they cannot grow cotton profitably without the extra-long growing season that allows the top crop to mature.

Purchasing entomological services from independent licensed pest control advisors (PCAs) on a fee per acre basis is a widespread practice among growers. About 65 percent of the Imperial Valley cotton growers sampled purchased pest control advise from "independent" pest control advisors in 1982. "Independent" is defined as having no connections, either salary, office space, or share in profits with a chemical company.[11] One out of eight cotton growers employed their own resident or "in-house" pest control managers. Approximately 19 percent continued to rely for advice on chemical company representatives or field men who might or might not have charged for their scouting services and control recommendations. Only about 3 percent of Valley growers in the sample managed their own pest control. Growers relied on outside professional advisors as their most important source of advice, although Cooperative Extension personnel, neighbors and friends continue to be important sources of information.

The vast majority of growers have assigned full control of pest management decisions to PCAs, the remainder indicating shared decision making. In addition, PCAs have assumed responsibility for compliance with pesticide regulatory laws. This includes preparation of the annual pesticide use permit, including the environmental impact report which must now be filed before restricted chemicals can be applied. Since passge of regulations in 1981

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[11] As far as could be determined, there were no direct connections between independent PCAs and chemical companies or suppliers. In only 50 percent of the cases did independent PCAs purchase chemicals for their customers. The shift toward independent PCAs as the dominant source of pest control advice appears to have taken place since Dunning (1973) reported that chemical company field men in Imperial Valley outnumbered other providers of pest advice, such as University of California Agricultural Cooperative Extension Service personnel, consulting entomologists or PCAs by 5 to 1.

requiring submission of written pesticide recommendations on all restricted chemicals prior to each application, PCAs have assumed even greater responsibility for regulatory compliance.

Pest management services were being provided by individual entrepreneurs in a highly competitive market.[12] If a PCA failed to perform, e.g., control costs or insect damage are excessive, growers switched to a PCA whom they believe would provide better services.

The range of services provided by PCAs includes monitoring of fields for pest population levels, placing traps, amd checking bolls for infestations as a basis for control decisions. At the time of the field study, pheromone or gossyplure traps were widely used (90 percent). Boll-cracking for purposes of assessing the extent of boll infestations had increased with pheromone use to 86 percent. Some PCAs also provided petiole or leaf analysis and arranged for biological controls, although most of the biological control services were provided by one source. In some cases PCAs were responsible for ordering chemicals for the growers (52 percent) and in most all cases (81 percent) arranged for their application.

Several of the PCAs have not only expanded their services beyond consulting on pest management to broader production management, but have developed increasingly sophisticated technical support for their activities. One PCA was developing computer based models for improved management. These models are designed to predict pest population levels as a basis for recommending chemical treatment or other controls. In addition, several PCAs were

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[12] Four PCAs represent 85 percent of the growers producing cotton. All had at least a Bachelor of Science degree in agricultural scineces, agronomy, or entomology. Several had Master of Science degrees.

developing the capability to evaluate the effects of water and fertilizer practices on pest populations and plant development.

Development of a Pest Abatement District

With leadership from the Agricultural Commissioner, the Colorado River Cotton Growers Association organized a pest abatement district for the Imperial Valley in December of 1981 (State of California, 1982). The district was formed recognizing that collective action was required to combat the continually increasing costs and declining effectiveness of chemical control of pests. Organophosphates and synthetic pyrethroids were losing their effectiveness and no new chemical tools were on the horizon. The program required postponement of early season use of organophosphate and synthetic pyrethroids normally employed to control pink bollworm in order to preserve populations of beneficial insects. The program relied on mandatory pheromone (autocidal) control in the early season combined with the opportunity to use controlled quantities of chlordimeform (re-registered on a one-year trial basis). Conditions were imposed to ensure safe use of chloredimeform and the costs of the program were met by a $1.50 per acre tax on cotton (*Arizona California Farm Press*, 4/10/82, p. 23).

Trends in Pest Control Technologies From Sample Growers

Trends in average pounds of active ingredient of insecticides applied per acre for cotton fields in the sample are shown in Table 2.5. Data indicate that for the period, 1978-1981, mean use levels increased for all insecticide categories; under the 1982 pest abatement district program, annual mean levels of insecticides declined. No organochlorine compounds were in use on cotton fields in the sample prior to 1981, although new products which contain small percentages of organochlorines are presently approved for use and appear after 1981.

Table 2.5--Quantities of Insecticide Used Per Acre
by Type of Material in Imperial Valley Cotton, 1978-1982

	Insecticides[a]				
Year	OC	OP	SP	CA	CH
			(# of a.i./acre)		
1978	0.0	1.87	.52	.32	.00
1979	0.0	4.39	1.04	.47	.00
1980	0.0	5.03	1.30	.08	.00
1981	1.1	10.03	1.69	.39	.00
1982	1.3	7.90	.48	.76	.906

[a] OC = organochlorines;
OP = organophosphates;
SP = synthetic pyrethroids;
CA = carbamates;
CH = chlordimeform.

Source: Pesticide Use Reports for 379 fields in the sample.

Annual mean use levels of organophosphates increased for growers in the sample by six times over initial levels in the five-year period. This masks the extremely high 1981 use rates which were 7.8 times greater. Similarly, average per acre quantities of synthetic pyrethroids increased approximately 3.25 times. As with organophosphates, the total quantity used dropped in 1982 during the pest abatement district program but rates per acre were above 1981 figures. Carbamate use among sample growers was not consistent over the period of the study. Given recent laboratory studies, it is apparent carbamates are no longer effective against tobacco budworm.

The trends in quantities of biological controls, pheromones and purchased pest management information over the period are shown in Table 2.6. Use of the microbial Bacillus thuringiensis (BT) did not increase substantially over the period. Pheromone (PHER) technology for pink bollworm control was used by a few growers in the sample prior to the mandatory collective pheromone program. Use levels during the 1982 program year were substantially above those in any other period. Purchased pest control information trended sharply upward over the period.

Table 2.6--Mean Use Levels of Less Environmentally Damaging Technology, 1978-1982

Year	Control Technology		Purchased Information
	BT	PHER	
	# of a.i./acre[a]		$ Per Acre
1978	.2137 (±.4027)	.0255 (±.0703)	10.62 (±4.66)
1979	.0529 (±.1712)	.0104 (±.0406)	13.75 _ (±2.27)
1980	.0042 (±.0291)	.0000	12.45 (±5.73)
1981	.2861 (±.6170	.031 (±.01)	15.53 (±6.22)
1982	.3792 (±1.895)	.3749 (±.3270)	18.20 (±4.61)

[a] Numbers in parenthesis are standard deviations.

BIO = Bacillus thuringiensis
PHER = Pheromones

Source: Pesticide Use Reports of Sample Growers; Survey of Sample Growers and Pest Control Advisors.

Yield, Pest Populations, and Cost Trends

Mean cotton yields per acre declined significantly over the period of study (Table 2.7). Mean heliothis virescens (tobacco budworm) populations were variable, but trended upward. At higher mean pest infestations the field data indicate that greater damage resulted as measured by cotton lint yield.

Table 2.7--Imperial Valley Mean Cotton Yields and Heliothis Populations for Sample Fields, 1978-1982

Year	Cotton Yields (# of lint/acre)	Heliothis Population (larvae/sq. ft.)
1978	1,489 (±223)	2.4
1979	1,449 (±376)	3.7
1980	1,599 (±54)	2.8
1981	1,217 (±147)	5.4
1982	1,291 (±196)	4.1[a]

[a] Projected.

Source: Sample means calculated from econometric analysis of cotton production and pest population data. Standard deviations are in parenthesis. An F test to test the null hypothesis that the sample means were equal rejected the null hypothesis at a .01 significance level where

$$F^*_{5,375} = \frac{\sum_{j=1}^{k} n_j(\bar{X}_j-\bar{Y})^2 \;/\; (k-1)}{\sum_{j=1}^{k} \sum_{i=1}^{n_j} (Y_{ij}-Y_j)^2 \;/(N-k)} = 4.34 > 3.02.$$

The intensity and costs of pest control for sample growers increased steadily in the years preceding the 1982 program. The number of organophosphate and synthetic pyrethroid applications per year trended upward over the three-year period, (Table 2.8) the mean total number of applications reaching 13.3 by 1981 and declining to 6.7 in 1982. However, as many as six applications of chlordimeform and four applications of pheromone were possible in 1982. Estimated costs of pest control per acre, based on actual insecticide use, exceeded $240 per acre in 1981. These figures are consistent with the costs reported by growers in the survey.

Table 2.8--Mean Number of Insecticide Applications for Sample Cotton Fields, Imperial Valley, 1979-1982

	1979	1980	1981	1982
		number of applications		
Organophosphate	6.3	6.0	8.2	5.4
Synthetic Pyrethroids	4.9	5.6	5.1	1.3
Total	11.2	11.6	13.3	5.7[a]

[a] Does not include 1982 application of pheromones and chlordimeform.

Value as a Laboratory

Given the Valley's long history of policies to reduce the externalities which result from pesticide use, an unusually rich base of experience and information exists. Pest problems continue to be a serious threat to cotton production in the Imperial Valley despite the years of efforts to control pesticide use and widespread adoption of integrated pest management programs. Data are available to investigate econometrically current production technology including use of the specific inputs, pest control advisors, biological controls, and pheromone use. It is also possible to examine econometrically the long-run contribution of chemical technology to development of resistance of insects thus allowing development of a measurable, intertemporal production externality. Opportunity exists to explore empirically the profitability of alternative technology and policies.

3. A DYNAMIC THEORETICAL FRAMEWORK

Economic analysis of agricultural production must employ models that accurately reflect the underlying physical and biological processes that constitute agricultural production. Since these processes take place over time, models must be appropriately dynamic. In order to manage these processes, technologies such as chemical pest control have been developed that introduce externalities with certain characteristics. Externalities, or negative side-effects result largely from some subset of the productive factors employed in a particular technology. They are the unpriced, unintended products from adoption of a particular production technology. Externalities in agriculture are frequently collectively produced resulting from the combined but unidentifiable actions of producers taking on the character of a common property and result in nonpoint pollution problems. Further, the substitution possibilities between the intended output (higher yield resulting from limiting pest infestations) and unintended output (development of resistance in the harmful species and reduction in natural predator populations) are neither fixed or unlimited. Economic production models must, therefore, be not only multi-input but multi-product to reflect the production of the primary agricultural output and the externality. If externalities are to be

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[1] Production externalities so defined are a much more specific concept than Pigou's (1932) traditional definition of production externalities as "incidental disservice" to others from economic activity such that technical considerations prevent compensation to the original parties, or that offered by Buchannan and Stubblebine (1962) and Henderson and Quandt (1971) which defines an externality as occurring any time a decision variable of one agent enters into that of another. It is closer to, but more explicit than, de V. Graff's producer-producer externality resulting from the choice of profit maximizing input or output levels (1957).

incorporated, andy economic model for agricultural production analysis must incorporate welfare implications of technology rather than confine the analysis to private returns.

In this section, a dynamic model of joint production with intertemporal collective externalities is developed for a single crop, cotton, and a single externality, pesticide resistance. The model can, however, be generalized to multicrop-multiexternality production systems. The production specification includes all feasible pest control inputs and allows for tradeoffs between pesticides, integrated pest management practices and externality levels. A conditional probability model used by biological scientists is used to model resistance and how it changes over time incorporating production uncertainty directly.

The dynamic model maximizes producers' surplus subject to the dynamic production system. The costs of resistance or a user cost based on pesticides'contribution to resistance is included as a tax on pesticide use. The approach results in socially efficient production yet retains the benefits of decentralized decision making consistent with present economic institutions. Uncertainty in the dynamic model is incorporated by embedding a probability model in the discrete dynamic optimization model.

Modelling Pesticide Resistance

Resistance is collectively produced because no one producer and no one application of pesticides alters the genetics of pest populations.
Biologically, the development of resistance is determined by the initial frequency of the resistant gene in the population and by the relative survival rates in each generation of susceptible (no genetic resistance), heterozygous

(recessive genetic resistance), and homozygous (dominant genetic resistance) insects.

Each pesticide application reduces the number of susceptible pests P(t) in a population at any given time and "selects" for resistant genes in the population. As these survivors reproduce, the relative number of resistant genes in the population [1 - P(t)] increases. The proportion of resistant insects is measured by the "selection factor," the ratio $(1 - P_t)/P_t$ of resistant survivors to susceptible survivors. The Hardy-Weinberg ratio (Smith, 1968) of resistant to susceptible genes from one period to the next can be represented by a first order difference equation,

$$(3\text{-}1) \qquad \frac{\frac{d(1-P_t)}{P_t}}{dt} = R_{t+1}-R_t$$

The relationship between pest mortality and pesticide use is represented by a dose-response relationship, or pesticide "kill function" (Figure 3.1) which research indicates increases monotonically and is sigmoidally shaped initiated at zero and approaching one (100 percent mortality) as pesticide use is increased. As a larger proportion of insects develop genetic protection against chemical action, their tolerance to previously lethal doses increases. The tolerance distribution (selection factor) shifts to the right and the variance of the distribution increases. The dose mortality curve shifts downward implying that the proportion of survivors increases or higher doses are required at all levels of pest mortality as in Figure 3.2. The degree of resistance in a population is measured by biologists as the ratio of median lethal dose (LD_{50}) for resistant and susceptible insects (Trevan, 1927).

Figure 3.1 Selection Factor and Pesticide Use

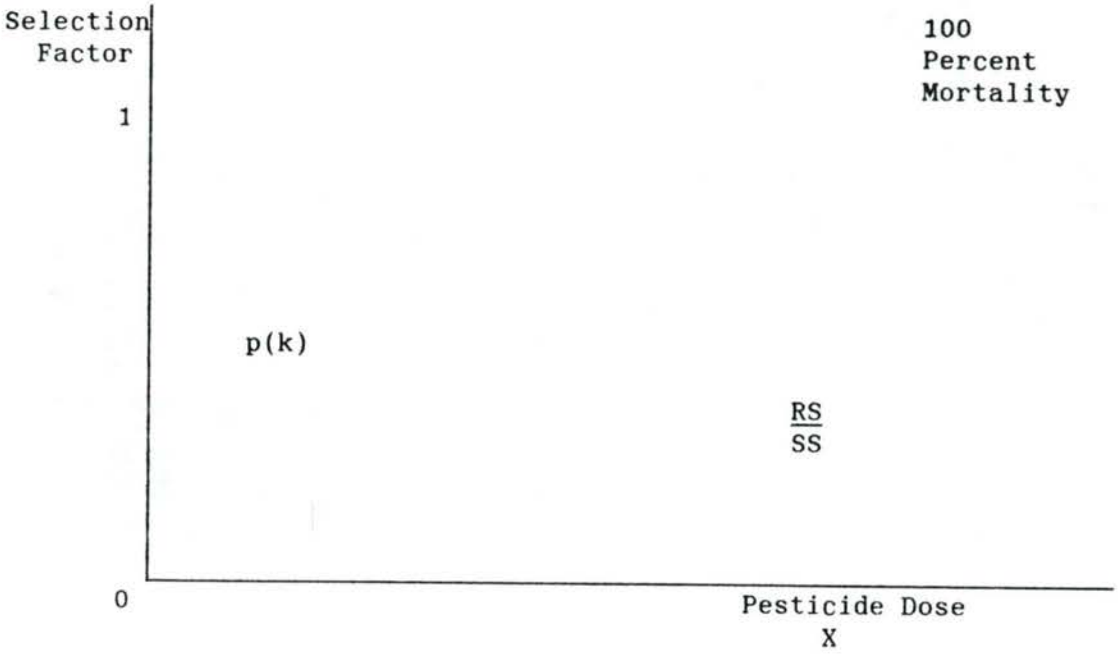
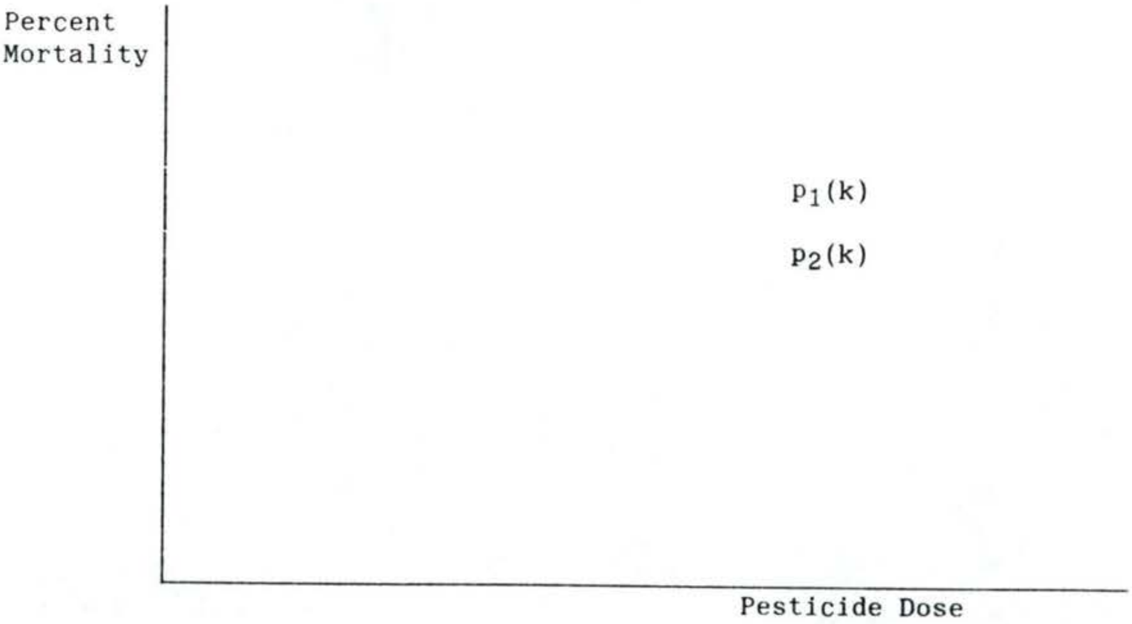


Figure 3.2 Shift in Dose-Mortality Curve Due to Resistance



The relationship between pest mortality and pesticide dose can only be determined in a probabilistic sense as not all pests are susceptible to equivalent doses of pesticide and use cannot be exactly controlled. The susceptibility of individual insects varies among insects and is influenced by such factors as age, size, weather, and genetic composition (FAO, 1980). Susceptibility varies, but when there are many different factors, the central limit theorem can be invoked and the tolerance of individual pests can be assumed to follow a normal probability density function. Research indicates that tolerance of individual insects in large populations is approximately normally distributed (Finney, 1964).[1]

Assuming that individual tolerances follow the normal probability density function, the area under the normal density function

$$P(k) = \int_{-\infty}^{b} \frac{1}{\sigma\sqrt{2\pi}} \exp - (Y-\mu)^2/2\ \sigma^2\ dy \tag{3-2}$$

provides the cumulative probability from negative infinity up to any point on the abscissa. From it, the probability of an insect being killed from a given amount of pesticide can be calculated. The cumulative normal distribution function accurately represents dose-mortality functions. If X > 0, the desirable properties of dose-mortality functions are met by the cumulative normal distribution function:

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[1] The Sech distribution has been used to represent tolerance distributions. Talpaz and Borosh (1974) and Moffitt and Farnsworth (1981) have represented toleranced by a Weibull density function leading to a logistic representation of dose-response. However, entomologists continue to represent dose-mortality relationships by the cumulative normal distribution function.

