DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA

WORKING PAPER NO. 564

ECONOMIC PERSPECTIVES ON PESTICIDE USE IN CALIFORNIA

A collection of research papers edited by:

David Zilberman and Jerome B. Siebert

California Agricultural Experiment Station
Giannini Foundation of Agricultural Economics
October, 1990

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PREFACE

This study summarizes the outcome of many previous research studies conducted at the University of California at Berkeley and Davis and the Western Consortium for Public Health in Berkeley, California, which were largely supported by the U. S. Environmental Protection Agency, U. S. Department of Agriculture, and Resources for the Future. The report was financed by a grant from Kenneth R. Farrell, Vice President —Agriculture and Natural Resources, University of California.

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EXECUTIVE SUMMARY

Economic Perspectives on Pesticide Use in California

The use of synthetic organic pesticides in California agriculture has expanded production possibilities, increased yield, improved product quality, and reduced cost, thus benefiting farmers, processors, and consumers. However, it has also created problems of environmental quality degradation and raised worker safety and public health concerns. The trade-offs associated with pesticide use and regulation, the performance of alternative pest management strategies, and pesticide policies are the subjects of economic research at the University of California. Some of its findings are discussed below.

California is the leading agricultural state in the United States, with gross farm income in 1989 valued at nearly $17 billion. In many cases, California agriculture is the major supplier of fruits and vegetables in the United States. Every dollar generated at the farm level is estimated to contribute, through a multiplier effect, an additional $2.50 to California's gross state product.

Overall, it is estimated that pesticide costs (excluding application costs) amount to about 3 percent of the gross farm value of California commodities, or $500 million. The use of pesticides vary by crop, pest, and location. For example, past studies show that costs vary from 1 cent per dollar of crop output for tomatoes, grapes, and potatoes to 4 cents per dollar for oranges.

Past studies also estimate that, for every dollar spent by farmers on pesticides, $3.00 to $6.00 are returned as a result of increased yield and improved quality. (These estimates exclude application, resistance, and safety costs.) Productivity of pesticides varies significantly across crops and regions. For example, insecticide productivity is lower than average in cotton. Other studies have found that quality accounts for one-third of the benefits of using fungicides in apples. Pesticides have also enabled many additional crops to be grown in California. Their combined impacts on yield, quality, and costs have led to lower consumer prices and extended availability of many fruits and vegetables throughout the year. While some would encourage an estimate of the overall cost of a policy that restricts the use of pesticides, caution must be exercised in doing so because of the variability of costs, narrowness of the data base, and uncertainties involved. Economic theory coupled with specific studies lead to conclusions that offer insights into the impact of restrictive use policies, but care must be exercised in their extrapolation.

Data from farm surveys of pesticide use in California and elsewhere in the United States suggest three major points: (1) The use levels of pesticides in California per acre and per dollar of farm output is low relative to the remainder of the United States for most crops and pesticide types; (2) use levels of most pesticides over the last decade are stable or declining especially when adjustments are made for dosages per application; and (3) California agriculture is among the world leaders in developing and adopting pest management practices leading to reduced levels of pesticides.

In particular, much research and development has gone into the idea of Integrated Pest Management (IPM). IPM combines chemical and nonchemical controls of pesticides and emphasizes the use of information to improve effectiveness of pesticide applications. While a certain amount of success in reducing pesticides has been accomplished using the IPM approach, further reductions are dependent on research now underway, particularly in the areas of sustainable agriculture and biotechnology.

In response to concern about environmental and health effects of pesticides, California has adopted the most restrictive regulations anywhere in the United States; and more are proposed. The impact of banning the use of a pesticide in the short run depends on the substitute available--be it another pesticide, technology, or cultural practice.

Without a close substitute, production costs will increase. In the short run, this effect may lead to a price increase, thus reducing both producer's and consumer's welfare. Short-run impacts on producers may be unevenly distributed. Some users of the banned chemicals may suffer substantially and even incur devastating losses. But losses to other users may be less significant with nonusers of chemicals gaining due to an increase in commodity prices. In some case studies, nonuser gains were estimated to be one-third of total users' loss from cancellation. Long-run effects depend on the success of research and development activities in developing technologies to replace banned chemicals. Without such innovations, the regulation may lead to increased out-of-state competition that may mitigate the initial price increase due to the regulation and further undermine California producers' competitiveness and productivity.

Estimates of the human and environmental health associated with pesticide use are surrounded with uncertainty because of the randomness of exposure and the reliance on animal studies to assess toxicity to humans. The extent of the food safety problem is subject to dispute since chemicals (in particular, fungicides) are being used to control the development of toxins in food. Studies of worker safety and water quality degradation resulting from pesticide use revealed that risk levels vary substantially across locations, across occupations, and over time. It was found that uniform policies (complete bans and uniform safety standards) are much costlier in attaining environmental and human health targets than discriminatory policies based on balancing the economic costs with the benefits of environmental and human health improvement across location and over time.

Past studies lead to a number of conclusions regarding the use and regulation of pesticides.

1. There are significant payoffs to using pesticides, both in terms of output quantity and quality. The data that substantiates this conclusion strongly suggest that pesticides are not over utilized from a grower's perspective.
2. The major short-run impact of removing pesticides without viable alternatives will both decrease yields and raise cost to producers of certain agricultural products. Impacts will vary by crop, pest, region, and market. These increased costs will be reflected in higher prices to consumers, substantial losses to some producers, and may impact the level and growth of the California economy.
3. Environmental impacts of pesticide use justify government regulation. This regulation should be done intelligently and under careful analysis which takes into account the cost of removal of the pesticide in question and the environmental and health benefits that are to be accomplished.
4. Governmental policies and regulations will be improved by reducing the uncertainty regarding their impact. This involves the development of data bases and analytical models designed to specifically pinpoint impacts of policy decisions.
5. Restriction or removal of pesticides will be mitigated in the long run through the introduction and adoption of new technologies. Research and development efforts leading to these technologies will be undertaken by both the private and public sectors. Government policies need to take this activity into account and provide incentive to move research and development into areas that will provide acceptable alternatives and substitutes.
6. Research activities should not only investigate the development of alternatives to pesticides but they also need to address environmental

and health effects. Methodologies have to be developed to assure improved and effective monitoring and implementation of regulations.

7. Pesticide regulation policies have to be discriminatory in their effects. Those activities which pursue a course of meeting environmental and health objectives should be encouraged while those which do not should be discouraged. Policies that have this property include regulations that use the government's ability to tax undesirable activities; in turn, they should provide a profit motive to encourage transition to environmentally sound practices. Monies derived from these policies may be reinvested into the development of new alternatives and technologies. In this way, California agriculture can continue to be the dominant leader in the development of these new technologies.

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ECONOMIC PERSPECTIVES ON PESTICIDE USE IN CALIFORNIA: OVERVIEW AND CONCLUSIONS

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California agriculture has relied to a significant extent on pesticides for pest management, making it possible for producers to introduce new crops, adopt new technologies, and substitute chemicals for other inputs. Measurable benefits have included a reduction in average costs to farmers and processors as well as lower relative prices and increased quality for consumers. This reliance on pesticides, however, has also created problems of environmental degradation and has raised concerns about worker safety and public health.

Such concerns have led to the establishment of policies and regulations for pesticide application. While the regulatory framework has evolved, however, the policy debate about appropriate use of chemical pesticide and amount of pesticide control has not yet been settled. Meanwhile, agriculture has sought new alternatives to pesticides, partly motivated by a desire to find more effective, less costly pest management methods and partly in response to the more restrictive policies and regulations.[1]

[1]In California, the passage of Proposition 65 introduced significant restrictions on pesticide use. This initiative was followed by state legislation that placed greater control over the registration, use, and reporting of pesticides as well as increased monitoring. At the national level, changes in the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); Environmental Protection Agency regulations; and proposed changes in farm policy legislation have added limitations on uses of pesticides. Finally, California has on its November 1990 ballot an initiative to phase out carcinogenic chemicals over the next five years (or a longer extension if justified).

Public policies affecting chemical pesticide use, as well as pest management alternatives at the farm level, have been the subject of considerable research by agricultural and resource economists at the University of California. This research has produced several lessons of value as pesticide policies in California are being shaped.

This report concentrates on the economic consequences of pesticide use on California farms with regard to productivity, water quality, raw food supplies, risk, and health. However, the analytical techniques used and the knowledge gained can be applied to other environmentally sensitive areas such as forests, deserts, range, and estuaries as well as to urban centers. Indeed, the chapters in this report offer ways to look at the entire spectrum of chemical use in society.

This report presents, in a nontechnical fashion, some of the main findings of economic research on pesticides. First, it gives background information on California agriculture and its pesticide-use patterns. The chapters following then survey some of the major lines of research in pesticide economics and summarize results of several studies addressing pesticide use in California. The purpose is to provide an overview of economic considerations related to the restriction of pesticide alternatives available for the production and processing of food and fiber in California.