(i) $P(k) = 0 \text{ if } X = 0$

(ii) $\lim_{X \to \infty} p(k) \to 1$

(iii) $\frac{\partial p(k)}{\partial X} > 0$

(iv) $\frac{\partial^2 p(k)}{\partial X^2} > 0$

If the observed mortality p(k) is assumed to be a normally distributed random variable, the probability that the observed kill $p(k) \leq P(k)$ can be approximated by the cumulative normal probability function. Integration of the cumulative normal distribution function gives

$$p(k) = F(Z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z_i} e \frac{-s^2}{2} ds$$

or the probability of insects being killed by a given control level or pesticide dose. The probit transformation transforms these observed probabilities to normal standard deviates $Z \sim N(0,1)$ by applying the inverse of the cumulative normal distribution function to observed probabilities $F^{-1}(p_i) = Z_i$. This assures that predicted probabilities fall within a [0,1] interval and also allows observed probabilities to be expressed linearly in terms of the dosage of the pesticide. Observed probabilities can then be fit by regression techniques to doses of pesticide (Brown, 1971). The regression coefficient β tells how the probability of being killed changes with a change in dose providing the conditional probability of survival given a pesticide dose. It measures the state of pesticide effectiveness.

"Selection pressure" is a result of the amount (and frequency) with which insects are exposed to chemical pesticides. The more widespread the use, the more frequent the exposure and the larger the amounts, the greater the selection pressure (Brown, 1964). The degree to which integrated pest management practices are substituted for chemical control reduces the rate of resistance development. Since chemical compounds affect pests by attacking different biological mechanisms, mortality rates and resistance development proceed at varying rates and the pest control vector X must be disaggregated by major chemical type. Thus $X = [X_1, X_2, \ldots, X_k]$ is a vector of pesticide inputs and V_1 a vector of integrated pest management inputs.

The change in resistant populations is:

$$R(t-1) - R(t) = f(R_t, \sum_{i=1}^{N} X_{it}, \sum_{i=1}^{N} V_t) \tag{3-4}$$

with properties

$$\text{(i)} \quad \frac{\partial f(R_t, \sum_{i=1}^{N} X_{it}, \sum_{i=1}^{N} V_{it})}{\partial \sum_{i=1}^{N} X} > 0$$

$$\text{(ii)} \quad \frac{\partial f(R_t, \sum_{i=1}^{N} X_{it}, \sum_{i=1}^{N} V_{it})}{\partial R_t} > 0$$

$$\text{(iii)} \quad \frac{\partial f(R_t, \sum_{i=1}^{N} X_{it}, \sum_{i=1}^{N} V_{it})}{\partial \sum_{i=1}^{N} V_t} \leq 0$$

$$\text{(iv)} \quad f(R_t, 0, 0) = 0$$

$$\text{(v)} \quad \frac{\dfrac{\partial f(R_t,\ \sum_{i=1}^{N} X_{it},\ \sum_{i=1}^{N} V_{it})}{\partial \sum_{j=1}^{N} X}}{\dfrac{\partial f(R_t,\ \sum_{i=1}^{N} X_{it},\ \sum_{i=1}^{N} V_{it})}{\partial \sum_{i=1}^{N} V_{it}}} < 0$$

The function f relates pesticide use to the development of resistance. Assumption (i) and (ii) assume resistance is nondecreasing in pesticide use X, and the current stock of resistance R_t. (iii) assumes that it is nonincreasing in V. If no pesticide is applied there is no change in the level of resistance (iv). Assumption (v) implies environmentally enhancing inputs are technical substitues for pesticides in the development of resistance. These assumptions together imply that the more pesticides used by producers in a region the faster the development of resistance and that the rate of change in resistance development can be altered by employing integrated pest management, specifically through employing labor--allocating management time--to monitor pest populations by setting gossyplure traps, field checking pest infestation levels, and cracking bolls.

A Dynamic Production System Incorporating Pesticide Resistance in Cotton Production

As resistance develops, the effectiveness of pesticides in production decreases, and the proportion of insects that survive increases. Survivors enter the production function negatively affecting cotton output. Cotton output is thus determined by

$$\text{(i)} \quad \frac{\partial f(Y_{i,t-1}, R_t, X_{it}, V_{it})}{\partial X_{it}} > 0$$

$$\text{(ii)} \quad \frac{\partial f(Y_{i,t-1}, R_t, X_{it}, V_{it})}{\partial V_{it}} > 0$$

and

$$\text{(iii)} \quad \frac{\partial^2 f_1(Y_{i,t-1}, R_t, X_{it}, V_{it})}{\partial X_{it}^2} < 0$$

$$\text{(iv)} \quad \frac{\partial^2 f_1(Y_{i,t-1}, R_t, X_{it}, V_{it})}{\partial V_{it}} < 0$$

with respect to the effect of last year's output on X_{it},

$$\text{(v)} \quad \frac{\partial f(Y_{i,t-1}, R_t, X_{it}, V_{it})}{\partial Y_{it}} \begin{smallmatrix}<\\=\\>\end{smallmatrix} 0$$

depending on the dynamics of the particular crop.[2]

Output decreases with positive levels of negative externality, R_t _ceteris paribis_

$$\text{(vi)} \quad \frac{\partial f(Y^{C}_{i,t-1}, R_t, X_{it}, V_{it})}{\partial R_t} < 0$$

Resistance then is clearly a nonoptional collectively consumed externality because producers cannot exclude the resistant populations from their production functions; the level of externality received by each firm is the same. Because of the negative relationship between pests and yields, resistance can be considered a collective "bad."

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[2] For cotton output it is assumed $Y_{t-1} = 0$, thus $\partial f(\cdot)/\partial Y_{t-1} = 0$.

Modeling Joint Production

Production externalities most often result from use of one or more specific inputs, such as pesticides or fertilizers. This has been noted in the earlier research by Langham, Headley, and Edwards (1972) which addressed externalities caused by agricultural pesticides in the Florida fruit and vegetable sector. These "externality-generating" inputs have the characteristics of joint inputs, as any positive quantity simultaneously or "jointly" produces the intended agricultural output and the unintended externality.[3] Technically, they are not separable into the amount that is used to produce the agricultural output and the amount used to produce the externality. For example, the quantity of pesticides used to produce cotton is also the quantity available to produce pesticide resistance. Nor in many cases can these inputs be reallocated away from production of the externality to the production of planned output, as in a normal multiproduct production problem. However, it is often technically feasible to substitute inputs or introduce new production processes or inputs (abatement technology) to reduce the level of the externality without reducing the level of planned output. For example, labor can be allocated to monitor pest population levels to better time pesticide applications, reducing the quantity of pesticide input and thus reducing externalities.

The standard single-output or output index framework that assumes separability of inputs and outputs and no joint production is clearly inappropriate to model production externalities. Although joint production specifications in which externalities result from technical interdependencies have been employed in externality analysis (Baumol and Oates, 1975) they are inadequate to capture the complexities of externality generation from agricultural pro-

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[3] The jointness of inputs was first noted by Meade (1952).

duction. This type of analysis has often assumed strict joint production relations, i.e., the externality is produced in fixed proportion with the crop output (Bator, 1958; Buchanan and Stubblebine, 1962; Baumol and Oates, 1975). It assumes the level of damages has a direct relationship to the quantity of agricultural production. It does not allow for the technical possibilities for abatement of negative externalities through rearrangement of productive inputs, and provides too little flexibility to describe accurately many externalities from production.

Multiproduct production specifications, on the other hand, can provide too much flexibility to be useful in analyzing externality production. Such formulations imply possibilities for tradeoffs between intended agricultural output and externality output that do not exist. For example, in the multiproduct model of production it is possible, given a fixed amount of inputs, to vary inversely the quantities of the two outputs produced. However, agricultural producers cannot allocate more of the joint input to the production of output and less to the production of the externality.

Generalized Joint Production

Generalized joint production allows an appropriate degree of flexibility and can be applied to modeling externality production. This framework, first developed by Carlson (1939), allows for joint inputs and the possibility of varying the proportion of intended agricultural output to externality output. Theoretical models employing generalized joint production have been applied to externality analysis (Buchanan, 1966; Whitcomb, 1972).[4] Whitcomb (1972) employed generalized joint production to model the supply of externalities in the static case. For example, this production model can be written in implicit form as

$$F_1(Y,R,V_1,X) = 0$$

$$F_2(R,V_2,X) = 0$$

where Y is a vector of agricultural outputs, R is the externality, and F_1 and F_2 are their respective implicit production functions. R is a vector of externalities received by the firm which enters negatively into the production of output Y. V_1 is a vector of ordinary or nonexternality-generating inputs allocated to the production of output Y, and V_2 is the quantity of these inputs allocated to the abatement of externality R. X is the vector of joint inputs contributing simultaneously to agricultural output and the externality, the same quantity appearing in both equations.

With this formulation, it is possible to reduce the level of externality production and increase the intended output by diverting externality-generating inputs. Sudit and Whitcomb (1976) show that in the translog case the rate of transfromation between Y and R depends upon variable inputs X and V_1. Assuming substitution possibilities or the existence of abatement technology, the quantity of externality outputs in the system can be reduced by reallocating nonjoint inputs, thus avoiding negative output effects implicit in other production models. Externality levels are not proportional to agricultural output levels but are a function of the production technology employed.

A Dynamic Economic Model for Determining Optimal Pest Control Strategies for Cotton

When production generates output and/or externalities over more than a single time period as in agriculture, these dynamic effects must be incorporated to determine efficient intertemporal resource use. If the objective is to use resources in a socially efficient manner, the economic problem in the presence of externalities becomes one of selecting the technology that optimizes welfare over the planning period subject to the dynamic production system. Factors will be allocated so that current production decisions account for the total cost (private costs plus user cost) of production over the planning period, and the result will be socially efficient. If prices are exogenous and externalities are those that affect only producers, joint profit maximization results in a Pareto-efficient allocation of resources.

Resistance results from collective pesticide use by growers in a region, over time. Hueth and Regev (1974) likened the development of pesticide resistance to overuse of a common property resource where the "biological captial", the stock variable, is total genetic susceptibility of the pest species, susceptibility being the inverse of resistance. If resistance is recognized, optimal application of pesticides includes simultaneous management of the pest (reducing current economic damage) and the associated effect on the biological stock which affects future profits because of increasing damage and declining effectiveness of pesticides.

Individual decision makers will, however, ignore the dynamics of production decisions when a collective production externality exists. They are myopic about their ability to influence pest populations on their own fields in future periods because of the common property aspects of pests, so no incentive exists to consider future effects. The producer knows that using pesticides to reduce pest populations on his own fields will reduce damage in period t. The economic incentive is to use pesticides in the current period to the point where marginal value product of reducing pests equals marginal cost of control (Headley, 1972). This myopic economic threshold is affected by prices of crops, and control input prices but does not consider the contribution of current actions to resistance (or to the decline in the stock of pesticide effectiveness). Socially optimal choice of pesticide in year t should consider not only current benefits from production but the effects of collective production on the stock of resistance in future periods. If the future value of the resource is positive (negative) but is valued at zero by the market in the current period, an intertemporal externality will result.

Building on generalized joint production concepts, an intertemporal model of production that incorporates the technical relationships between input use and externality production for the class of collective producer/producer externalities is modeled as a simultaneous production system incorporating time directly. When this system is used as the constraint set in a dynamic economic optimization problem, output affects technical change, and intertemporal effects of various policies on producer welfare can be investigated.

Cotton output and resistance development are modeled as the following production system

$$(3\text{-}6)\qquad \begin{aligned} Y_i^c(t) &= f[Y_i(t-1),\ X_i(t),\ V_i^c(t), R(t)] \\ R(t) &= f^r[R(t-1),\ \sum_{i=1}^{n} X_i(t),\ \sum_{i=1}^{n} V_i^r(t)]. \end{aligned}$$

In this model, f^c is the i^{th} firm's production function for cotton output and f^r is the externality production function for resistance. $Y_i(t)$ is the quantity of cotton output in time t from firm i, a function of previous period $Y_i(t-1)$, a vector of environmentally "neutral" or ordinary inputs V_i^c allocated to agricultural production, and a vector of joint or externality-producing inputs X_i. Resistance R(t) enters into production directly and its production depends upon the previous period's externality level R(t-1), the level of the joint or externality-producing inputs X(t) used in the production of intended output, and the quantity of inputs $V^r(t)$ allocated to abate the externality. Here the externality is collectively produced by all firms and is thus a function of the combined use over all producers of the externality-generating and abatement inputs.

The results of the production system serve as constraints on the optimization. Control, or decisions on production input levels, consists of pest control strategies employing combinations of chemical insecticides, $X_i(t)$, and IPM inputs, $V_i(t)$. Each strategy reflects a combination of organophosphate, synthetic pyrethroid, pest scouting and monitoring, and biological controls (pheromones), and reflects the technical substitution possibilities that were observed in the sample.

The state or output variables in the dynamic model are the externality output, insect resistance R(t), measured as those insects surviving control and entering negatively into cotton production; and cotton output $Y^c(t)$, measured as pounds of cotton lint. There are 100 possible discrete states of insecticide effectiveness which were calculated from the probit model.

Just and coauthors (1982) demonstrate that producer surplus adequately represents welfare from production under a producer-producer externality if information on costs and benefits are available. The production function and the externality function provide this information. Thus, the objective function maximizes discounted producer surplus over the planning period.

The dynamic model also incorporates uncertainty associated with the pest control technology. At each period t, production depends on the realization of a random variable--the probability of insects surviving a given control strategy--that affects current period returns. To caputre this uncertainty, the probit model is embedded in the dynamic programming model such that in each period, the entire probability distribution of net revenues is calculated.

The discrete-time stochastic dynamic programming problem is then composed of system dynamics,

$$R(t+1) = f[R(t),U(t)],$$

the rate at which resistance changes for a given pest control strategy, where $U(t) = [X(t),V(t)]$; an initial condition, $R(0) = R_0$; the control constraints $U(t) \epsilon U$, where U represents the nine control strategies; the terminal value function, $\tau(T)$, which for this problem represents the "user cost" or externality tax on insecticide use evaluated in terms of the value of lost yields from pesticide resistance resulting from a given pest control strategy summed over the planning period; and the objective function

$$(3\text{-}7) \qquad J^* = \sum_{t=0}^{T-1} \beta_t (\sum_{i=0}^{1} p_i r[R(t),Y^c(t),U(t)]) + \tau(T).$$

The objective function is composed of two terms. The first represents the discounted value of the probability distribution of net revenues; the second is the externality tax on insecticide use. In equation (3-7), p_i denotes the probability of insects surviving the given control strategy, $U(t)$; and $r[\cdot]$ denotes the Hicksian producer surplus measure. The rate of change in resistance is governed by the conditional probability model. The producer observes the externality state $R(t)$, selects a control strategy $U(t)$ which results in a cotton output level or state $Y^c(t)$ and causes a transition to state R(t+1). The transition to R(t+1) captures the dependency of the current state of resistance on both the previous resistance state and past control decisions.

J* represents the net value of production in time t measured in terms of discounted net revenues including the effects of current production on future welfare. At the social optimum, pest control inputs must be chosen such that current benefits from production equal the value of pesticides in future production of cotton, and consider the contriubtioin of that pesticide to the development of the externality. Social efficiency is thus assured.

In a static private solution, the producer does not recognize the contribution externality-generating inputs make to future returns or development of the collective externality. Even with perfect foresight in which producers recognize the effects of pesticide use on future output, the terminal value $\tau(T)$ would be zero. Even though individual producers know that they contribute to the development of the collective externality, $\tau(T)$ would be ignored because of the free rider problem.

Inducing Socially Efficient Pest Control Technology

Joint profit maximization or decision making by a sole owner takes into account collective intertemporal externalities. White it is a theoretically valid internalization scheme, centralized production decisions are at variance with the existing private ownership of resources and individual decision making fundamental to our current economic institutions. Thus practical alternatives which retain decentralized production decisions, such as taxes and subsidies, should be considered, although Pigouvian taxes and subsidies have not been widely applied due to the inherent difficulty in setting optimal levels.

An Optimal Tax Approach

Appropriate Pigouvian taxes and subsidies may be defined for the region to achieve the centralized solution with decentralized decision making. Hueth and Regev (1974) suggested that the user cost serve as the optimal tax as it does represent foregone benefits from current use. Applied to externality output, it could achieve optimal outputs yet allow for decentralized decision making. However, an ex ante tax equivalent to the cost of employing externality-generating inputs could be placed on the inputs to achieve socially optimal resource use. In the case of stochastic nonpoint problems, such tax on production technology is preferred (Just, Hueth, and Schmitz, 1982). A tax on inputs is consistent with the notion that production externalities are generated from the cumulative use of a specific input whose market price reflects its marginal value product (MVP) in production of planned output but does not include its negative effects. It avoids the assumption of identical marginal costs and benefits inherent in other schemes.

The necessary information for such a tax based on the negative contribution of the input to the production of the externality can be obtained from the production system and included in the optimization problem. The imputed cost of collective use of the externality-generating input can be determined by centralized information on total pesticide use and an estimate of the aggregate (regional) damage function. If a tax t* equal to the user cost is placed on externality-generating inputs, each producer would face input price $v_X' = v_X + t^*$ and, through individual production decisions, equate MVP to the price of the input which has been adjusted by policy to reflect total costs of use over time. Given the assumption that each unit of input contributes equally to externality production, the tax could be constant per unit of pesticide input for all users. Therefore, individual assessments could be avoided. Optimal subsidies to encourage use of nonexternality-generating inputs can likewise be determined from production information. In the short-run, substitution between externality and nonexternality inputs would be expected. In the long-run, consistent with the induced innovation hypothesis, such relative price changes should result in development of more socially efficient technology.

The productivity effects and implications for technical change of alternative environmental policies can be assessed from the dynamic model. Time rates of change in the value of the optimal objective function $J^*(t) - J^*(t-1)$ can be considered a dynamic analogaue to the rate of change in total factor productivity (measured as gains or losses in producer surplus) achieved under alternative policies. This measure is net of externalities and incorporates changes in input quality due to regulation or decay of the resource stock. Alternatively, changes in output levels for the crop $Y^{*C}(t) - Y^{*C}(t-1)$ and the externality $R^*(t) - R^*(t-1)$ can be used to assess productivity under different policy options. The optimal paths of the externality-generating inputs, $X^*(t) - X^*(t-1)$, relative to the optimal path of nonexternality inputs, $V^*(t) - V^*(t-1)$, provide information about the bias in technical change, from which the effects of regulatory policy on the bias can be assessed.

4. EMPIRICAL ANALYSIS

The dynamic production system developed in Chapter 3 was estimated econometrically investigating the development of resistance of <u>Heliothis virescens</u> (tobacco budworm) as the collective, intertemporal externality from pesticide use in Imperial Valley, California cotton production. A two-stage estimation process was used in the empirical analysis. First, the production system in equation (3-6) was estimated recursively and, second, the empirical estimates were used as constraints in the dynamic optimization model in equation (3-7).[1] Conditional probabilities of pesticide effectiveness and changes over time were estimated from a time series of pesticide and pest population data using GLS estimation of a probit model. Coefficients for pest damage, alternative pest management technologies and selected physical and management factors were obtained from production analysis. The econometric estimates of the production system were used as constraints in a discrete time dynamic programming model to determine the pest control input combinations that maximize the probability distribution of discounted producer's welfare over the planning period incorporating resistance. The probit model captures state uncertainty at any time t, and is used to specify state transitions dependent upon prior states and controls. User's costs are estimated from the empirical results and incorporated through the terminal value

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[1] Simultaneous solution of the production system determines output levels by allocating given constrained amounts of productive inputs. Systems estimating procedures estimate all the identified structural equations as a set. In cases of unidirectional dependency among the endogenous variables, the system may be estimated recursively (see Theil, 1971).

function. The programming model was solved for a ten-year period using a brute force search and a recursive fixing, or backward solution, approach.