With pesticide economics as the main theme, this introductory section gives highlights of the background information as well as the primary findings of the chapters on pesticide productivity, market effects of restricting the use of pesticides, and the combination of environmental and market considerations in pesticide regulations.

I. Dimensions of California Agriculture

The second chapter in the report reviews recent findings on agricultural production, income, and land-use patterns in California and on the role of agriculture in California's economy.[2]

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[2]Siebert's paper relies on Carter and Nuckton (1989).

More than 250 crop and livestock commodities are grown in California. The 1988 farm value of these commodities was $17 billion, divided among the livestock and poultry sector with a gross farm product of $4.7 billion, fruits and nuts with $4.0 billion, vegetables with $3.7 billion, field crops with $3.0 billion, and nursery with $1.6 billion. Exports are significant for many crops with a total value of nearly $4 billion in 1988.

California leads the nation in the production of many fruits and nut crops. In terms of value, grapes account for nearly one-third of fruit and nut production. Citrus accounts for an additional 16 percent, and almonds, 14 percent. One recent development is the importation of fresh fruits, particularly from the southern hemisphere, to fill in voids left by the California fruit production seasons. These imports have generally complemented California production with a limited amount of competition due to overlaps in seasons.

California is the principal producer of vegetables in the United States, accounting for 54 percent of the 10 major fresh market vegetables grown and 57 percent of the five major processing vegetables. Lettuce is, by far, the largest commodity in terms of value, with nearly 25 percent of total vegetable production, and processing tomatoes account for another 15 percent. California vegetable production has expanded in response to consumer demand, with acreage and production up over 30 percent during the past decade.

California fruit and vegetable growers-shippers are highly integrated and are frequently multi-regional and multi-commodity in scope. They have increasingly expanded into other regions and countries. Significant expansion has taken place in Mexico, which has lower labor costs and less stringent environmental regulation. Currently, a high degree of integration among vegetable industries in Arizona, California, and Mexico has dramatically changed the vegetable industry.

California grows significant quantities of cotton, rice, sugar beets, dry beans, and alfalfa. Although the value of field crops accounts for only 15 percent of the total farm value of California commodities, harvested acres account for almost two-thirds of total harvested acreage.

Market conditions for California field crops depend largely on conditions elsewhere, particularly international markets and federal farm and trade policy. While federal crop subsidies are less than 2 percent of the total value of farm production in California, they account for significant percentages of farm income for producers of rice, cotton, and wheat. In particular, federal subsidy payments in 1988 amounted to 18.1 percent for cotton, 19.3 percent for barley, 25.2 percent for rice, and 28.8 percent for wheat.

Cotton, grown largely in the San Joaquin Valley, is the leading field crop and principal agricultural export. It is grown on 16 percent of the state's cropland and consumes about 8 percent of available water supplies. Because it is such a strategic crop, the profitability of cotton has a large effect on other crops planted in California, particularly the San Joaquin Valley.

Alfalfa is another significant field crop accounting for over 20 percent of the state's total harvested acreage. In addition, it consumes about 16 percent of total available water supplies in the state.

The $17 billion in farm sales has been a significant factor in California's economy. This amount contributes an additional $42.5 billion to the California economy through a multiplier effect (2.5 times the income generated by agriculture).

Historically, the value of farm production, as a percentage of the California Gross State Product, has averaged over 3 percent. During the past decade, however, this percentage has been decreasing and reached a low of 2.3 percent in 1985. While the gross product of agriculture in California have been expanding, the gross products of other sectors in the California economy has been expanding even faster. This trend is likely to continue as California becomes more urbanized, increasing the pressures on land, air, and water resources used in agricultural production.

II. Pesticide Use in California

Carlson analyzes major trends of pesticide use in the United States and California.[3] Overall, the value of pesticides in California has averaged around 3 percent of gross farm value. This figure varies according to the commodity involved, the location of production, and pests and diseases being treated. Variations also result from the use of data from several sources. Data from farm surveys have led Carlson to the following conclusions: (1) use levels of pesticides in California per acre and per dollar of farm output are low relative to those in the rest of the United States for most crops and pesticide types; (2) use levels of most pesticides over the past decade are stable or declining, especially when adjustments are made for dosage per application; (3) many crops grown in California are "minor use crops" (those using relatively small amounts of pesticides compared with major users such as cotton, corn, and soybeans) which means that the cost of safety and efficacy studies for pesticide registration is relatively high per acre; and (4) California agriculture has been a world leader in developing pest management practices that substitute information and labor for pesticides.

Some crops are more susceptible to certain pests than others. Hence, for example, Carlson found that a typical insecticide program cost about $.01 per dollar of crop output for tomatoes, grapes, and potatoes and up to $.04 for oranges. This observation is reinforced by Siebert's study on the economic impact of the establishment of the Medfly in California. In particular, Siebert found that costs varied significantly depending on the degree of susceptibility, canopy cover, and time of year for the crops affected (which included citrus, avocado, tomatoes, grapes, and most stone fruits).

[3]This study summarizes data from recent farm surveys of pesticide use in California and the United States.

Farmers use pesticides to obtain higher yields, increase quality, reduce uncertainty, and extend the growing season to provide produce throughout much of the year. Contrary to the perhaps common assumption that pesticide use is increasing, Carlson points out that the number of pesticide applications has been stable or declining during the past decade. He attributes this finding to the increase in pesticide prices relative to land and labor costs and, in particular, falling energy costs relative to herbicide costs. His explanation is based upon the fact that, in the latter case, fuel, oil, and electric costs as a percentage of gross farm product in California declined from 5.1 percent in 1983 to 3.5 percent in 1987. During this same period, pesticide costs remained constant. In the future, if energy prices continue their current rise, the number of pesticide applications may increase as chemicals are substituted for energy in pest control.

The total amount of pesticides used has declined substantially, because average dosages applied have decreased. This reduction has been made possible through the development of more efficient pesticides and of integrated pest management (IPM) approaches. While the amount of pesticides being used has declined, individual application costs may have actually risen.

IPM has been evolving as an alternative approach to conventional chemical control over the last 40 to 45 years.[4] IPM combines chemical with biological and other nonchemical controls of pests and emphasizes monitoring of environmental conditions to increase effectiveness of pesticide applications. There is evidence that it tends to increase profitability, especially in the long run as pest management becomes more accomplished. Diffusion of this technology has been slow, but it now is widespread and, in many crops, is used by most farmers. Introduction of this approach has led to

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[4]An early exposition of the principle of IPM appears in Smith and Allen (1954).

institutional change, including the emergence of a pest adviser and crop consultant industry and regional cooperation in pest management research.

The comprehensive literature review by Hurd and Howitt demonstrates that economic incentives have induced the development and adoption of a large number of technologies in agriculture. They further argue that economic considerations have been crucial in the adoption of many technologies in agriculture, including tractors, tomato harvesters, water conservation, and computers. The economic incentives that increase innovation include both price and restrictive regulations. Adoption of technology has been gradual, reflecting differences in farm characteristics (location, size, education level of the farmer, etc.). This adoption has tended to benefit consumers, but declining prices have caused the financial situation of some farmers to worsen.

III. Major Themes of the Economics of Pesticides

Extensive economic research on effects of pesticide regulations has been conducted since the early 1970s, much of it financed by the U. S. Environmental Protection Agency (EPA) and some by the U. S. Department of Agriculture. The departments of agricultural economics in Berkeley and Davis have been leading centers of research on pesticide economics and have conducted joint projects with entomologists, agronomists, and public health scholars.

Ten themes emerge throughout the literature on pesticide economics and reappear in the chapters presented in this report. They are:

(1) *Public regulation of pesticides is justified.*—Use of some chemical pesticides has been found to have negative side effects on environmental health and safety. Individual growers, who mostly operate to make profits, are not likely to incorporate these environmental health effects appropriately into their decisions on pesticide use. Public policies and regulations need to be established to improve

welfare of society. *Society faces the challenge of selecting effective, efficient, and fair policies of controlling pesticide use.*

(2) *The multiple dimensions of pesticide use and impacts have to be recognized as policies are designed and assessed.*—Chemical pesticides are used to reduce production costs, to increase product output and quality, and to extend product storability and shelf life. Their use may result in problems related to environmental (especially groundwater) contamination, water safety, and food safety.

(3) *There are many trade-offs between market welfare and environmental health and safety.*—The desirable pesticide regulations are those that attain environmental quality and health targets at least market cost or that provide the greatest environmental quality at a given cost.

(4) *Heterogeneity of both producers and consumers needs to be considered when analyzing impacts of a policy.*—The effects of a policy, such as canceling a pesticide, will vary among both groups. Producers will be affected differently, depending on crop, geographical location, and pesticide-use patterns. Pesticide-use cancellation may benefit nonusers while hurting users. Impact on consumers will vary by income level, geographical location, and consumption patterns.

(5) *Magnitudes of the impact of pesticide regulations depend on the alternatives available.*—The cancellation of a chemical pesticide is likely to have minor effects when a close chemical, biological, cultural, or management substitute is available in terms of cost and yields. When a widely used chemical (or group of chemicals) with unique capabilities in pest control is discontinued, impacts are likely to be substantial.