Data Base

The data for econometric estimation of the production system were obtained from a stratified random sample of cotton producers in the Imperial Valley (Appendix A). Time series data covering the five-year period 1978-1982 on actual pesticide use, pest management practices, cotton lint yields, water use and other production inputs were obtained for each grower in the sample. A survey instrument administered through personal interviews (Appendix B) provided information on cotton production technology.[2] Insect population data used to estimate the pesticide resistance function were gathered by the Division of Economic Entomology, University of California, Riverside as part of its ongoing research efforts; data consisted of weekly field samples of pests and beneficial insects collected over the period 1978-1981.

Resistance in *Heliothis virescens*

The tobacco budworm (*Heliothis virescens*) is a key cotton pest in the United States. It was first discovered in the Imperial Valley in 1972 (Sharma *et al*., 1977) and has been identified by growers as the most serious cotton pest problem in the Valley.

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[2] Cotton yields for each field were obtained from U.S. Agricultural Stabilization and Conservation Service records in Imperial County; irrigation data for each field were obtained from the Imperial Valley Irrigation District. Imperial County Pesticide Use Reports provide data on actual materials and quantities applied to each field. Integrated pest management practices were obtained by personal interview with the Pest Management Advisors employed by the growers in the sample.

Tobacco budworm is a secondary pest resulting from control of primary cotton pests.[3] Early season use of chemicals to control pink bollworm populations decimates predators of the tobacco budworm, requiring chemical control to reduce tobacco budworm damage. Thus, integrated pest management (IPM) practices (pheromones or improved field scouting) that reduce early season chemical use maintaining beneficials are key to control of tobacco budworm insects. This insect is interesting for empirical estimation of resistance development because of the speed with which resistance to chemical control develops. Each generation of tobacco budworm has five instars, or stages of development, and the duration of each instar is temperature dependent. In the desert climate, each instar has a duration of approximately two to three days resulting in as many as five generations of tobacco budworm per cotton cycle. The warm, often frost-free winters allow pupae to overwinter, further speeding the development of resistance as these resistant insects enter the gene pool the following year.

Tobacco budworm has shown laboratory resistance to many chemical compounds, including organophosphates in most cotton growing regions (Adkisson and Brown, 1968; Lentz _et_ _al_., 1974; Plapp, 1971). The strain of budworm that reached the Imperial Valley was already highly tolerant. Research has not, however, statistically estimated the loss of effectiveness of pesticides due to development of resistance in the field. Further, despite evident economic

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[3] Secondary pests, in contrast to primary pests, are those normally under adequate control by biological or environmental factors, but which require control if natural predators are destroyed through control measures aimed at primary pests. Entomologists believe the only two primary cotton pests in the California desert areas are the pink bollworm and lygus.

losses attributed to tobacco budworm, a significant correlation between tobacco budworm populations and yield loss (Townsend, Van den Bosch, et al., 1975) has yet to be demonstrated. Since tobacco budworm destroys the fruit, thus directly affecting quantity of product rather than quality of the product, it is possible to estimate damage from tobacco budworm.

Resistance in Field Insect Populations

Empirically a population may be judged to have become resistant to a particular pesticide when: (1) a perceived change in mortalities has been confirmed by some set test in which it is compared to populations from untreated areas or to normal laboratory colonies; and (2) when in the field it has come to resist control by the insecticide currently employed (FAO, 1980). A population that is significantly less susceptible by laboratory test, but is nevertheless still controlled by that insecticide in the field is best described as "tolerant" to control measures. Increasing tolerance in the field directly implies decreased pesticide effectiveness and is indicative of developing resistance (Leigh et al., 1961).

The effectiveness of a material is characterized by its median effective dose or LD_{50} (Trevan, 1927). Tolerance to a given dose or loss of effectiveness is evident if increased dosages are required each year to obtain a 50 percent kill. LD_{50}s are estimated from the parameters of pesticide dose-response or kill function; the slope represents the amount by which the probability of mortality is increased for every unit of chemical dosage. By process of inverse prediction, estimates of the value of the dosage X corresponding to a kill probability of 50 percent are determined. Changes in effectiveness can be measured by slope shifters implying changes in the probability of surviving a given pesticide dose. These changes approximate the transition from one state of pesticide effectiveness to another.

Probit Model Specification

Under the assumption that the proportion of insects susceptible to pesticides follows the standard normal cumulative density function, the probit transformation can be used to obtain

$$F^{-1}(p_i) = F^{-1}(P_i) + e_i/Z(P_i) = X'B + e_i/Z(P_i)$$

where F^{-1} is the inverse of the normal CDF, thus $F^{-1}(p_i)$ and $F^{-1}(P_i)$ are the observed and true "probits", respectively; $Z(P_i)$ is the value of the standard normal density evaluated at P_i; and X a regressor vector (see Zellner and Lee, 1965).

Sample proportions can be used as observed probabilities if decision makers face only two alternatives, death or survival, and enough responses per experimental setting are available (Judge and Griffiths *et al.*, 1980). Repeated observations for each value of the explanatory variable are available in this study, thus the sample proportion $p_i = r_i/n_i$ is used as an estimate of the observed probability of death for each group of identical individuals receiving pesticide dose X_i.[4]

The estimating equation becomes:

$$F^{-1}(p_i) = B_0 + B_1CB_i + B_2OP_i + B_3SP_i + B_4DD_i + n_180CB_i + n_281CB_i + n_380OP_i + n_481OP_i + n_580SP_i + n_681SP_i \quad (4\text{-}1)$$

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[4] n_i should be at least five and observed probabilities should not concentrate at either 0,1 values as error variances grow large, guaranteeing inaccurate parameter estimates.

where the dependent variable is the transformed sample proportions P_i where p_i is the proportion of tobacco budworm larvae killed. Independent variables are the four major insecticide classes: organochlorines (OC) carbamates (CB), organophosphates (OP), and synthetic pyrethroids (SP) measured in dry pounds of active ingredients.[5] A weather variable defined as cumulative degree days (DD) is included at each observation, since both insects and insecticides are temperature sensitive.[6] Slope dummies were included to determine shifts in the slope of the dose-mortality curve over time approximating the time rate of change in pesticide effectiveness. From these coefficients, LD_{50}s can be calculated and changes used to measure changes in resistance. Data on pest populations were weekly observations on tobacco budworm larvae for 179 fields in Imperial Valley; temperature data are from the same source. Pesticide quantities applied to each field were obtained from county pesticide use records.

Calculating Observed Probabilities

Weekly tobacco budworm larvae population counts, starting from about the 219 Julian day to the end of the cotton season, were obtained through DVAC suction sampling methods, over the four-year period for a subset of cotton

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[5] Pesticidee use data indicated that organochlorine compounds were used at very low levels by only a few producers. Regressions including them as an explanatory variable showed none to be significant. Pheromones were not included because they are specific to pink bollworm; sulfur was excluded for a similar reason. Chlordimeform was only used in 1982 for which pest population counts were not available.

[6] A degree day is the number of 24-hour periods during which the temperature is above 70°F.

fields in the sample.[7] $P_i = r_i/n_i$, the proportion of tobacco budworm larvae killed was calculated from pest population and pesticide use data where r_i was the number of tobacco budworm larvae killed by the spray and n_i the initial population level observed.[8]

Pesticide Use Data

Sample proportions were regressed against dry pounds of active ingredients of actual chemicals applied per acre aggregated by major insecticide class. Actual amounts of all pesticides applied to sample fields were obtained from use records of the county Agricultural Commissioner. Pesticides were classified into broad categories: insecticides, herbicides (and defoliants), productivity aids (chemical adjuvants), plant growth regulators, soil fumigants, nutrients, and miscellaneous.[9] For the probit analysis,

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[7] Each field was divided into four quadrants with 25 random vacuums taken in each quadrant for each weekly sample; the number of larvae reported out of 100 DVAC vacuums is approximately equivalent to the number of larvae per square foot in an acre. The DVAC collects all larval sizes, thus the assumption is that these pest populatiion counts adequately represent all sizes and ages.

[8] To calculate the sample proportion of pests killed by a given pesticide application, the date of the first population count C_1 initiated a search over pesticide records for that field for the control or spray day (CD) greater than C_1. Given, pest population records were searched to obtain C_2, the number of larvae surviving the pesticide application. The decision rule used, based on personal communication with Dr. Vahram Sevecherian was that the window between the initial count C_1 and control action CD and between CD and C_2 should not exceed four Julian days, implying $(C_1\text{-CD}) \leq 4$ and $(C_2\text{-CD}) \leq 4$. Then $r_i = (C_1 - C_2)$ and $n_i = C_1$.

[9] All trade names were cross checked with State registration codes and labels to assure proper classification. Data were surprisingly accurate. In a total of over 10,000 records of individual materials applied less than 1 percent were rejected. However, extensive editing was required on about 10 percent to obtain an accurate record.

insecticides only were used as explanatory variables. Insecticides were aggregated by major chemical class as different chemical compounds induce death by alternative mechanisms making resistance specific. Insecticides used in the anaysis are shown in Table 4.1.

Table 4.1--Description of Insecticide Categories

(1) Organochlorines (OC):	Chlorinated hydrocarbons are a persistent (stable) class of chemicals not easily broken down in the environment or by man's biological processes. They affect neurons blocking transmission of nerve impulses leading to death. DDT, the most well-known and widely used organoclorine, is highly effective as a pesticide, and very inexpensive but was banned by regulatory policy in 1973. Dicofol is another OC still in use.
(2) Organophosphates (OP):	Derived from phosphoric acid, they are chemically unstable and less persistent chemicals that have replaced organochlorines, largely as a result of regulatory policy aimed at reducing persistent chemicals in the environment. As a class, they are more acutely toxic to vertebrates than organochlorines. They work by inhibiting enzymes needed by the nervous system (cholinesterase inhibitor) leading to paralysis and death.
(3) Carbamates (CB):	Derived from carbamic acid, are similar to organophosphates in that they are cholinesterase inhibitors. They were designed to replace organophosphates in cases of OP resistance but are more costly and provide effective control for only a narrow spectrum of insects.
(4) Formamidines (CL):	Chlordimeform is the most widely known formamidine compound. It is relatively new and valuable in control of organophosphate and carbamate resistant pests because it inhibits the enzyme (monoamine oxidase) whose action is not well understood but toxic to mammals. In 1976 it was removed from use by the manufacturer because of indications of cancer in laboratory mice. It was restored in 1978 for use on cotton. In California, its use is permitted only under exceptional circumstances.

Table 4.1 (continued)

(5) Synthetic Pyrethroids (SP):	Natural pyrethrins are an insecticide derived from plants. Synthetic pyrethrin-line materials are the newest insecticide available and are valued for their fast action and relatively low toxicity to mammals although the control mechanism remains unknown. SPs are usually used in combination with synthetic organic compounds as use alone can lead to quick resurgence. SPs are relatively expensive but effective at low doses, are not environmentally persistent, and meet regulatory standards on toxicity.
(6) Microbials:	Insect-disease causing bacteria whose action and effect on humans are not yet known. They are slow acting, taking several days to bring about control.
(7) Biological Controls:	Use of natural predators, parasites or pathogens to reduce pest populations. The tricograma wasp is a natural predator of the tobacco budworm bred commercially and purchased as a pest control input. Biological controls are considered important tools in integrated pest management strategies.
(8) Pheromones:	Highly potent sex attractants produced by insects, some of which have been synthesized and used to confuse mating and reduce pest population growth.

Estimation Techniques

OLS estimates of the probit model correspond to heteroskedastic regressions of X on observed kill rates. Since

$$\mathrm{Var}[e_i/Z(P_i)] = \frac{P_i(1-P_i)}{n_i[Z(P_i)]^2}$$

the generalized least squares (GLS) estimator provides efficient estimates of β:

$$\beta = (X'\phi^{-1}X)^{-1}X'\phi^{-1}v$$

where ϕ is an (MxM) diagonal matrix and v is a vector of observed probits $F^{-1}(p_i)$. A consistent GLS estimator is obtained by replacing ϕ with Φ obtained from sample proportions. If sufficient repetitions are not available or if observed frequencies concentrate at either [0,1], maximum likelihood estimates (MLE) will be consistent and efficient. In this case, the logarithmic likelihood function is

$$(4\text{-}2) \qquad \text{Log } L = \sum_{i=1}^{n'} \log\,(P_i) + \sum_{i=n+1}^{n} \log\,[1-(p_i)]$$

where (P_i) is as above.

n' = those pests who die from dosage X;

n = those surviving dosage X.

Differentiation (4-2) of results in nonlinear equations whose estimates can be derived numerically by iterative search procedures (Theil, 1971). In this problem, GLS estimates are used as starting values for the maximum likelihood estimation. The analytic Hessian is used to compute the variance matrix for the estimator. GLS estimates are first adjusted by a series of steepest descent iterations and Davidon-Fletcher-Powell (DFP) iterations are performed to compute final estimates (Greene, 1982).[10]

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[10] MLE estimates were obtained and were significant at .06 level. Signs and coefficients were close to GLS estimates. However, the MLE estimates were relatively unstable showing sensitivities to scaling. Results are reported in Appendix D. Given that model results are expected to generate feasible policy recommendations, the GLS estimates were used in the policy model since they provided slightly more conservative estimates of resistance development.

Estimating Cotton Yields

The probit model provides estimates of the probability of surviving insecticides. Yield loss or pest damage is generally specified as an increasing function of pests surviving insecticide control (Feder and Regev, 1975). Insects surviving pesticides enter the cotton yield equation producing loss. Cotton yield levels result, however, from the effectiveness of the entire production technology and should be included in analysis of pesticide productivity (Miranowski, et al, 1974). Physical production data obtained from the field survey were also included to estimate cotton lint yields. Details on variable definition are in Table 4.3. Following Hall and Norgaard (1973), Talpaz and Borosh (1974), and Feder and Regev (1975), a linear cotton yield equation was specified.

The estimating equation becomes:

$$Y_i = f(N, I_i, M_i, LQ_i\ W_i, K_i) + e_i \tag{4-3}$$

$$e_i \sim N\ (0,\sigma^2)$$

$$E\ (e_i e_j) = 0 \quad i \neq j$$

$$i = 1\ .\ .\ .\ 380 \text{ cotton fields}$$

where

Y_i = yields in terms of actual pounds of cotton lint per acre,

N = number of tobacco budworm larvae,

I_i = IPM services (purchased pest control information),

M_i = management skills in equivalent years of formal education by grower,

LQ_i = land quality,

W_i = acre feet of water per acre,

K_i = current ratio.

Table 4.3--Discription of Variables Included in Cotton Production Function

(1) Cotton Yield	Yields, in terms of pounds of cotton lint per acre of cotton planted, for each field in the sample were computed from cotton gin filed with the county Agricultural Stabilization and Conservation Service.[11]
(2) Management Risk	Previous research has found that the quality of management significantly affects growers' ability to utilize pest management advice (Grube, 1977, 1986). Years of farming experience and formal education were used to compute a management index. Each four years of experience was valued as one equivalent year of formal education.
(3) Purchased Pest Control Information:	Following Grube (1977) and Hall (1977) a measure of pest control information was iancluded directly in the production function. Time series data on costs of specific pest management activities--field scouting (trap checking), placing gossyplure traps, and boll cracking, regulatory responsibilities--were obtained from each pest control advisor employed by a grower in the sample (Appendix Bi) From data on type and frequency of services purchased by each grower, expressed as weighted of services measured in dollars per acre was computed as the measure of purchased information.

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[11] If yield records wre for two or more fields which were not adjacent, or with different soil characteristics, a percent of the total net pounds of cotton lint recorded for those combined fields was allocated to each of these fields on the basis of ASCS program yeild history, e.g., by average yields on that field for other years. Otherwise, yield and input data were aggregated for adjacent fields.

Table 4.3 (continued)

(4) Land Quality Index:	A land quality index (LQI) was computed for each cotton field. The LQI is a Storie index adjusted for actual investments in drainage and weighted to reflect the percentage of different soil types present in each field sampled.[12]
(5) Water Quantity	The water variable is the total acre feet per acre delivered to a given irrigation gate serving each field during a cotton season. Imperial Valley Irrigation District (IVID) water records were obtained for the sampled fields.
(6) Fertilizer	Only pounds of fertilizer applied per acre for each grower were obtained from the survey; it is highly correlated with the soil index and excluded from the estimating equation.
(7) Machine Input	Survey results indicated that cultivation and harvest practices do not differ widely among growers, in fact, the majority employ custom operators. The machine complement did not vary significantly for owners or by size of operation, thus was not included in the analysis.
(8) Capital Position	The current ratio is calculated for each producer and used to measure his ability to finance pest control during the season.

The Dynamic Economic Model

The empirical problem is to numerically solve the dynamic economic model in Section 3, for the pest management strategy that optimizes producer's surplus over time incorporating changes in the state of pesticide effectiveness from resistance development. Econometric estimates from the produc-

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[12] A field for the purposes of this study is defined as a tract of land farmed as a unit and irrigated by at least one named irrigation gate. In nearly all cases a field is a minimum of 40 acres and except in a few cases does not exceed 160 acres, or one quarter section. Where two adjoining fields were farmed as one, soils and drainage are represented proportionately.

tion system were used to develop the parameters for a discrete time dynamic programming solution to the dynamic economic problem. A discrete probit model was embedded in the dynamic programming model to calculate the distribution of net revenues in order to capture the inherent uncertainty in pest control.

Dynamic Programming

Dynamic programming exploits the dynamic structure more directly than the variational approaches of optimal control (Luenberger, 1982).[13] Solution algorithms that depend on calculus techniques can be employed to solve dynamic programming problems. However, they can also be solved by conducting a "brute force" search which is relatively slow but effective in dealing with complex problems. Dynamic programming can solve stochastic problems and has the advantage of allowing inequality constraints on the variables and nonlinear constraints.[14]

Incorporating Uncertainty

Agricultural production technology is stochastic as a result of the underlying biological and physical processes whose outcomes cannot be known

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[13] Formally, it is inappropriate to make a distinction between dynamic programming and control methods since they can be shown to be equivalent (Intrilligator, 1971). Generally, however, "control methods" refer to the use of calculus techniques to solve continuous optimization problems and dynamic programming refers to the use of numerical methods to solve a discrete form of the problem.

[14] In a stochastic control formulation all control variables enter the objective function with squared terms and there are no inequality constraints. Theil has shown that stochastic control problems can be simplified under certain conditions. In the general case in which the objective function is not quadratic and equations of motion are nonlinear, approximation methods are available (Athans, 1972).

with certainty. The sources of uncertainty with respect to pest control are several: (1) uncertainty regarding pest infestation and damage levels; (2) the effectiveness of pest control technology in reducing pest damage; and (3) effectiveness or productivity of pest control technology over time due to resistance development. A certainty equivalence problem formulation of this problem would assume the variability of the pesticide effectiveness has no effect on the optimal policy, implying the same result would prevail at all pest control variability levels. This is not likely to be the case with respect to pesticide use. What is needed is the probability distribution of production which is generated in this model through use of a probit model incorporated in the dynamic programming.[15]

Uncertainty is most frequently incorporated into dynamic programming problems by (1) allowing current period rewards to depend upon realization of a random variable assuming the state transition is independent of current states and controls (Nemhauser, 1966); or (2) allowing transitions from one state to another to be governed by transition probabilities as in a Markov decision process (Howard, 1960). In this problem current period returns are uncertain due to the stochastic nature of pesticide effectiveness modeled earlier.

The programming model was constructed to incorporate this production uncertainty directly. At each period t, production depends on the realization of a random variable--the probability of insects surviving a given control

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[15] Gardner (1979) points out, in the case of storage problems, that the use of control methods which substitute the expected value of future production can lead to recommended carryover stocks significantly lower than the optimal levels. He finds that as optimal storage increases as the variance of future production increases.

strategy--the dynamic programming model has embedded in it a discrete probit model to calculate the entire probability ditribution of net revenues at each period.

Feasible Pest Control Strategies

Control or pest management decisions consist of nine strategies employing combinations of chemical and nonchemical (externality and nonexternality) inputs determined from empirical analysis. Each strategy has a level of organophosphate, synthetic pyrethroids, pest scouting and monitoring and biological controls (pheromones) reflecting technical substitution possibilities estimated from the econometric production system.[16] Feasible pest control strategies are represented by a matrix CON of dimension (k x MT) where k is equal to a (1 x k) control vector of pest control inputs: organophosphates, synthetic pyrethroids, carbamates, pheromones and purchased pest control information and M = 10 and is the number of feasible control strategies for all T.

Defining States

The state of pesticide effectiveness R_t is defined as the probability of surviving pesticide use, $(1 - p_i)$. Feasible statea are defined in the dynamic model by partitioning the distribution of probit slopes into ten feasible states of effectiveness. These states are shown in Table 4.4. The range was ± one standard error around β and the difference in effectiveness between each possible state corresponds to the rate of change in effectiveness estimated by

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[16] Given low use levels of carbamates and econometric evidence of their ineffectiveness in controlling tobacco budworm, they were eliminated from the dynamic policy analysis.

Table 4.4--Resistance States: Probability of Surviving Cumulative Levels of Chemical Control

Control Level (# of a.i./acre)	Externality State Based on Shift in Probit Slopes Over Time									
	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10
					Organophosphates					
(1) 0.45	.454	.453	.464	.468	.470	.472	.480	.486	.490	1.00
(2) 0.90	.409	.416	.425	.438	.436	.444	.460	.470	.482	1.00
(3) 1.80	.322	.348	.361	.387	.389	.420	.440	.425	1.000	1.00
					Synthetic Pyrethroids					
(1) 0.12	.370	.390	.400	.417	.432	.444	.460	.472	.492	
(2) 0.24	.255	.305	.337	.364	.390	.417	.488	1.000	1.000	
(3) 0.48	.093	.195	.289	.340	.382	.472	1.000	1.000	1.000	

the slope shifters. Ten states were chosen to correspond to the expected 10-year lifetime of chemical pesticides. OPCO is a (1 x 10) vector of estimated probit slopes or states of effectiveness of organophosphate chemicals in killing tobacco budworm larvae. SPCO is a (10 x 1) vector of probit slope shifters for synthetic pyrethroid. Feasible system states are represented by a (SPCO x OPCO) matrix of probit slopes.

The yield state is determined uniquely in this problem by R(t).[17] The cotton output state Y which results from the pesticide effectiveness state r for any control strategy m is modeled as

$$Y^{C}_{rm} = Z + [1-p(k|X_m)]\ \hat{B}_1\bar{N} + B_2I_m + B_3PH_m \qquad (4-\_\_)$$

$m = 1,\ldots,M$ control strategies

$r = 1,\ldots,R$ resistance states

where Z = the yield contribution from the non pest control input vector estimated in the cotton production equation.

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[17] Cotton yields change with a change in pesticides. The yield change is decomposed into the effects of how Y^C changes with a change in surviving insects R^S and how R^S changes with a change in pesticides. Specifically, let cotton yield be represented as

$$Y^C = f(R^S,V,Z)$$

where R^S are tobacco budworm surviving pesticides, V is purchased IPM services, and Z a vector of nonpest control inputs. R^S is a function of pesticide, $R^S = g(x)$ implying $Y^C = f(g(x),v,z)$. Totally differentiating Y^C with respect to X,

$$\frac{dY^C}{dx} = \frac{\partial f(\cdot)}{\partial g} \cdot \frac{\partial g(\cdot)}{\partial x}.$$

$\frac{\partial g(\cdot)}{\partial x}$ is estimated from the dose-response function and $\partial f(\cdot)/\partial g(\cdot)$ from the yield equation.

State Transition

The state transition R_t - R_{t+1} is a deterministic function of previous states and controls. If in time t, state i is occupied and control u applied, transition to state t+1 is determined in the state transition matrix. Transitions are based on slope changes from the probit regression equations conditioned by previous states and controls providing all feasible state-control combinations. Tables 4.5 - 4.6 provide information on feasible states and control dependent transitions.

Table 4.5--Control Dependent State Transition Matrix: Organophosphates (QMAT)

	Effective State								
Control	1	2	3	4	5	6	7	8	9
(,1) =	2	2	3	3	2	2	2	2	2
(,2) =	3	3	4	4	3	3	3	3	3
(,3) =	4	4	5	5	4	4	4	4	4
(,4) =	5	5	6	6	5	5	5	5	5
(,5) =	6	6	7	7	6	6	6	6	6
(,6) =	7	7	8	8	7	7	7	7	7
(,7) =	8	8	9	9	8	8	8	8	8
(,8) =	9	9	10	10	9	9	9	9	9
(,9) =	10	10	10	10	10	10	10	10	10
(,10) =	10	10	10	10	10	10	10	10	10

Table 4.6--Control Dependent State Transition Matrix: Synthetic Pyrethroids (PMAT)

	Effective State								
Control	1	2	3	4	5	6	7	8	9
(,1) =	2	2	2	4	3	4	2	3	4
(,2) =	3	3	3	5	4	5	3	4	5
(,3) =	4	4	4	6	5	6	4	5	6
(,4) =	5	5	5	7	6	7	5	6	7
(,5) =	6	6	6	8	7	8	6	7	8
(,6) =	7	7	7	9	8	9	7	8	9
(,7) =	8	8	8	10	9	10	8	9	10
(,8) =	9	9	10	10	10	10	9	10	10
(,9) =	10	10	10	10	10	10	10	10	10
(,10) =	10	10	10	10	10	10	10	10	10

$(1-p_i|X_m)$ = The probability of surviving a given pesticide dose X_m.

B_1 = the damage coefficient $\partial Y^c/\partial N$ from the cotton damage/production function. It gives the effect of a unit change in tobacco budworm larvae on cotton lint output. B_1 is a constant in the control model yield equation.

N = mean tobacco budworm infestation levels. N is a constant in the dynamic model determined by the mean 5-year damage infestation levels in the Imperial Valley.

B_2 = is the regression coefficient on purchased pest control services from the production function.

I_m = the level of purchased pest control advice in control strategy u.

B_3 = is the estimated coefficient on pheromones for control of pink bollworm populations.

PH = the level of pheromone for the u^{th} control strategy.

User's Cost

The externality tax or user's cost is the discounted present value of the stream of services from the remaining stock of pesticides. It is calculated as the dollar cost of yields lost over the planning period from a given control path due to the development of resistance. Table 4.7 calculates yield loss associated with alternative states of resistance used to calculate user's costs in the control model. The terminal value function $\tau(T)$ represents user cost.

Table 4.7--Yield Losses Associated With Alternative Control Levels and Resistance State

Control Level	State (Conditional Probability of Survival)									
	1	2	3	4	5	6	7	8	9	10
					Organophosphates					
1 0.45	191.80	191.38	196.03	197.72	198.57	199.41	202.79	205.32	207.10	422.48
2 0.90	172.79	175.75	179.55	185.04	184.20	187.58	194.34	198.57	203.64	422.48
3 1.80	136.03	1471.02	152.51	163.50	164.34	177.44	185.89	199.55	422.48	422.48
4 1.20	154.41	161.38	166.03	172.13	174.27	182.51	190.12	289.06	313.06	422.48
					Synthetic Pyrethroids					
1 0.12	156.00	164.77	168.99	176.17	182.51	187.58	194.20	199.40	208.00	422.48
2 0.24	107.73	128.86	142.37	153.78	164.77	176.14	206.17	422.48	422.48	422.48
3 0.48	39.29	82.38	122.10	143.64	161.39	199.41	422.48	422.48	422.48	422.48
4 0.32	73.51	105.62	132.24	151.78	163.08	187.77	314.32	422.48	422.48	422.48

Solution Approach to the Dynamic Programming Model

A solution algorithm relying on a "brute force" recursive fixing approach was written for the VAX 750 using SPEAKEASY. Basically, all feasible state-control combinations and revenues using the econometrically derived coefficients were calculated. Then in a backward loop, starting with the terminal period T, the probability distribution of net revenues for all feasible resistance states were calculated using the embedded probit model; the expectation of profits relies, therefore, on the frequency distribution of kill-rates. The returns wree evaluated for each feasible terminal state of resistance. Next, for T-1 the optimal value function

$$\text{(4-\_)} \qquad \text{Max } J^* (R_{T-1}, U_{T-1}) = \sum_{i=0}^{1} p_i [r(R_{T-1}, U_{T-1}) + J^*(R_T, U_T)]$$

was calculated relying on the recurrence relation (see Intrilligator, 1981). The optimal value of production in year T-1 is the probability distribution of net income in year T-1 plus the expected future cost in year T. Calculations continued until $t = t_0$ and the results stored. Optimal inputs and preferred net returns are solved in a forward loop at $t = t_0$. When $t = T$, the optimal solution is obtained. The optimal pest strategy, cotton control yields and discounted net revenues are obtained from the results.

5. ECONOMIC ANALYSIS

Empirical results from the production analysis suggest that, over the study period despite present regulatory policy, as rates of insecticide use have increased, yields have declined and effectiveness of insecticides in controlling Heliothis virescens (Tobacco budworm) has been reduced indicating resistance development. Results of the dynamic analysis indicate that alternative policy mechanisms are required to reduce resistance development and encourage adoption of less chemical intensive strategies are to be adopted. Under current regulatory policies, pesticides will likely remain the dominant pest control strategy until resistance is well developed.

Estimates of Field Resistance in Heliothis Virescens

Probit Estimates of the Dose-Response Function

Results of the probit regression are presented in Table 5.1. All but two probit coefficients are significant at a .01 level of significance. Degree days is not significant in explaining insect mortality and organophosphates are significant at the level .05 for 1981. The signs indicate declining effectiveness of pesticides over the period, with the exception of 1980 synthetic pyrethroids which are still significantly positive. Predicted probabilities and their distribution are included in Appendix D.

Table 5.2 presents the conditional probabilities computed from probit coefficients. Numbers in parentheses are pounds of active ingredients. It is evident that the dose-response function has shifted--despite higher doses lower kill rates are being experienced over time.

Table 5.1--Estimates of the Dose-Response Function: GLS Probit Results

Variable	Coefficient	Standard Error	T-Ratio	Mean of X	S.D. of X
Constant	1.2870	0.63626E-01	20.227[a]	1.0000	0.54411E-08
CB	9.9700	1.6895	5.9010[a]	0.14251	0.37181
OP	0.17636	0.81370E-01	2.1674[a]	0.77464	1.3178
SP	0.59619E-01	0.15855E-01	3.7603[a]	0.21564	1.07646
DD	0.10126E-02	0.83232E-03	1.2166	60.862	36.415
80 CB	-9.1163	1.6929	-5.3849[a]	0.91098E-02	0.76049E-01
81 CB	-9.5042	1.6836	-5.6450[a]	0.13165	0.36770
80 OP	-0.31398	0.87937E-01	3.5705[a]	0.13797	0.65232
81 OP	-0.14605	0.84056E-01	-1.7375[b]	0.50933	1.1809
80 SP	1.6886	0.22008	7.6728[a]	0.28920E-01	0.10661
81 SP	-1.4364	0.21832	-6.5795[a]	0.90530E-01	0.18586

[a] Significant at .01.
[b] Significant at .05.

Log - Likelihood	-1502.8
Restricted (Zero Slopes) Log L	-1536.0
Chi-Squared	66.501
Degrees of Freedom	10
Significance Level for Test	.001

Current Data subset contains 179 observations.

Table 5.2--Conditional Probabilities Computed from Probit Results[a]

	Probability of Mortality		
	1979	1980	1981
Carbamates[b]	92.0 (.14)	88.3 (.142)	56.7 (.27)
Organophosphates	55.2 (.774)	53.6 (.911)	52.4 (1.28)
Synthetic Pyrethroids	50.4 (.215)	52.4 (.243)	45.6 (.305)

[a] Calculated using GLS estimates. Conditional jprobabilities are derived by evaluating Z values from estimated slope coefficients and mean pesticide levels. Feigures in parentheses are pounds of active ingredients per application.

[b] Carbamate estimates must be considered cautiously given known loss of effectiveness and only sporadic use over the period.

Test for Model Significance

The likelihood ratio test is employed to test the null hypothesis that slope coefficients equal zero or

$$H_o: \; B_i = 0$$

$$H_a: \; B_i \neq 0$$

For large samples, the null hypothesis is rejected if $\Lambda = 2[\ln(\mu_{ML}, \sigma^2_{ML}) - \ln(\mu_R, \sigma^2_R)]$ exceeds the critical χ^2(dof) at a specified level of significance. The calculated $\chi^2(10) = 66.5$, exceeds the critical value at .01 level of significance. Thus, the null hypothesis that the regression slopes do not explain pesticide kill is rejected.

Calculated LD_{50}s

Despite the increased amounts of chemicals used per acre, the probability of tobacco budworm surviving all insect control at mean levels of materials used increased, indicating increased tolerance. Probit slope estimates were used to calculate LD_{50}s for the three chemical compounds that have increased in use over the period (Table 5.3). Confidence intervals at the 95 percent level are shown in parenthesis. Because of documented laboratory test failures (see Martinez-Carrillo and Reynolds, 1983) with carbamates, no LD_{50} was calculated for 1982. It is apparent that significantly greater amounts of any of the three common insecticides used are required to kill Tobacco budworm.

Field Resistance Factor

A field resistance factor using these estimated LD_{50}s was calculated for organophosphates, synthetic pyrethroids, and carbamates. Since a laboratory base of susceptibles was not available, the resistance factor was calculated

Table 5.3--Calculated Lethal Doses to Kill 50 Percent of Tobacco Budworm Populations (LD_{50})

Chemical Compound	LD_{50} (# of Active Ingredients/Acre/Application) 1979	1980	1981	1982
Organophosphate	.70 (±.157)	.84 (±.17)	1.22 (±.164)	1.46
Synthetic Pyrethroids	.213 (±.030)	.231 (±.43)	.334 (±.427)	.360
Carbamates	.076 (±.20)	.08 (±.66)	.20 (±.56)	NA[a]

[a] Because of documented failures to produce mortality, carbamates dropped from analysis (see Martinez-Carrillo and Reynolds, 1983).

Source: Calculated from Probit results, Table 5.1.

Table 5.4--Field "Resistance Factors" Calculated from Probit Results by Class of Insecticide[a]

Insecticide Class	Resistance Factor $81LD_{50}/79LD_{50}$
Organophosphates	1.74
Synthetic Pyrethroids	1.56
Carbamates	2.63

[a] Resistance factor is defined as the ratio of LD_{50} (or LD_{80}) of resistant to susceptible pests. In this case of field analysis, the susceptible population is defined as the base population (1979) and resistant as the 1981 population.

as the ratio of LD_{50} with 1979 as the base year. These resistance factors are shown in Table 5.4.

These data indicate, at a minimum, declining effectiveness of currently approved chemical insecticides in control of Tobacco budworm. In addition, these data are consistent with recent laboratory measures of resistance development. Table 5.5 compares the field resistance factors estimated from the probit results with laboratory resistance factors from an entomological study of Tobacco budworm populations in the Imperial Valley by Martinez-Carrillo and Reynolds (1983). The probit results are consistent with their findings. The field resistance factor of 1.74 for organophosphates compares to the laboratory derived resistance factor for methyl parathion of 1.58 over the same period (1979 to 1981). The field resistance factor of 1.56 for synthetic pyrethroids compares favorably as well (1.57 for the synthetic pyrethroid permethrin and 1.98 for fenvalerate, another synthetic pyrethroid).

Table 5.5--Comparison of Field Resistance Factors and Those Derived from Laboratory Populations

	Resistance Factors Estimated From Probit (1979-1980)[a]	Laboratory Resistance Factors
Organophosphates	1.74	1.58[b] 2.76[b]
Synthetic Pyrethroids	1.56	1.57[c] 1.98[c]
Carbamates	2.63 ±54	d

[a] Source: Table 5.5.

[b] Source: Martinez-Carrillo and Reynolds (1983). 1.58 represents the ratio of LD_{50} for methyl parathion between 1979 and 1981; 2.76 is the ratio of LD_{50} for methyl parathion for the period 1979 to 1980.

[c] Source: Martinez-Carrillo and Reynolds (1983). 1.57 is for permethrin and 1.98 for fenvalerate.

[d] Source: Martinez-Carrillo and Reynolds comparison not available.

The field resistance factors imply that 74 percent more organophosphates were required in 1981 than in 1979 to kill 50 percent of Tobacco budworm populations; comparably, 56 percent more synthetic pyrethroids were required in 1981. These data indicate that increases in materials applied were necessary to offset the effects of development of resistance.

Cotton Yields

Estimation and Results for Cotton Yield Equation

The yield function was estimated using ordinary least squares (OLS).[1] Results of the regression analysis are shown in Table 5.6. All signs are as expected and all but two coefficients are significant at a .01 level of significance. The lower significance level on water may be explained by the fact that water management practices are closely related to soil salinity control, thus water use is not entirely aimed at plant growth. Surviving Tobacco budworm populations have the expected sign implying increased pest populations significantly reduce cotton yields. Purchased pest control information measures the contribution of IPM services. It is positively associated in this study with yields and is statistically significant at a .05 level of significance.[2]

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[1] It is well known that OLS estimation of production coefficients can lead to biased coefficient estimates since some of the variables may be simultaneously determined with output and thus not independent of the error term. In general, the simultaneous equation bias will be small if the equation is well-specified or there are relatively large disturbances in other equations such as the profit maximizing conditions.

[2] The management variable was not included in the estimating equation due to high collinearity between management and purchased pest control information. Since over 90 percent of the growers reported that pest management decisions were left to the PCA, the management variable was not included.

Table 5.6--Results of Estimates of the Cotton Yield Function

Variable[a]		Estimated Coefficient	Standard Error	t Statistic	Mean of Variable
B_0:	Intercept	1,377.1	104.47	13.18***	
B_1:	Tobacco Budworm	-111.18	16.63	-6.69***	3.80
B_2:	Purchased Information	7.07	3.94	1.79*	15.05
B_3:	Water	18.82	9.70	1.94**	5.86
B_4:	Land Quality	3.68	.98	3.74***	39.80
B_5:	Financial Health	31.62	9.71	3.26***	2.44

[a] Tobacco budworm are mean larvae/square ft.; Purchased Information (PI) is in dollars spent/acre; Water (H_2O) is acre feet/acre; Land Quality (LQI) is a Storie soil index adjusted for drainage improvements; Financial Health (FH) is a measure of current assets to current liabilities.

320 observations

$\bar{R}^2 = .278$

$F_{5,320} = 17.22$***

Durbin Watson 2.002

***Significance level .01
**.03
*.05

Output Elasticities

As expected, land quality is a significant factor in explaining output differences as is the measure of current capital position. The assumption of no technical change in cotton technology was maintained in obtaining production estimates for the control model. Dasgupta and Heal (1979) point out that it is important to investigate growth potential under the pessimistic assumption of no technical change. This is especially important when exhaustible inputs are involved. Resistance would not pose a fundamental policy problem if output could be maintained at economically high levels with increasing resistance. Roughly speaking, if the output elasticity of resistant pests is less than that of other inputs, the possibility exists that other inputs can allow for a permanently maintainable output despite the increase in resistance.

Output elasticities η_i were computed at sample means where $\eta_i = MP_i\bar{X}/Y$ for factors $i = 1,\ldots,N$. Output is relatively inelastic with respect to changes in the use of purchased information, water and land quality; and only slightly less inelastic with respect to current capital position. It is relatively less inelastic with respect to pest populations. Without technical change, output is likely to be driven to zero over time (Dasgupta and Heal, 1979). Insects are important to cotton production and it is unlikely that biological, physical, management and capital variables compensate to maintain output as pest populations increase due to the development of resistance.

Pest Control Under the Abatement District

Estimates of the productivity of pheromones, biological controls and chlordimeform used in the 1982 program for the dynamic analysis were determined in a separate regression (Table 5.7). A partial production function, $Y_i = \beta_0 + \beta_1 SP_i + \beta_2 PH_i + \beta_3 CL_i + \beta_4 IN_i + e_i$ was estimated using OLS. Due to multi- collinearity between biologicals and pheromones the final estimating equation does not include biological controls. While the explanatory power of the regression is low, the value of the $F_{(5,43)}$ test indicates the independent variables together explain output.

County and state restrictions on chlordimeform allowed a maximum of six applications for the season at a rate of 1/2 pint per application (1.5 pounds of active ingredients per acre). Mean use levels for sample growers was .9 pounds of active ingredients per acre. Given the lack of significance and the fact that the one year's data did not allow for rates of resistance development to be calculated, chlordimeform was not included in the dynamic analysis.

Table 5.7--1982 Pheromone/Chlordimeform Program

Variable[a]		Estimated Coefficient	Standard Error	t Statistic	Mean of Variable
B_0:	Intercept	977.00	305.33	3.20*	
B_1:	SP	22.10	9.21	2.40*	.760
B_2:	PH	29.45	9.96	2.958*	.374
B_3:	CL	55.30	52.17	1.060**	.900
B_4:	IN	7.81	6.61	1.180**	18.200

[a] Synthetic pyrethroids (SP) are in pounds of active ingredients per acre (dry weight); Pheromones (PH) are in pounds per acre (dry weight); Chlordimeform (CL) is in pounds per acre (dry weight); and purchased information (IN) is in dollars per acre.

$R^2 = .12$

$F_{5,45} = 7.02$*

*Significant at .01
**Significant at .15

Yield Losses from Tobacco Budworm

Using the recursive relationship between the production/damage and the conditional probability of surviving insect control, the econometric estimates (Tables 5.1 and 5.6) are used to calculate damage estimates in terms of yield losses. Table 5.8 estimates damage from Tobacco budworm. Total damage is decomposed into: (1) losses due to the increased survivors; and (2) losses due to changes in pesticide effectiveness.

The value of these losses, calculated at a constant price of .72 cents per pound, is shown in Table 5.9. Although there is variability from year to year, the trends are clear: costs of yield losses due to declining effec-

Table 5.8--Expected Net Yields and Losses from Tobacco Budworm Damage

Year	Damage Coefficient[a]	Mean Infestation Level[b]	Expected Probability of Survival[d]	Predicted Yield Loss Due to Declining Effectiveness (# of Cotton Lint)	Predicted Net Yields[e] $\hat{Y}$	Observed Yields[e] $\bar{Y}$
1979	-111.18	3.7	.44	186	1530	1450
1980	-111.18	2.8	.47	199	1565	1599
1981	-111.18	5.4	.52	220	1399	1211
1982	-111.18	4.6[c]	.59[c]	249	1410	1292

[a] Source: Table 5.6.

[b] Source: Table 2._.

[c] Estimated

[d] Source: Table 5.1. Includes only organophosphates and synthetic pyrethroids.

[e] Estimates of yield from the static model are slightly higher than the sample means although all are within one standard deviation. This is realistic since damage from other cotton pests are not reflected in the damage function.

tiveness of chemical insecticides are increasing, implying that the external costs of chemical technology are positive and increasing. Additionally, control costs are increasing as more insecticides must be used to maintain kill levels. From the producers' perspective, however, insecticides still continue to be productive resources. If only private control costs are considered as in earlier studies (column 2), one dollar invested in pest control returns on the average approximately $2.50, based on constant input and output prices. This is consistent with earlier estimates. If total costs (control costs plus cost of lost yields) are considered (column III), one dollar invested returns on the average approximately $1.14. This estimate considers the cost of resistance.

Table 5.9--Cost Per Acre of Tobacco Budworm Damage, Imperial Valley, 1979-1982

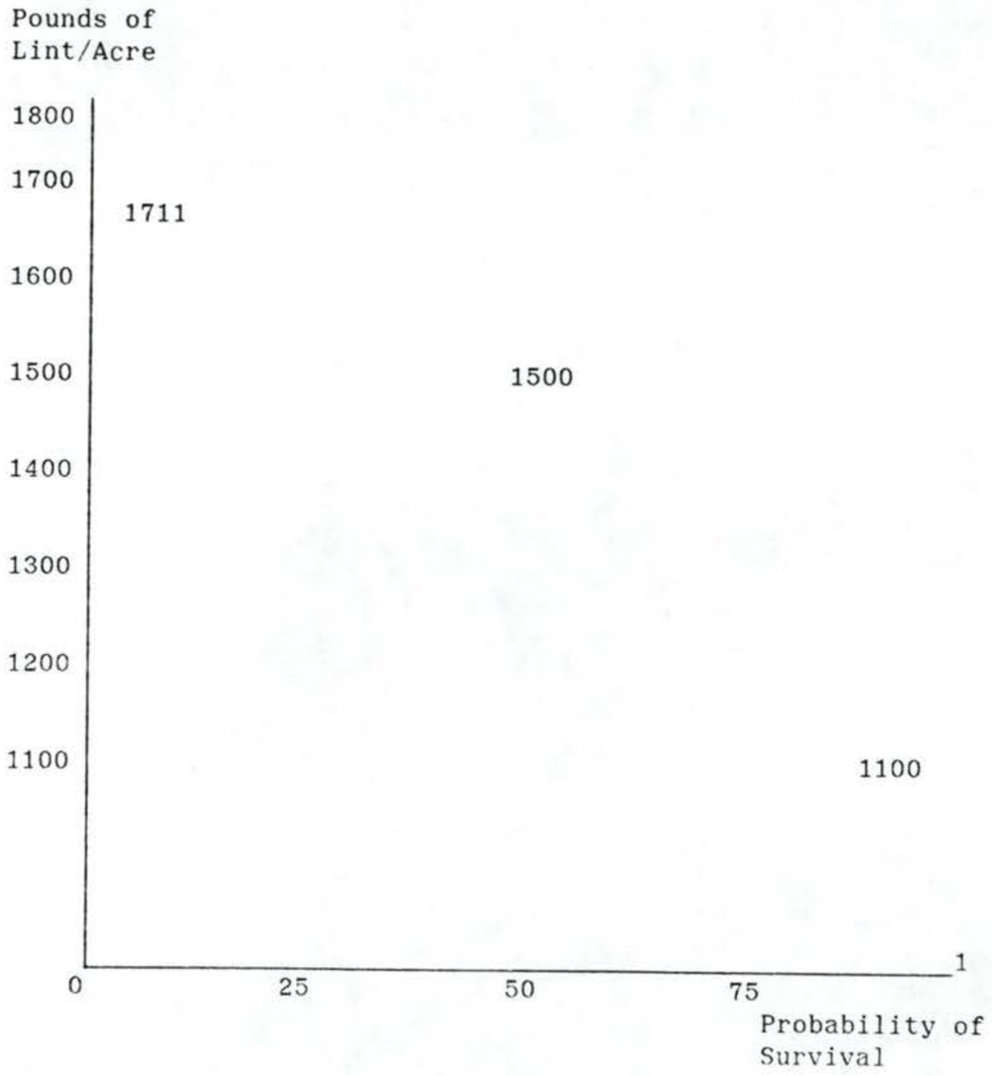
Year	Cost of Yield Loss After Pest Control (1)	Cost of Pest Control Per Acre[b] (2)	Total Cost of TB Control (3)	Cost of TB Losses Without Pest Control (4)
			dollars	
1979	130	108	238	296
1980	143	117	260	264
1981	158	167	417	420
1982	179	134	365	368

[a] Source: Table 6.10, Agricultural Commissioner Reports (1979-1982).

[b] 1979 and 1980 from Cooperative Extension, Costs of Production, Imperial County, El Centro, California. 1981 and 1982 estimated from pesticide use reports.

Figure 5.1 indicates how yields respond to an increase in the probability of surviving insecticide treatment based on the econometric results that a one

Figure 5.1 Relationship Between Yield and Resistance in Terms of Probability of Surviving Insect Control



unit (one insect per square foot) increase in pest levels indicates over 110 pound loss of lint per acre. At a zero probability of survival, given the measured effectiveness of materials, per acre yields could reach a potential maximum of about 1711 pounds of cotton lint per acre or 3.4 bales of cotton, assuming no other damage from other pests. These yields have been achieved previously by some growers in the Imperial Valley. At high levels (1981) of pest infestation, if insecticides failed to control Tobacco budworm (100 percent survival), per acre yields are estimated to decline to approximately 1100 pounds of lint per acre, or 2.2 bales per acre. A 50 percent survival at mean pest levels over the period results in a yield of 1500 pounds of lint per acre. Recall that these yields do not consider damage from other cotton pests so are higher than what was observed in the sample.

Productivity Effects of Regulatory Policy

Production system results indicate that the decline in the effectiveness of insecticides is responsible for a majority of the observed yield decline indicating the failure of regulatory policy to address the intertemporal common property aspects of chemical control. However, any differences in the effectiveness between materials, e.g., of synthetic pyrethroids and organophosphates (and between organochlorines and other newer chemical compounds) can probably be attributed to regulatory policy since regulatory policy has embodied certain quality requirements in chemicals approved for use.

Marginal productivities for organophosphates and synthetic pyrethroids were calculated using conditional probabilities to calculate expected damage reduction from pesticide use (Table 5.10). Data indicate that the marginal productivity of organophosphates is statistically higher in every period.

Additionally, using the standard deviation as a measure of risk in terms of yield variability, synthetic pyrethroids demonstrate greater yield variability. Organophosphates' average yield variability is approximately 1.2 percent where synthetic pyrethroids average about 4.67 percent variability. This finding is consistent with growers' perceptions and laboratory results (see Martinez-Carrillo and Reynolds, 1983). This variability can be explained in part by the fact that synthetic pyrethroids are designed to be less persistent to meet environmental concerns over the effects of persistent chemicals such as the organochlorines. Synthetic pyrethroids are less stable chemical compounds and, as these data indicate, less reliable in controlling pest damage.

Table 5.10--Comparison of Marginal Productivities of Organophosphate and Synthetic Pyrethroids

	Marginal Productivity[a] (# of cotton lint)		
Insecticide	1979	1980	1981
Organophosphates	233 (±5.0)[b]	226 (± 0.9)	222 (± 2.7)
Synthetic Pyrethroids	213 (±6.8)	221 (±17.6)	193 (±19.3)

[a] Marginal productivity is defined as the reduction in Tobacco budworm damage from use of insecticides at mean levels. It was calculated from $\hat{Y} = \beta_{TB}(1-\hat{p}_i)$ where β_{TB} is the coefficient from the cotton damage-production function and X_{TB} is mean Tobacco budworm levels. $\hat{p}_i$ is the estimated conditional probability of surviving from the Probit regression. Since the damage function is linear, average and marginal productivity are equivalent.

[b] Figures in parentheses are calculated variability in yields based on standard errors of probit slope estimates.

Synthetic pyrethroids are important primarily in cotton. Currently they comprise less than 5 percent of the U.S. insecticide market, although use levels were initially projected to be much higher. Growing evidence of resistance is expected to limit their use (Eichers, 1982). These estimates support other evidence of the fairly rapid rate in loss of effectiveness of synthetic pyrethroids which were in use less than five years in the Imperial Valley at the time of this study. Using econometric estimates from the probit model it appears that the productivity in terms of kill effectiveness of synthetic pyrethroids deteriorates more rapidly than organophosphates (and organochlorines). The slope shifter (decline in conditional probability of mortality) for synthetic pyrethroids is between 5 and 6 percent per year at mean use levels. If higher levels of these materials are used, the decline is accelerated. Organophosphates' decline in effectiveness is estimated from the probit results to be between 2 and 3 percent per year, approximately half that of synthetic pyrethroids.

Economies of Alternative Pest Control Inputs

IPM services provided by PCAs were statistically significant in the production/damage function; their use was positively correlated with output. The estimated marginal productivity at mean use levels is approximately 7.07 pounds of lint per acre from a one unit increase in services. At mean use levels, purchased pest control information returns approximately $5 for every dollar invested. Since purchased information does not produce resistance, there are no social or external costs associated with its use. Current use of purchased pest control information appears to be economically inefficient as MVP exceeds the input price. A possible explanation is that such services are really collective inputs; when left to the private market, they will be underutilized. The reservation price solicited from growers was somewhat above current per acre prices (approximately $25-30 per acre) but still less than their apparent economic value. One possible explanation offered by a pest control advisor is that PCAs do not charge full costs of cotton service to cotton but spread the cost to other crops.

From the partial regression, pheromones significantly affected cotton output with a marginal productivity of 11 pounds of lint per acre. At a price of $.72 for cotton lint, the MVP of pheromones at 1982 use levels is approximately $7.50 per acre. The cost of this program was estimated to be approximately $30 per acre based on the calculated costs of one pound of active ingredient. From this partial analysis it appears the cost of the pheromone program exceeded the benefits to producers.

This analysis indicates that pheromones may, like pesticides, be a collective input: without intervention they will be underutilized. Imperial Valley growers did not continue the pheromone program in 1983 because short-run private returns did not justify the costs.

Calculating a User Cost

The marginal cost of resistance in any period is calculated as the sum of losses when an additional unit of insecticides is added. The use of an additional pound of active ingredient of synthetic pyrethroids is estimated from the probit model to be about a 36 pounds, or at $.72 per pound about $26 per acre yield loss at estimated rates of decay. For organophosphates, whose rate of change in effectiveness is less steep and level of productivity slightly higher, loss is about 30 pounds per acre or about $22 per acre per pound of active ingeredient. Expected losses increase over time as the level of effectiveness declines and use levels increase. These user costs associated with continued use of organophosphates and synthetic pyrethroids are calculated and used in the dynamic model as the optimal tax. Given the uncertainty of losses, the optimal tax to encourage socially efficient production would have to be based on expected losses such as is done here.

Dynamic Analysis of Productivity, Technical Change and Net Revenues Under Alternative Regulatory Policy

Current environmental policy has not addressed the intertemporal externalities, likely contributing to increased total chemical use, and has not encouraged adoption of less environmentally damaging technology. Therefore, high priority needs to be given to exploring alternative policies that overcome these shortcomings in present environmental policy governing pesticide use. Particular attention needs to be given to adopting policy which specifically encourages adoption of less environmentally damaging technology. The dynamic model developed in Section 4 provides the basis for analyzing some policy alternatives.

The objective of the application or dynamic model is to demonstrate how the optimal actions of producers change in response to regulations governing the use of chemical insecticides and the impacts they have on the long-run productivity of these inputs. Two policy programs--the current standards-based program and the externality tax program--are the focus of this analysis though other policy options were explored. The current standards-based pesticide regulations are imposed on the model by restricting the control strategies to lie within the set U, i.e., to be one of the nine strategies listed in

Table 5.11, and setting the externality tax to zero. Under the externality tax program, the objective function includes the terminal value function which reflects the value of yield losses due to pesticide resistance; the feasible controls also are restricted to lie within the set U.

Optimal Pest Control Strategies

The control strategies for the dynamic programming model under the two policy programs are shown in Tables 5.11 and 5.12. Optimal pest control strategies are shown in Table 5.13. Under the standards-based regulatory program (column (2)), strategies relying primarily on chemical control dominate other less chemical-intensive strategies. Growers follow a strategy that employs high levels of organophosphates and relatively low use of synthetic pyrethroids (strategy B). They do not employ biological controls and use the lowest possible level of pest scouting and monitoring for the first seven periods. They switch to the IPM controls (strategy A) only after a high level of resistance buildup. Under the base case externality tax policy (column (3)), the lowest levels of insecticide available are employed and the highest levels of IPM adopted (strategy A). Producers alternatively use higher levels of organophosphate and synthetic pyrethrins (6 and 8) as resistance emerges, consistent with optimal resistance management strategies. When the uncertainty associated with the effectiveness of the IPM strategies is increased (column (4)), there tends to be a greater reliance on chemical control. When it is less, a greater reliance on IPM strategies is evident (column (5)).

Although not shown here, the optimal strategy was also sensitive to the price of cotton. At a higher price of cotton more insecticides are employed. This suggests that high price supports for cotton may contribute to higher insecticide use levels as marginal value product increases. Additionally, at lower cotton prices growers appear not to be as responsive to increases in uncertainty of effectiveness of pesticides.

Table 5.11--Pest Control Strategies Used in the Dynamic Optimization Model

Strategy	Organophosphate (OP)	Synthetic Pyrethroids (SP)	Pheromone	IPM Index[a]
	Pounds of Active Ingredients Per Acre			$/acre
A	0.45	0.12	0.665	21
B	0.90	0.12	0	15
C	0	0.24	0.665	15
D	0.75	0.48	0	0
E	0.45	0.24	0	18
F	1.20	0.32	0	15
G	0.90	0.24	0	15
H	0.75	0.24	0	15
I	1.80	0.48	0	15

Note: The levels of input use for each combination were based on actual combinations used by cotton producers.

[a] Integrated pest management (IPM) includes the following services: scouting, trapping, and boll cracking.

Table 5.12--Description of Pest Control Strategies

Strategy A:	Assumes a low level of Organophosphate (OP) use (close to 1979 levels) and approximately the mean use level for OP (1978-1982) in Imperial Valley. The Pheromone level is the 1982 level used under the collective management program as no previous year's use levels were statistically significant. This strategy also employs a high (1982) level of purchased pest management services including trapping, field scouting, boll-cracking, and pesticide treatment recommendations.
Strategy B:	Assumes a higher use level for OP equal to the 1981 mean levels. No pheromones are used. A relatively lower level of information use is assumed and the low 1982 level of SP use is used.

Table 5.12 (continued)

Strategy C:	No organophosphates are used but relatively higher level of synthetic pyrethroids (SP), pheromones are used with a low level of information.
Strategy D:	Assumes no pheromone or information and a high level of pesticide use.
Strategy E:	Uses moderate (1979) levels of OP, high levels of SP (same levels of use observed in 1981), no pheromone use and about the 1981 level of information.
Strategies F, G, H:	These are variations in combinations of insecticides at various levels, no pheromones and low information.
Strategy I:	Assumes the highest OP, SP but no pheromones are employed and relatively low levels of information.

Table 5.13--Optimal Control Strategies Under Alternative Policy Assumptions[a]

Time Period	Standards-based Policy	Externality Tax Policy[b]		
(1)	(2)	(3)	(4)	(5)
1	B	A	A	A
2	B	A	A	A
3	B	A	A	A
4	B	A	G	A
5	B	A	G	E
6	B	B	B	B
7	B	A	B	A
8	A	E	E	A
9	A	A	B	A

[a] Control strategies are keyed to Table 5.11. Both time paths are based on the dynamic programming model which has a 9 percent discount rate, and a cotton output price of \$0.80 per pound.

[b] Column (3) shows the base case externality tax results and corresponds to a standard deviation of the probability of the insects being susceptible to pesticide dosage of 0.20. Columns (4) and (5) employ standard deviations of 0.40 and 0.10, respectively.

The model also was run with several discount rates. The base rate of 9 percent per year was varied from 2 to 12 percent. While net revenues were affected, the model is more sensitive to state transitions (the rate at which resistance develops) which overwhelms effects of variations in discount rates. This strongly underscores the need for resistance rates to be accurately measured if they are to be useful information for productivity-related analyses.

These results indicate that current standards-based regulatory policy, at least in the case of cotton, has not succeeded in reducing total chemical use due to the neglect of resistance as a collective (or common property) externality. Further, the relatively slow rate of adoption of IPM technology can be explained because its private returns are less than those from chemical insecticides. This situation continues even as resistance develops until resistance reaches such a high level that producers adopt IPM approaches. These results suggest that current pesticide regulatory policy needs to be reexamined and that an externality tax can induce adoption of practices that delay resistance, thus maintaining the productivity of insecticides for a longer period. While strongly indicative, these findings are sensitive to the definition of the control strategies and the length of time horizon chosen and thus should be interpreted carefully.

Output Effects

Under the externality tax policy, the rate of change in resistance is estimated to increase by 1.3 percent per year and cotton output per acre declines approximately 0.3 percent per year. In contrast, under the current standards-based regulatory policy, the rate of increase in resistance is

5.5 percent per year and the rate of decline in cotton yields per acre is 0.4 percent per year. What this analysis suggests is that the private economic returns to producers who follow the IPM strategy may be modest relative to a purely chemical strategy, but the social benefits of following an IPM approach in terms of reduced pesticide resistance are substantial.

Bias in Input Use

Optimal input use in the externality tax solution, as contrasted to the current standards-based regulatory solution, is biased toward less environmentally damaging inputs (see Table 5.13). Under the standards-based policy in which producers face increasing resistance but do not pay for future losses in the current period, producers use twice as much organophosphates relative to the usage levels under the externality tax program. Furthermore, no biological controls are used in the standards-based solution. Optimal quantities of pest scouting and monitoring are also lower than under the externality tax approach. As resistance increases and yields decline, growers switch to an IPM strategy in periods 8 and 9 (see Table 5.13). This is consistent with observed behavior among Imperial Valley producers. Only when control costs and yield losses became so high that cotton was being produced at a loss did producers enforce mandatory IPM practices. In contrast, the externality tax policy induced earlier adoption of nonexternality-generating inputs.

Productivity Effects

Not surprisingly, when resistance is accounted for, previous estimates of insecticide productivity are overstated.

The changes in the output index which reflects both cotton yields (positive output) and pesticide resistance (negative output) for the two policy simulations are provided in Table 5.14. Under the externality tax, the joint cotton-resistance index declines at a substantially lower rate than the same index for the standards-based simulation, primarily due to the lower rates of pesticide resistance that have been produced. This index is not directly comparable to conventional indexes of output growth since it reflects all outputs of the production process and not simply the marketed products. It clearly demonstrates that substantial differences in productivity indices would be forthcoming if the output measures of agricultural production processes included both marketed and nonmarketed products.

Table 5.14--Output Index of Crop and Resistance Production Under Alternative Regulatory Policy

Period	Standards-based Regulation	Externality Tax
1	100.0	100.0
2	98.9	99.5
3	95.6	98.9
4	94.2	98.3
5	92.8	97.8
6	81.5	97.5
7	81.0	96.8
8	66.3	96.3
9	66.1	96.1

Net Revenue Effects

The time path of discounted net revenues from the optimal solution are shown in Table 5.1 along with estimates of user cost. Discounted net revenues (based on profits only) are positive in every period. The user cost is within the range discussed previously.

Table 5.15--Tax Solution: Low Levels of Chemical Insecticides Combined with High Levels of IPM

Year	Discounted Net Revenues[a]	User Cost[b]
1	909.93	27.45
2	850.00	31.44
3	792.92	38.84
4	741.79	38.02
5	681.19	39.52
6	630.68	46.39
7	587.73	47.58
8	579.40	48.99
9	500.91	48.30
10	106.00	45.52

[a] Discounted (1.09) expectation of net revenues from following the optimal strategy.

[b] Discounted present value of the loss of effectiveness resulting from use levels which is assumed to be equivalent to User Cost.

6. SUMMARY AND CONCLUSIONS

A dynamic joint production system was developed and applied to the production of cotton and pesticide resistance as the externality from pesticide use. Evidence from this study indicates that under present regulatory policy, cotton yields have declined and rates of insecticide use have increased, due to resistance development. Yields per acre are estimated to decline about 2.25 percent per year over the five-year study period. Estimates from the joint production model indicate that, approximately 49 percent of the total decline, or 1.10 percent per year may be attributed to the declining productivity of organophosphates and synthetic pyrethroids. The field estimates of declining effectiveness obtained were consistent with laboratory data on the Tobacco budworm from the same geographic region, providing some evidence that empirical field analysis can be used to estimate declines in effectiveness.

The direct return on one dollar from chemical insecticides in cotton production is about $2.50 consistent with previous studies. When resistance is included, returns drop to $1.14 per dollar spent. Purchased pest management information is found to positivily affect yields returning approximately $5.00 per dollar of expenditure, twice the return from chemical pesticides at mean use levels. Pheromones positively affect yields at high use rates observed under the mandatory collective management program, but costs exceed returns; $1 invested in pheromones returns approximately $.75. Economic costs of resistance--measured lost productivity attributable to declining effectiveness--range between $20 and $50 per acre at present use levels.

When the price of pesticides does not reflect the full cost of their use because of spillover effects on the environment, the combination of pesticides and other inputs that is used may not be the least cost combination from a collective point of view. The dynamic analysis indicates that under the current regulatory program, technology relying primarily on chemical control continues to dominate other strategies over the model's time horizon. When producers are faced with an externality tax reflecting the opportunity cost of current pesticide use, an IPM technology becomes the preferred strategy.

This study provides some evidence that current standards-based pesticide policy has contributed to lower agricultural output without reducing total chemical use and, further, offers some explanation as to why adoption of environmentally-less-damaging technology has been slow. The results suggest that alternative policies should be considered that provide economic incentives for the adoption of alternative pest management methods such as IPM.

One of the key benefits of the dynamic programming approach is that the entire future path of production, costs, net benefits and externality levels can be determined for all feasible policy alternatives. An optimum plan for a several year period can be obtained providing valuable information on the process of long-run adjustment. In this case, uncertainty about the effect of pesticides in reducing pests was incorporated using a probability model. Obviously, the underlying assumption is that the econometrically determined biologic and physical relationships accurately capture the effects of any policy changes. When analyzing known technologies, this is probably not too restrictive an assumption. An additional advantage of this study is that all of the relationships in the model were econometrically determined. The empirical base allows the complex dynamic programming model results to be subjected to tests of empirical validity. This process of validation highlighted and other inputs that is used may not be the least cost combination from a collective point of view. The dynamic analysis indicates that under the current regulatory program, technology relying primarily on chemical control continues to dominate other strategies over the model's time horizon. When producers are faced with an externality tax reflecting the opportunity cost of current pesticide use, an IPM technology becomes the preferred strategy.

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In interpreting the results from the dynamic optimization model for this sector, the following limitations of the study should be noted. First, the nine control strategies are defined as discrete combinations, i.e., fixed proportions, of chemicals and IPM inputs. Only to the extent that these combinations are reflective of the input mixes growers would select under the alternative policy programs are the implications for levels of input use valid. Second, the results are sensitive to the level of uncertainty associated with the effectiveness of chemicals in suppressing the pest population. Improvements in the accuracy of the measurement of pesticide resistance would narrow the bounds of input use. In addition, modifications of the linear specification of the production function for cotton to reflect a more flexible functional form might minimize errors associated with model specification. Finally, it is not clear how the terminal conditions affect results, given the fairly short time horizon for the simulation, although the productive lifetime for pesticides expected by chemical manufacturers is within this bound.

The case study presented here suggests that dynamic models can provide useful information for analyzing the effects of regulations on agricultural productivity and technical change. This is a particularly important research tool when natural resources are employed in production and when the longer-run productivity effects of technology must be taken into account for proper analysis of alternative policies.

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APPENDIX A

SAMPLE SELECTION PROCEDURES AND RESPONSE ANALYSIS

A stratified random sample of cotton producers was selected to represent cotton producers for this study. The population was defined as those cotton producers in the Imperial Valley who had participated in USDA commodity price support and set-aside programs and was drawn from the USDA Agricultural Stabilization and Conservation Service's (ASCS) list of producers in Imperial County who have grown cotton in the past several years.[1] The ASCS list from which the sample was drawn provided information on the 1982 base cotton acreage by farm and 1982 calculated base total cropland.[2] Although annual changes in cotton farm acreage occur, the ASCS 1982 base total cropland was considered indicative of farm size and was used to stratify the sample by size.

All producers included in the ASCS list of producers were ordered by the total number of acres of 1982 base

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[1] Since it is frequently the case that more than one farm as defined by ASCS is farmed by the same producer, all farms identified as being operated by the same producer in any given year were considered together in determining total acreage managed by a given producer for each year over the period.

[2] The ASCS base cotton acreage for a given farm is calculated as the larger of the 1981 cotton acres harvested on that farm or the average of the cotton acres harvested on that farm in 1980 and 1981. Similarly, the 1982 base total cropland is determined as the larger of the 1981 total cropland on the farm or the average of the 1980 and 1981 total cropland on the farm.

cropland. Seven size strata were then determined based on the observed distribution of farms in the county. The size strata employed in the U.S. Census of Agriculture were judged not appropriate given the observed distribution of farm sizes primarily because of the number of larger sized farms in the Imperial Valley. The size categories chosen which appeared to best fit the distribution were:

Class Size	Acres
I	0 - 239
II	240 - 379
III	380 - 649
IV	650 - 1219
V	1220 - 1999
VI	2000 - 3499
VII	above 3500

As a first step in sample selection, the producers in each stratum were ordered and numbered according to the total cropland farmed by them. Twelve numbers were then drawn from a table of random numbers as the basis for selecting the sample from each stratum. Six randomly selected producers in each size category were contacted by mail and asked to participate. If producers had not returned self-addressed post cards within 2 weeks indicating whether or not they would participate they were contacted by telephone. Additional producers from the 12 originally selected were contacted in the order in which their numbers were drawn until 6 producers in each of the 7 size strata had agreed to cooperate. Of the producers who agreed to cooperate, 42 producers were interviewed in person by at least 2 members of the research team. Thirty-two surveys were complete enough to be included in the analysis.

Tables A.1 through A.4 present descriptive analysis of the sample as well as some comparable data for the County as a whole. The sample excellently represents cotton acreage in the Valley. Cotton acres were 11.4 percent of total acres in the sample or 6,821 acres out of 65,632 total acres. The cotton acreage for Imperial County as a whole for 1982 comprised 11.1 percent or 51,216 out of 461,506 total acres farmed (Office of Agricultural Commissioner, 1982).

Table A.1 shows the number and distribution by size of farms with completed schedules which were utilized in the analysis. Obtaining participation in size category four and five proved to be difficult. Apparently above size four and five, more management help is available such that producers had the time to participate.

Using the U.S. census to compare the distribution of farms sampled with those of Imperial County, it is clear from Table A.2 that eliminating farms with less than 100 acres as was done misses about 29 percent of these size farms in the county. In fact, the sample under-represents all size classes up to 200 acres and slightly

Table A.1 Number of Farms with Completed Field Schedules in Each Size Category

Class Size	Range of Harvested Acres	Number of Farms
I	Less than 240 acres	3
II	240 - 379 acres	5
III	380 - 649 acres	6
IV	650 - 1219 acres	2
V	1220 - 1999 acres	5
VI	2000 - 3499 acres	6
VII	Greater than 3500 acres	5

Table A.2 Comparison by Farm Size of Number of Farms in the Sample and Imperial County

Farm Size	1982 Sample No. of Farms	%	Imperial County (1978) No. of Farms	%
Less than 100 acres	0	0	181	29.0
100-199 acres	2	6.0	72	12.0
200-499 acres	4	13.0	136	22.0
500-999 acres	7	22.0	93	15.0
1000-1999 acres	9	28.0	133	21.0
2000 acres or more	10	31.0		
Total Farms	32			

Source: "1978 Census of Agriculture-County Data," Washington, D.C.: U.S. Dept. of Commerce, Bureau of the Census. Table 1. 250.

over-represents those over 500 acres. However, there were virtually no cotton growers among farms of less than 100 acres. For the purposes of estimating resistance as a collective externality, the proportion of cotton acres represented by the sample was most critical in capturing pesticide use. It is clear from Table A.3 that farms smaller than 100 acres comprise only two percent of the county's total harvested acres and farms up to 200 only 4 percent. Farms of this size represent even less of the cotton acreage in the Valley.

Examination of selected characteristics of the producers sampled (Table A.4) indicates that the producers sampled were fairly representative of Imperial Valley producers as a whole. The discrepancy between producers reporting off-farm work in the sample exists as a result of the decision to focus on cotton growers and thus eliminate those producers with less than one hundred acres who are most likely to have off-farm employment.

Table A.3 Comparison by Farm Size of Acres Harvested in the Sample and Total Acres Harvested for Imperial County

	1982 Sample		Imperial County (1978)	
Farm Size (Acres)	Acres Harvested (00's acres)	Percent	Acres Harvested (00's acres)	Percent
Less than 100	0	0	8.3	.02
100-199	.2	.4	10.4	.02
200-499	1.3	2.0	41.4	.10
500-999	5.3	8.1	65.2	.15
1000-1999	13.0	19.7	305.3	.71
2000 or more	45.7	70.0		

Source: "1978 Census of Agriculture-County Data," Washington, D.C.: U.S. Dept. of Commerce, Bureau of the Census. Table 4. 251.

Table A.4 Selected Characteristics of Sampled Cotton Producers Compared to all Imperial Producers

	Sample (1982)		Imperial County (1978)[a]	
Characteristic	Number of Producers	Percent	Number of Producers	Percent
Number of Producers Reporting Work Off-Farm	7	21.9	304	43.1
Age of Producers				
Less than 35 years	6	18.8	118	15.9
35-44 years	4	12.5	152	20.5
45-54 years	9	28.1	199	26.8
55 or older	13	40.6	273	36.8
Average Age of Producers	48.53 years		49.0 years	
Tenure of Producer				
Full Owner	6	18.8	180	29.3
Part Owner	15	46.9	264	42.3
Tenant	11	34.4	171	27.8
Average Years of Formal Education (Including College and/or Vocational School)	14.4 years		Not Available	
Type of Organization				
Individual or Family	22	68.0	483	65.1
Partnership	4	12.5	155	20.9
Corporation (Family)	5	15.6	71	9.6
Corporation (Other)	1	3.1	27	3.6
Others: Co-ops, Estates	0	0	6	.8
Total Number	32		742	

[a] Source: "1978 Census of Agriculture-County Data." Washington, D.C.: U.S. Dept. of Commerce, Bureau of the Census. Tables 1 and 4. 250-251.

APPENDIX B

SURVEY INSTRUMENT

Code Number ________

SECTION I. Pesticide Regulatory Program and Pest Management Issues: Cotton

THIS SECTION DEALS ONLY WITH COTTON PEST MANAGEMENT PRACTICES.

1. The Imperial Valley appears to have unique agricultural pest problems. How do you rank the factors listed below as contributing to present management problems with cotton pests in the Imperial Valley? (RANK 1 to 5, 1 MOST IMPORTANT.)

____ a. unique weather system (long, hot growing season)

____ b. limits placed on pest management materials and practices by regulation

____ c. new pests are always emerging

____ d. insects are becoming more resistant to present chemicals

____ e. past management practices by growers

2. If past management practices are responsible, in part, why do you believe they have continued? (RANK 1 to 5, 1 MOST IMPORTANT.)

____ a. other methods too expensive

____ b. other methods unreliable

____ c. other methods not available

____ d. other methods too technical

____ e. other (SPECIFY ______________________________)

3. What has induced you to adopt the "Pheromone-Chlordimeform Program"? (RANK 1 to 3, 1 MOST IMPORTANT.)

____ a. high costs of pest control in recent years

____ b. recognition of resistance buildup to present chemicals

____ c. opportunity to use chlordimeform

____ d. other ______________________________

4. Which of the following cotton pests do you consider to be PRIMARY cotton pests in the I.V. and which SECONDARY (P = 0 and S = 1) and what portion of yearly yield loss due to insect damage can be attributed to each.

Primary or Secondary	Percent of Yield Loss	
_____	__________	a. lygus
_____	__________	b. tobacco budworm
_____	__________	c. white flies
_____	__________	d. pink bollworm
_____	__________	e. cotton bollworm
_____	__________	f. spider mites
_____	__________	g. leaf perforator
_____	__________	h. other

5. What technical services do you purchase and how many times during the year are these services provided? (WRITE FREQUENCY NEXT TO APPROPRIATE SERVICE.)

_____ a. soils fertility analysis

_____ b. water timing and application analysis

_____ c. leaf analysis

_____ d. entomology services

_____ e. other (SPECIFY ______________________________)

6. Rank the following possible sources of pest control advice in cotton you now use in order of importance (1 BEING MOST IMPORTANT) and indicate frequency of contact with each in a growing season.

Rank	Frequency of Contact	Inf. Source
_____	__________	a. chemical company representative
_____	__________	b. neighbors/friends
_____	__________	c. county farm advisor
_____	__________	d. independent pest control advisor
_____	__________	e. in-house entomologist
_____	__________	f. extension service personnel other than c
_____	__________	g. agricultural scientists other than above
_____	__________	h. other (SPECIFY ____________________)

Code Number __________

7. Do you employ an <u>independent</u> pest management consultant to advise you on pest control?

____ a. Yes = 0 No = 1

IF <u>NO</u>, SKIP TO QUESTION <u>16</u>. IF <u>YES</u> INDICATE:

____ b. years of employment

____ c. total fee per acre for current year

____ d. entomology fee for cotton per acre for current year

8. What services provided by your PCA do you presently subscribe to: (0 = YES, 1 = NO)

____ a. field scouting

____ b. insect traps

____ c. boll cracking

____ d. treatment recommendations

____ e. chemical purchases

____ f. application arrangements

____ g. biological controls (IF YES, SPECIFY ____________________)

9. Did you employ an independent pest management consultant prior to changes made in pesticide use in 1981.

____ YES = 0 NO = 1

10. If all independent pest management consultants raised their prices, how high a price could your consultant charge before you would stop using his services?

_______ (A ROUGH $ PER ACRE ESTIMATE)

11. If you hire a PCA, what proportion of the time is the final decision on individual treatments made by:

____ a. you, the grower

____ b. pest control advisor

____ c. both you and the PCA jointly

____ d. don't approve individual treatments but approve a treatment plan for the season

____ e. other (SPECIFY __________________________)

12. How many times per week during the cotton growing season do you receive <u>information</u> from your PCA on pest conditions in your fields?

_____ a. early season (March to June)

_____ b. mid-season (June to September)

_____ c. late season (September to November)

13. In your opinion is information used by PCAs on which they base recommendations for treatment:

_____ a. has been adequate

_____ b. could be improved and would be worth the extra cost
(ASK HOW MUCH ____________________)

_____ c. could be improved but don't know if it would be worth extra money

14. Are you satisfied that the information available to you would allow you, the grower, to make treatment decisions?

_____ YES = 0 NO = 1

15. If NO, what technical information would be of most value to <u>you</u> in improving your ability to manage cotton pests? (RANK 1 THROUGH 5.)

_____ a. easily accessible information on pest levels, plant development, and guidance on when best to spray (economic threshold)

_____ b. more information on how chemicals affect plant development directly (fertilizers, herbicides and insecticides) and how they interact to affect growth and yields

_____ c. more specific information on costs and benefits of alternative control methods

_____ d. more specific information on effectiveness of certain chemicals as resistance develops

_____ e. more information on how chemicals work under certain conditions (e.g. high temperatures)

SKIP TO QUESTION 21

Code Number ______________

START HERE AFTER A "NO" TO QUESTION 7. IF YOU DO NOT NOW PRESENTLY EMPLOY AN INDEPENDENT PCA

16. Did you <u>ever</u> employ an independent PCA?

______ YES = 0 NO = 1

IF NO, SKIP TO QUESTION <u>18</u>

17. Did you stop using his services due to:

_____ a. cost

_____ b. performance

_____ c. better alternative (SPECIFY ______________________________)

_____ d. other (SPECIFY ______________________________)

SKIP TO QUESTION <u>21</u>.

18. If you do not use a PCA, have you ever considered using a PCA?

______ YES = 0 NO = 1

IF YES, SKIP TO QUESTION <u>20</u>.

19. If not, why haven't you?

_____ a. costs

_____ b. effectiveness

_____ c. better alternative (SPECIFY ______________________________)

_____ d. other (SPECIFY ______________________________)

SKIP TO QUESTION <u>21</u>.

20. If you have considered using a PCA, why haven't you?

_____ a. costs

_____ b. effectiveness

_____ c. better alternative (SPECIFY ______________________________)

_____ d. other (SPECIFY ______________________________)

21. Do you subscribe to <u>any</u> <u>other</u> pest management services? (e.g. biological controls or other?)

______ YES = 0 NO = 1

IF YES, SPECIFY ______________________________

22. Are insects becoming resistant to approved chemicals faster than they did in the past?

_____ a. Yes

_____ b. No

_____ c. Don't know

23. IF YES, do you attribute this to:

_____ a. faster development of resistance due to past exposure to chemicals

_____ b. less effective chemicals on the market

_____ c. other (SPECIFY ____)

24. Approximately how many times have you switched chemicals to control key cotton pests in the past 10 years specifically because of pest resistance to a chemical?

_____ a. lygus

_____ b. tobacco budworm

_____ c. pink bollworm

_____ d. spider mites

_____ e. other

25. What is most likely to extend the life time of present chemicals in controlling cotton pests? (RANK IN ORDER OF IMPORTANCE: 1 to 4, 1 BEING MOST IMPORTANT.)

_____ a. looser controls on their use such as eliminating label restrictions and application permit system

_____ b. allow previously banned chemicals to be used under stringent controls

_____ c. cooperative efforts of growers to control the level of pesticide use

_____ d. improved information on weather, pest levels and economic threshold levels available to PCAs and growers to allow for better timing of pesticide application

26. What, in your opinion, is the best pest control strategy for the long run?

_____ a. improve chemicals to kill (knock down) pest populations during the season

_____ b. eradicate key cotton pests (e.g. pink bollworm, tobacco budworm)

_____ c. use a variety of pest management strategies to reduce economic losses and keep insect populations in balance biologically (preserve beneficials)

_____ d. Other (SPECIFY ____)

NOTE: IF THEY HIRE A PCA I WILL BE ASKING THE FOLLOWING QUESTIONS OF THE PCA. IF THEY DO NOT HIRE A PCA, GO ON TO QUESTIONS 27-37.

27. How many times have you received in the past ten years the following types of sanctions from the County Agricultural Commissioner's office for violating pesticide regulations?

Frequency	Type
________	a. verbal (or telephone)
________	b. written notice
________	c. fine
________	d. suspension
________	e. other
________	f. don't know

28. How many times have your requests for permits for application of restricted pesticide materials been questioned by the county?

_____ a. in the past two years

_____ b. in the past five years

_____ c. in the past ten years

_____ d. don't know

_____ e. none (IF NONE, SKIP TO QUESTION 30)

29. If they have been questioned, for what reason? (NUMBER OF TIMES EACH REASON GIVEN.)

_____ a. incomplete information on the application

_____ b. method of evaluation of pest problems questioned

_____ c. treatment judged not necessary

_____ d. other methods for control were available

_____ e. treatment judged too hazardous

_____ f. other (SPECIFY ____)

30. How many times have you received an alternative to spraying recommendation from the county when you filed for a permit to spray?

________ (NUMBER OF TIMES)

31. How many times have your pest control recommendations been audited by the county commissioners office?

_____ a. past two years

_____ b. past five years

32. How many times has the County Commissioner "pulled" or removed labels on class I restricted materials in Imperial County?

_____ a. past two years

_____ b. past five years

33. How many information meetings held by the Ag. Commissioner's office regarding use of specific pesticides have you attended?

_____ a. past two years

_____ b. past five years

34. What were your per acre pest control costs ("charges" if a PCA) in:

_______ a. 1980

_______ b. 1981

35. _______ What proportion of these costs do you attribute <u>SOLELY</u> to changes in the regulatory program last year?

36. Has the 24 hour rule changed the way you make pest control recommendations?

_______ YES = 0 NO = 1

IF YES, DO YOU

_____ a. spray less frequently

_____ b. spray more frequently

_____ c. other (SPECIFY ____)

37. What specific information would be of most value to <u>YOU</u> in improving your ability to manage cotton pests? (RANK 1 THROUGH 4.)

_____ a. more reliable information on pest levels, plant development, and guidance on when best to spray (economic threshold)

_____ b. more information on how chemicals affect plant development directly (fertilizers, herbicides and insecticides) and how they interact to affect growth and yields

_____ c. more specific information on costs and benefits of alternative control methods

_____ d. more specific information on effectiveness of certain chemicals and how they behave over time as resistance develops.

STOP HERE (unless a PCA)

ASK NEXT QUESTIONS ONLY OF PCAs.

38. Are insects becoming resistant to approved chemicals faster than they did in the past?

_____ a. Yes

_____ b. No

39. IF YES, do you attribute this to:

_____ a. faster development of resistance due to past exposure to chemicals

_____ b. less effective chemicals

_____ c. both a and b

40. Approximately how many times have you switched chemicals to control key cotton pests in the past <u>10</u> years specifically because of pest resistance to a chemical?

_____ a. lygus

_____ b. tobacco budworm

_____ c. pink bollworm

_____ d. spider mites

_____ e. other

41. What is most likely to extend the life time of present chemicals in controlling cotton pests? (RANK IN ORDER OF IMPORTANCE: 1 to 4, 1 BEING MOST IMPORTANT.)

_____ a. looser controls on their use such as eliminating label restrictions and application permit system

_____ b. allow previously banned chemicals to be used under stringent controls

_____ c. cooperative efforts of growers to control the level of pesticide use

_____ d. improved information on weather, pest levels and economic threshold levels available to PCAs and growers to allow for better timing of pesticide application

42. What, in your opinion, is the best pest control strategy for the long run?

_____ a. improve chemicals to kill (knock down) pest populations during the season

_____ b. eradicate key cotton pests (e.g. pink bollworm, tobacco budworm)

_____ c. use a variety of pest management strategies to reduce economic losses and keep insect populations in balance biologically (preserve beneficials)

_____ d. Other (SPECIFY ____)

Code Number ________

SECTION III.A. Producer Descriptive Information

1. ________ Age   2. ________ Years of formal education.

3. ________ Years of vocational training.

4. ________ Number of years as owner-operator in agricultural production.

5. Type of business operation:

____ a. Corporation (# of stockholders ____)

____ b. Family farm

____ c. Family partnership

____ d. Family corporation

____ e. Part-time farm

____ f. Partnership

____ g. Property management

____ h. Limited partnership (#____)

____ i. Other ____________

6. Is the farm as addressed in our letter the total farming property that you operate?

____ a. Yes

____ b. No

If not, what other names in the ASCS records make up the property that you operate?

____

____

____

7. In a normal year, what percentage of net income (after taxes) comes from nonfarm sources? ____________ percent. Of this, what comes from land that you lease out? ____________ percent.

8. What percent of your time is devoted to farming the above property(ies)? ________

9. What percent of your time do you spend on the following activities?

________ a. Managing finances (including obtaining annual financing, estate planning, etc.).

________ b. Supervising production personnel.

________ c. "Hands-on" production.

________ d. Working with consultants.

________ e. Marketing products.

10. Into which of the following intervals does the ratio of all debt obligations to the value of all assets fall for your farm? (For example: if you owe $100,000 on your land plus $50,000 for current operating expenses such as fuel, chemicals, etc. and your land, machinery, cash reserves, inventories, etc. are worth $500,000, then your debt to asset ratio is $\frac{\$100,000 + \$50,000}{\$500,000} = .3$).

0-.3	.3-.5	.5-.7	.7-.9	.9-1.1	>1.1

11. Into which of the following intervals does the ratio of current assets to current liabilities fall for your farm? (Current assets include cash, accounts receivable, warehouse receipts, etc. Current liabilities include all loan payments due and payable in the current year plus accounts payable.) (Example: if you have $5,000 in cash and a warehouse receipt for 200 bales of cotton valued at $60,000 and you had $10,000 in loan payments due in the next year plus $50,000 in accounts payable for operating expenses, your current asset to current liability ratio would be $\frac{\$60,000 + \$ 5,000}{\$10,000 + \$50,000} = 1.083$.)

0-.5	.5-1.	1.-1.5	1.5-2.	2-3	3-4	>4

12. What is your major source of borrowing for?

	Operating Capital	Long-term Borrowing
Self		
Private Individual(s)		
Bank		
PCA		
FHA		
Insurance Company		
Federal Land Bank		

Code Number ________

SECTION III.B. Farm Location, Acreage by Crop, Land Rental Terms, Irrigation Facilities

1. Please mark fields currently operated (owned or leased) by you and owned and operated by others on the attached map(s). Please indicate the location of the farm headquarters.

Assigned Field No.	Grower's Field No. (if available)	Gross Acres	Acres Owned	Acres Leased

2.a. What is your general rotation plan, if any? [IT MAY VARY BY LOCATION OR SOIL. IF SO, NOTE THIS. IF DON'T HAVE A GENERAL PLAN, ASK FOR CURRENT.]

2.b. Do you have any fields on which you cannot follow this rotation plan because of soil and/or water problems? If so, which fields and what crops do you grow on them?

Code Number ______

Assigned Field No.	Grower's Field No. (if available)	Gross Acres	Acres Owned	Acres Leased

Production Schedules

1. Cotton Lint: Production Practices

Operation	No. of Times Performed		Custom Rates 1/ (per acre per treatment)		If Performed by Producer: Hand Labor (man hours)		Machine		Materials Used 2/ (name and quantity/acre)	
	Typical	Yours	Typical	Yours	Typical	Yours	Examples	Yours	Typical	Yours
Land Preparation										
Subsoil	1X		24.00		--		Crawler ___ HP 5-shank sub-soiler		--	
Disc	2X		8.00		--		Crawler ___ HP 16' offset disc		--	
Float			7.00		--		Crawler ___ HP Float ___'		--	
Laser Plane			20.00		--		Crawler, laser leveller, laser equipment		--	
Border-cross check			14.00		--		Crawler ___ HP checker/border disc		--	
Fertilizer			11.00		--		Wheel tractor fertilizer rig.		104 N-96 P_2O_5	
List			9.00		--		Crawler ___ HP lister		--	
Irrigate					2		--		1/2 acre-ft. water	
Lilliston ?			9.00		--		Crawler ___ HP Lilliston? Bedder?		--	

Code Number

1/ Source of "Typical": Guidelines to Production Costs and Practices 1981-82 Imperial County Crops, Circular 104, Coop. Ag. Ext., El Centro.

2/ Note if includes or excludes materials.

(Cotton Lint)

Operation	No. of Times Performed		Custom Rates (per acre per treatment)		If Performed by Producer				Materials Used (name and quantity/acre)	
					Hand Labor (man hours)		Machine			
	Typical	Yours	Typical	Yours	Typical	Yours	Examples	Yours	Typical	Yours
Growing Period										
Plant-Herbicide			11.50		--		Wheel tractor ___ HP, 4-row planter		20 lbs seed @ .45 Herbicide Type___ Rate___	
Cultivate	3X		8.50		--		Wheel tractor ___ HP, cultivator		--	
Fertilize (other nutrients)	2X		10.00				Wheel tractor ___ HP, fert. rig.		185 lbs N.	
Hand Thin			--		5.7		--		--	
Insect Control	SEE PAGE ON PEST MANAGEMENT									
Layby Herbicide			4.00				Wheel tractor ___ HP, herbicide applicator		Herbicide	
Irrigate	10X		--		10		--		5.5 acre-feet water	
Defoliate	1X		4.00		--		Fly-on		Defoliant $15.00	
Chop Stalks			8.00				Wheel tractor chopper ___ HP			
Disc	10X		17.00							

Code Number

(Cotton Lint)

Operation	No. of Times Performed		Custom Rates (per acre per treatment)		If Performed by Producer				Materials Used (name and quantity/acre)	
					Hand Labor (man hours)		Machine			
	Typical	Yours	Typical	Yours	Typical	Yours	Examples	Yours	Typical	Yours
Harvest										
Machine Picking			52.50/ bale 45.00/ ac. min		--		2-4 row cotton pickers		--	
Hauling			7.00/ bale				4-cotton trailors 2-wheel tractors			
Ginning			2.50/ cwt of cotton seed							

Code Number ____________

(Cotton Lint)

Pest Management

Operation	No. of Times Performed	Custom (PCA) (rate per acre)		Performed by Producer (rate per acre or man hours)		Performed by Other ________ (rate/acre)	Materials Used (name and quantity/acre	
		Typical	Yours	Typical	Yours		Typical	Yours
Information on Pest Populations								
scouting/field checks								
traps								
weather								
Chemical Controls								
organophosphates								
organochlorines								
carbamates								
pyrethroids								
pheromones								
other								
Cultural Controls								
early termination								
chop stalks								
hand weed								
other								

Code Number

APPENDIX C

PESTICIDE USE REPORT

STATE OF CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE — PESTICIDE USE REPORT — Submit to Agricultural Commissioner within 7 days of the app

1 County No.	2 Section	3 Township	4 Range	5 Base & Meridian	6 Application Method	7 Commodity or Site Treated	APPLICATOR NAME & ADDRESS
13	31	13 N [✓ S]	13 [✓ E] W	S H S M	☑ Air ☐ Ground ☐ Other	COTTON	

9 DESCRIBE LOCATION	10 DATE(S) APPLIED	11 ACRES OR UNITS TREATED	8
THISTLE 8 - 3	6-3-81	34	
	12 EQUIPMENT IDENTIFICATION	**13 PERMIT NO**	**14 CUSTOMER**
	BAILEY 04K	R-27-81	G 35

15 Name of Product Applied	16 Registration Number from Label	17 Total Product Used (circle unit of measure)	18 Target P
DOW CHEM. LORSBAN	00464 — 00448 — AA — 000	5 LB OZ PT QT [✓ GA]	A ARMY B
GRIFFIN CORP. SUPER 6 SULFUR	01812 — 00196 — AA — 00000	10 LB OZ PT QT [✓ GA]	A SPIDE B
	— — —	LB OZ PT QT GA	A B
	— — —	LB OZ PT QT GA	A B

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APPENDIX D

STATISTICAL RESULTS FROM PROBIT ESTIMATION

Appendix D.i Maximum Likelihood Probit Estimates

Variable	Coefficient	Std. Error	T-Ratio	Mean of X	S.D. of X
Constant	0.62118	0.10175	6.1050	1.0000	0.54411E-08
CB	9.6699	4.6412	2.0835	0.14251	0.37181
OP	-0.17267E-01	0.94792E-01	-0.18216	0.77464	1.3178
9/23 SP	0.86357E-01	0.11832	0.72987	0.21564	1.0746
DEG/DD	0.89071E-03	0.12976E-02	0.68644	60.862	36.415
80 CB	-9.2312	4.6746	-1,9747	0.91098E-02	0.76049E-01
81 CB	-9.5725	4.6357	-2.0650*	0.13165	0.36770
80 OP	-0.95337E-01	0.12694	-0.75102	0.13797	0.65232
81 OP	0.58734E-01	0.98652E-01	0.59536	0.50933	1.1809
80 SP	1.4061	0.65460	2.1480	0.28920E-01	0.10661
81 SP	-0.71516	0.26273	-2.7220	0.90530E-01	0.18586

Log- Likelihood	-527.11
Restricted (Zero Slopes) Log L	-525.72
Chi-Squared	17.212
Degrees of Freedom	10
Significance Level for Test	0.69810E-01

Appendix D.ii Conditional Mean Probabilities Computed From MLE Probit Results

	Probability of Mortality		
	1979	1980	1981
Carbamates	91.5 (.140)	90.2 (.142)	55.0 (0.27)
Organophosphates	49.6 (.774)	48.2 (.911)	50.8 (1.28)
Synthetic Pyrethroids	50.7 (.215)	52.3 (.243)	48.4 (0.305)

```
OBSER.    OBSERVED Y       FITTED MEAN    BETA X

   1      0. 99990         0. 75609       0. 69377
   2      0. 99990         0. 75056       0. 67626
   3      0. 99990         0. 73418       0. 62550
   4      0. 99990         0. 94525        1. 6005
   5      0. 16670         0. 75675       0. 69590
   6      0. 80000         0. 75777       0. 69913
   7      0. 99990         0. 75777       0. 69913
   8      0. 85710         0. 75675       0. 69590
   9      0 33330          0. 94336        1. 5836
  10      0. 99990         0. 74843       0. 66955
  11      0. 75000         0. 73543       0. 62933
  12      0. 50000         0. 76221       0. 71342
  13      0. 66670         0. 75794       0. 69968
  14      0. 99990         0. 75198       0. 68074
  15      0. 99990         0. 74300       0. 65262
  16      0. 99990         0. 74137       0. 64758
  17      0. 99990         0. 73543       0. 62933
  18      0. 94440         0. 75794       0. 69968
  19      0. 99990         0. 94008        1. 5554
  20      0. 99990         0. 76256       0. 71457
  21      0. 66670         0. 75643       0. 69487
  22      0. 75000         0. 76256       0. 71457
  23      0. 99990         0. 73459       0. 62676
  24      0. 75000         0. 94008        1. 5554
  25      0. 50000         0. 75643       0. 69487
  26      0. 99990         0. 73459       0. 62676
  27      0. 99990         0. 94008        1. 5554
  28      0. 50000         0. 76256       0. 71457
  29      0. 99990         0. 75513       0. 69071
  30      0. 99990         0. 98983        2. 3202
  31      0. 70000         0. 76412       0. 71963
  32      0. 10000E-03     0. 75987       0. 70588
  33      0. 66670         0. 75987       0. 70588
  34      0. 66670         0. 74888       0. 67098
  35      0. 99990         0. 75503       0. 69039
  36      0. 80000         0. 75494       0. 69011
  37      0. 99990         0. 75679       0. 69603
  38      0. 99990         0. 75974       0. 70547
  39      0. 99990         0. 75010       0. 67482
  40      0. 10000E-03     0. 76595       0. 72558
```

```
41    0. 71430        0. 75945      0. 70454
42    0. 50000        0. 75010      0. 67482
43    0. 10000E-03    0. 76093      0. 70931
44    0. 99990        0  75902      0. 70316
45    0. 10000E-03    0. 75902      0. 70316
46    0. 99990        0. 75902      0. 70316
47    0. 99990        0. 76355      0. 71776
48    0. 10000E-03    0. 74708      0. 66533
49    0. 99990        0. 75894      0. 70289
50    0. 99990        0. 75894      0. 70289
51    0. 99990        0. 75483      0. 68977
52    0. 99990        0. 75483      0. 68977
53    0. 16670        0. 75780      0. 69924
54    0  75000        0. 69771      0. 51782
55    0. 99990        0. 75780      0. 69924
56    0. 99990        0. 75345      0. 68539
57    0. 99990        0. 77332      0. 74983
58    0. 50000        0. 81604      0. 90039
59    0. 87500        0. 79102      0. 80997
60    0. 66670        0. 79102      0. 80997
61    0. 99990        0. 79195      0. 81322
62    0. 99990        0. 77650      0. 76042
63    0. 50000        0. 79495      0. 82372
64    0. 50000        0. 83932      0. 99166
65    0. 99990        0. 84948        1. 0342
66    0. 99990        0. 85381        1. 0529
67    0. 99990        0. 84763        1. 0263
68    0  99990        0. 84763        1. 0263
69    0. 10000E-03    0. 84948        1. 0342
70    0. 10000E-03    0. 83788      0. 98577
71    0. 99990        0. 85381        1. 0529
72    0. 99990        0. 79506      0. 82412
73    0. 50000        0. 78887      0. 80251
74    0. 10000E-03    0. 81774      0. 90677
75    0. 99990        0. 80002      0. 84169
76    0. 99990        0. 84161        1. 0011
77    0. 99990        0. 68621      0. 48514
78    0  99990        0. 62987      0. 33150
79    0. 99990        0. 84161        1. 0011
80    0. 33330        0. 79886      0. 83754
81    0. 99990        0. 72995      0. 61265
82    0. 99990        0. 86955        1. 1243
83    0. 33330        0. 65755      0. 40578
84    0. 10000E-03    0. 32782     -0. 44594
85    0. 76920        0. 82136      0. 92056
```

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 86   0. 99990       0. 88418     1. 1961
 87   0. 99990       0. 77335    0. 74991
 88   0. 99990       0. 78562    0. 79130
 89   0. 10000E-03   0. 88892     1. 2208
 90   0. 99990       0. 93199     1. 4908
 91   0. 50000       0. 79502    0. 82396
 92   0. 99990       0. 93199     1. 4908
 93   0. 66670       0. 79502    0. 82396
 94   0. 99990       0. 93199     1. 4908
 95   0. 10000E-03   0. 77610    0. 75907
 96   0. 99990       0. 86313     1. 0945
 97   0. 66670       0. 74468    0. 65785
 98   0. 99990       0. 74468    0. 65785
 99   0. 99990       0. 77610    0. 75907
100   0. 99990       0. 71938    0. 58101
101   0. 99990       0. 74669    0. 66411
102   0. 76920       0. 71313    0. 56255
103   0. 10000E-03   0. 75803    0. 69999
104   0. 50000       0. 71604    0. 57113
105   0 88870        0. 73353    0. 62353
106   0. 99990       0. 74063    0. 64530
107   0. 95000       0. 63917    0. 35625
108   0. 66670       0. 70221    0. 53076
109   0. 87500       0. 80729    0. 86794
110   0. 36360       0. 60110    0. 25621
111   0. 99990       0. 77654    0. 76056
112   0. 66670       0. 66129    0. 41598
113   0 88870        0. 70833    0. 54850
114   0 20000        0. 71597    0. 57092
115   0. 99990       0. 77137    0. 74336
116   0. 99990       0. 75061    0. 67640
117   0. 99990       0 74758     0. 66689
118   0. 99990       0 76272     0. 71507
119   0. 80560       0. 73996    0. 64322
120   0. 50000       0 74435     0. 65680
121   0. 10000E-03   0. 71568    0. 57005
122   0. 10000E-03   0. 74445    0. 65714
123   0. 66670       0. 70432    0. 53687
124   0. 50000       0. 73408    0. 62521
125   0. 10000E-03   0. 75771    0. 69895
126   0. 10000E-03   0. 74225    0. 65029
127   0. 10000E-03   0. 67528    0. 45455
128   0. 99990       0. 71666    0. 57295
129   0. 99990       0. 74393    0. 65551
130   0. 50000       0. 74814    0. 66863
```

```
131   0. 99990        0. 73708      0. 63436
132   0. 99990        0. 69592      0. 51271
133   0. 50000        0. 74225      0. 65029
134   0. 10000E-03    0. 73585      0. 63060
135   0. 99990        0. 72519      0. 59833
136   0. 10000E-03    0. 75771      0. 69895
137   0. 10000E-03    0. 71483      0. 56756
138   0. 60000        0. 78097      0. 77546
139   0 44440         0. 64840      0. 38100
140   0. 90000        0. 69078      0. 49807
141   0. 50000        0. 77016      0. 73937
142   0. 10000E-03    0. 73305      0. 62206
143   0. 83330        0. 77979      0. 77150
144   0. 99990        0. 72475      0. 59701
145   0. 99990        0. 75236      0. 68192
146   0 99990         0. 76352      0. 71766
147   0. 10000E-03    0. 72904      0. 60991
148   0. 70000        0. 75606      0. 69369
149   0. 67740        0. 75595      0. 69332
150   0. 99990        0. 75595      0. 69332
151   0. 99990        0. 72475      0. 59701
152   0. 99990        0. 75563      0. 69230
153   0. 30000        0. 52129      0. 53380E-01
154   0. 99990        0. 80635      0. 86451
155   0. 50000        0. 73473      0. 62718
156   0. 50000        0 68236       0. 47430
157   0. 10000E-03    0. 76840      0. 73360
158   0. 85710        0. 63933      0. 35667
159   0. 50000        0. 63933      0. 35667
160   0. 99990        0. 65561      0. 40050
161   0 71430         0. 76840      0. 73360
162   0. 65450        0. 68236      0. 47430
163   0. 99990        0. 75510      0. 69062
164   0. 99990        0. 74665      0. 66397
165   0. 55560        0. 75510      0. 69062
166   0. 82350        0. 75865      0. 70196
167   0. 99990        0. 75568      0. 69248
168   0 55560         0. 80230      0. 84988
169   0. 50000        0 74396       0. 65560
170   0. 80950        0. 77189      0. 74508
171   0. 50000        0. 74240      0. 65077
172   0. 82350        0. 78807      0. 79975
173   0. 99990        0. 78807      0. 79975
174   0. 99990        0. 77189      0. 74508
175   0. 99990        0. 80230      0. 84988
176   0. 99990        0. 75865      0. 70196
177   0. 99990        0. 74677      0. 66437
178   0. 73910        0. 81188      0. 88484
179   0. 50000        0. 70518      0. 53934
```

APPENDIX E

SOLUTION ALGORITHM FOR DYNAMIC PROGRAMMING PROBLEM

```
:_LIST SATDP
LISTING OF PROGRAM SATDP
   1.0 PROGRAM
   2.0 $CHETDP 12/17/84 SOA FOR BUGS
   3.0 $STAGES=TT, STATE LEVELS=NT, CONTROL LEVELS=MT
   4.0 TT = 10
   5.0 PMX=10
   6.0 QMX=10
   7.0 RMX=1
   8.0 NT=PMX*QMX*RMX
   9.0 MT = 9
  10.0 VAL=ARRAY2D(NT,TT)
  11.0 PREF=ARRAY2D(NT,TT)
  12.0 GOTO=ARRAY2D(NT,TT)
  13.0 PROB=ARRAY(NT)
  14.0 OPT=ARRAY(TT)
  15.0 TCST=VECTOR(6:)
  16.0 PMAT=ARRAY2D(MT,PMX)
  17.0 QMAT=ARRAY2D(MT,QMX)
  18.0 RMAT=ARRAY2D(MT,RMX)
  19.0 PMAT(,1)=2,2,3,3,2,2,2,2,2
  20.0 PMAT(,2)=3,3,4,4,3,3,3,3,3
  21.0 PMAT(,3)=4,4,5,5,4,4,4,4,4
  22.0 PMAT(,4)=5,5,6,6,5,5,5,5,5
  23.0 PMAT(,5)=6,6,7,7,6,6,6,6,6
  23.1 PMAT(,6)=7,7,8,8,7,7,7,7,7
  23.2 PMAT(,7)=8,8,9,9,8,8,8,8,8
  23.3 PMAT(,8)=9,9,10,10,9,9,9,9,9
  23.4 PMAT(,9)=10,10,10,10,10,10,10,10,10
  23.5 PMAT(,10)=10,10,10,10,10,10,10,10,10
  23.6 PMAT
  24.0 QMAT(,1)=2,2,2,4,3,4,2,3,4
  25.0 QMAT(,2)=3,3,3,5,4,5,3,4,5
  26.0 QMAT(,3)=4,4,4,6,5,6,4,5,6
  27.0 QMAT(,4)=5,5,5,7,6,7,5,6,7
  28.0 QMAT(,5)=6,6,6,8,7,8,6,7,8
  28.1 QMAT(,6)=7,7,7,9,8,9,7,8,9
  28.2 QMAT(,7)=8,8,8,10,9,10,8,9,10
  28.3 QMAT(,8)=9,9,10,10,10,10,9,10,10
  28.4 QMAT(,9)=10,10,10,10,10,10,10,10,10
  28.5 QMAT(,10)=10,10,10,10,10,10,10,10,10
  28.6 QMAT
  29.0 RMAT(,1)=1,1,1,1,1,1,1,1,1,1
  30.0 RMAT(,2)=2,2,2,2,2,2,2,2,2,2
  31.0 RMAT(,3)=3,3,3,3,3,3,3,3,3,3
  32.0 RMAT(,4)=4,4,4,4,4,4,4,4,4,4
  33.0 RMAT(,5)=5,5,5,5,5,5,5,5,5,5
  34.0 STA=ARRAY(9:.1,.2,.3,.4,.5,.6,.7,.8,.9)
  35.0 CON=MATRIX(6,MT)
  36.0 CON(,1)=.45,.12,0.0,0.0,.665,15.
  37.0 CON(,2)=.75,.12,0.0,0.0,.665,15.
  38.0 CON(,3)=.45,.05,0.0,0.0,.665,15.
  39.0 CON(,4)=.45,.12,0.0,0.0,.665,15.
```

```
40.0 CON(,5)=.45,.24,0.0,0.0,.665,15.
41.0 CON(,6)=.45,.12,0.0,0.0,0.0,15.
42.0 CON(,7)=.45,.12,0.0,0.0,.665,21.
43.0 CON(,8)=.45,.12,0.0,0.0,.8,15.
44.0 CON(,9)=.75,.24,0.0,0.0,0.0,15.
45.0 CON
46.0 OPCO=ARRAY(PMX:.983,.8,.779,.6,.575,.4,.371,.2,.167,.0)
47.0 SPCO=ARRAY(QMX:2.74,2.4,2.11,1.8,1.48,.7,.26,.25,.23,.0)
48.0 CACO=ARRAY(5:4.6,4.55,4.35,4.0)
49.0 PRDCOE=VECTOR(6:0.0,0.0,0.0,5.53,29.1,7.82)
50.0 TVAL1=ARRAY(PMX:0.0,10.0,22.3,30.0,44.6,50.0,67.0,70.0,
     89.2,90.0)
51.0 TVAL2=ARRAY(QMX:0.0,12.0,26.5,35.0,50.0,60.0,79.5,92.0,
     106.0,120.0)
52.0 CST=VECTOR(6:68.715,389.82,19.32,56.0,80.0,1.0)
52.1 CST
53.0 P=INTEGERS(1,PMX)
54.0 Q=INTEGERS(1,QMX)
55.0 R=INTEGERS(1,RMX)
56.0 MELD(P,Q,R)
57.0 OPCO=VFAM(OPCO(P))
58.0 SPCO=VFAM(SPCO(Q))
59.0 CACO=VFAM(CACO(R))
60.0 SHIFT=MATRIX(NT,6)
61.0 SHIFT(,1)=OPCO
62.0 SHIFT(,2)=SPCO
63.0 SHIFT(,3)=CACO
64.0 INDEX=((P*(QMX*RMX))+(Q*RMX)+R)-RMX-RMX*QMX
65.0 SIZE=MAX(INDEX)
66.0 TERM = MATRIX(SIZE,3)
67.0 TERM(,1)=TVAL1(P)
68.0 TERM(,2)=TVAL2(Q)
69.0 TERVAL=VECTOR(SIZE:)
70.0 TERM
70.1 TERVAL
70.2 SIZE
71.0 FOR S=1,SIZE,1
71.1 TERVAL(S)=0.0
72.0 TERVAL(S)=TERM(S,1)+TERM(S,2)
73.0 NEXT S
74.0 TERVAL=TERVAL/0.09
75.0 TERVAL
76.0 PROBIT=SHIFT*CON
76.1 PROBIT
77.0 TCST=TRANSPOSE(CST)
78.0 CONCST=TCST*CON
78.1 CONCST
79.0 TPRDCOE=TRANSPOSE(PRDCOE)
80.0 INFO=TPRDCOE*CON
80.1 INFO
81.0 J=INTEGERS(1,NT)
82.0 M=INTEGERS(1,MT)
83.0 PX=P
```

```
 84.0 QX=Q
 85.0 RX=R
 86.0 PL=PMAT(M,PX)
 87.0 QL=QMAT(M,QX)
 88.0 RL=RMAT(M,RX)
 89.0 TPL=TRANSPOSE(PL)
 90.0 TQL=TRANSPOSE(QL)
 91.0 TRL=TRANSPOSE(RL)
 92.0 LINDEX(J,M)=(TPL(J,M)*(QMX*RMX)+TQL(J,M)*RMX+TRL(J,M))
      -RMX-RMX*QMX
 93.0 PROBIT=AFAM(PROBIT)
 94.0 MEAN=GAUSS(PROBIT)
 94.1 MEAN
 95.0 Z=INTEGERS(1,9)
 96.0 MELD (M,Z)
 97.0 ZVAL=-MEAN(J,M)+STA(Z)
 98.0 ZVAL=ZVAL/.20
 99.0 PR=GAUSS(ZVAL)
 99.1 PR
100.0 SIZE=NT*MT
101.0 PR2=ARRAY2D(SIZE,9:PR)
102.0 LAG2=ARRAY2D(SIZE,9)
103.0 LAG2(,1) = PR2(,2)
104.0 LAG2(,2) = PR2(,3)


105.0 LAG2(,3) = PR2(,4)
106.0 LAG2(,4) = PR2(,5)
107.0 LAG2(,5) = PR2(,6)
108.0 LAG2(,6) = PR2(,7)
109.0 LAG2(,7) = PR2(,8)
110.0 LAG2(,8) = PR2(,9)
111.0 LAG2(,9) = 1.0
112.0 PROB=LAG2-PR2
114.0 YLD = 1711.25-111.18*3.8*(1-STA)
114.1 YLD
115.0 INFO = AFAM(INFO)
116.0 NYLD = (ARRAY2D(MT,9)+1)*YLD
      + TRANSPOSE((ARRAY2D(9,MT)+1)*INFO)
117.0 NYLD
118.0 CONCST = AFAM(CONCST)
119.0 REV = 0.70*NYLD - TRANSPOSE((ARRAY2D(9,MT)+1)*CONCST)
120.0 REV
121.0 REV1 = REV(,1)
122.0 REV2 = REV(,2)
123.0 REV3 = REV(,3)
124.0 REV4 = REV(,4)
125.0 REV5 = REV(,5)
126.0 REV6 = REV(,6)
127.0 REV7 = REV(,7)
128.0 REV8 = REV(,8)
```

```
129.0 REV9 = REV(,9)
130.0 CC=ARRAY(NT:)
131.0 C=CC
132.0 MELD(C,REV1)
133.0 C=CC
134.0 MELD(C,REV2)
135.0 C=CC
136.0 MELD(C,REV3)
137.0 C=CC
138.0 MELD(C,REV4)
139.0 C=CC
140.0 MELD(C,REV5)
141.0 C=CC
142.0 MELD(C,REV6)
143.0 C=CC
144.0 MELD(C,REV7)
145.0 C=CC
146.0 MELD(C,REV8)
147.0 C=CC
148.0 MELD(C,REV9)
149.0 REV1 = PROB(,1)*REV1
150.0 REV2 = PROB(,2)*REV2
151.0 REV3 = PROB(,3)*REV3
152.0 REV4 = PROB(,4)*REV4
153.0 REV5 = PROB(,5)*REV5
154.0 REV6 = PROB(,6)*REV6
155.0 REV7 = PROB(,7)*REV7
156.0 REV8 = PROB(,8)*REV8
157.0 REV9 = PROB(,9)*REV9
158.0 REV1 = REV1+REV2+REV3+REV4+REV5+REV6+REV7+REV8+REV9
159.0 REV1
160.0 PROF = ARRAY2D(NT,MT:REV1)
161.0 W=INTEGERS(1,NT)
162.0 X=INTEGERS(1,MT)
163.0 MELD(X,W)
164.0 SCRAP=VFAM(TERVAL(W))
165.0 SCRAP=-SCRAP
166.0 MARK=ARRAY(SIZE:LINDEX)
167.0 MARK
168.0 SCRAP=MATRIX(MT,NT:SCRAP)
169.0 SCRAP= TRANSPOSE(SCRAP)
170.0 SCRAP
171.0 FOR T=TT-1,1,-1
172.0 PASTVAL=VAL(,T+1)
173.0 PASTVAL
174.0 LVAL=PASTVAL(MARK)
175.0 LGVAL=ARRAY2D(NT,MT:LVAL)
176.0 IF (T .EQ. TT-1) LGVAL=SCRAP
177.0 "START OF PERIOD"
178.0 LGVAL=MFAM(LGVAL)
179.0 LGVAL
180.0 PROF=PROF*(1/(1.09**T))
181.0 PROF=MFAM(PROF)
182.0 PROF
183.0 OBJ = PROF+LGVAL
```

```
 184.0 OBJ
 185.0 FOR K=1,NT,1
 186.0 VAL(K,T)=MAX(OBJ(K,))
 187.0 PREF(K,T)=LOCMAX(OBJ(K,))
 188.0 GOTO(K,T)=LINDEX(K,PREF(K,T))
 189.0 NEXT K
 190.0 NEXT T
 191.0 PREF
 192.0 GOTO
 193.0 VAL
 194.0 'CONTROL CHOICE'
 195.0 STATE = ARRAY(TT)
 196.0 OPTCON=ARRAY(TT)
 197.0 FOR T=1,TT,1
 198.0 STATE(1)=1
 199.0 STATE(T+1)=GOTO(STATE(T),T)
 200.0 OPCON(T)=PREF(STATE(T),T)
 201.0 NEXT T
 202.0 STATE
 203.0 OPCON
 204.0 END
:_EDIT SATDP
EDIT COMMAND MODE
:%LIST 1 6
EDITING SATDP
    1.0 PROGRAM
    2.0 $CHETDP 12/17/84 SOA FOR BUGS
    3.0 $STAGES=TT, STATE LEVELS=NT, CONTROL LEVELS=MT
    4.0 TT = 10
    5.0 PMX=10
    6.0 QMX=10
:%4 TT=3
:%LIST 1 6
EDITING SATDP
    1.0 PROGRAM
    2.0 $CHETDP 12/17/84 SOA FOR BUGS
    3.0 $STAGES=TT, STATE LEVELS=NT, CONTROL LEVELS=MT
*   4.0 TT=3
    5.0 PMX=10
    6.0 QMX=10
:%END
PROGRAM SATDP IS NOW DEFINED
```