(6) *Market conditions affect policy impacts.*—The direction and magnitude of effects vary substantially depending on market conditions, the properties of demand and supply for affected products, and the extent to which the products are traded internationally. Cancellation of a pesticide may have a substantial price effect when

demand for the products for which it is used is inelastic. Supply-reducing pesticide regulations may lead to substantial reduction in government commodity price-support payments.

(7) *Short-run and long-run policy impacts may differ.*—Economic and natural resource systems are subject to dynamic forces of adjustment and change. These forces should be recognized in policy assessment. For example, cancellation of a pesticide with no close substitutes may cause substantial short-term effects. Eventually, however, a substitute may be developed and, once adopted, significantly reduce the long-run effects of the cancellation. Government policies and programs can affect long-run impacts of regulation by increasing research and extension activities to encourage more rapid innovation and adoption of new technologies.

(8) *Behavior is responsive to incentives.*—Farmers adjust patterns of behavior as prices change, new information is made available, and uncertainties are removed. Governments can induce change in farming practices by using monetary incentive schemes as well as educational and regulatory programs.

(9) *Evaluation procedures need to be consistent.*—Policy assessments are based on estimates that are subject to much uncertainty. Statistical and measurement procedures are used to adjust for these uncertainties in generating estimates. Standards should be established so that the adjustments will be made in a consistent manner.

(10) *Political considerations need to be recognized.*—To be useful to policymakers, economic analysis has to include both the impact on efficiency and the distribution of impacts. It also has to consider implementation and enforcement dimensions of new policies and evaluate new proposals within existing institutional and political structures.

Lichtenberg, Zilberman, and Archibald (1990) review the developments pesticide economics over the past 25 years and point to needed analysis in the futur In their summary statement, they state that "in recent years policy concerns regardi pesticides have become increasingly broad, encompassing issues that include residu on foods, protection of endangered species and other wildlife, cosmetic uses, ar productivity. The ramifications of pesticide policy decisions are, correspondingl: increasingly complex. As a result, the narrower concerns of the past no longer suffic More and more, the issues facing policymakers require analysis using integrate management models that take into account these broad ramifications." This repor attempts to provide some insight into factors that need to be considered when makin an assessment and presents some examples of likely outcomes given various assumptions and conditions.

IV. Productivity Impacts of Pesticide Use

Carrasco-Tauber surveys studies measuring the productivity of pesticide use in agriculture.[6] She points out locational variabilities reflecting differences in pest problems, climatological conditions, soil types, and cultivation practices. Furthermore, increasing resistance to pesticides by targeted pests may cause differences between short-term and long-term productivity effects.

Pioneering work in measuring aggregate pesticide productivity was done by Headley (1968) and by Fischer (1970). These studies estimate the impact on the gross output of the agricultural economy caused by an increase in costs due to use of pesticides. Headley's studies in the 1960s found that the marginal value product of

[5]An earlier version of this paper was presented as an invited paper at the Australian Association of Agricultural Economics meeting in 1988 in Melbourne, Australia.

[6]This chapter relies mostly on Carrasco-Tauber and Moffitt (1990).

pesticide exceeded the marginal factor cost by a ratio of \$4.00 : \$1.00.[7] A later study done by Pimentel et al. (1978) estimated the chemical control cost in the United States to be \$2.2 billion annually with a gross return on those costs of \$8.7 billion. In a related study, Pimentel et al. (1980) also looked at the indirect costs that pesticide use poses to the rest of the ecosystem and found that the ratio of average value to average cost would decline to \$3.00 : \$1.00—still a relatively profitable ratio for using pesticides. A review of studies on pesticide productivity in specific industries finds similar outcomes. A recent aggregate study by Carrasco-Tauber (1989) estimated returns of \$6.15 and \$6.48 for each dollar of pesticide spent in 1984 using two alternative specifications.

There are unique cases when pesticide productivity is found to be very small; for example, Miranowski (1975) found pesticide productivity in cotton in the 1970s to be negligible. However, almost all results suggest that the additional revenue to be gained through the use of pesticides exceeds the added cost by several times. Figures used in most of the pesticide productivity studies did not include costs related to application, resistance, and safety. These omissions may explain at least some of the measured differences between the revenues and costs associated with increased pesticide-use levels. Nevertheless, it is quite reasonable to argue that, for the grower, pesticide productivity gains substantially outweighed costs. These findings do not imply that reductions in pesticide-use levels necessarily lead to reduced productivity or profitability levels. The development and adoption of new technologies and use of management systems such as IPM contribute to the stabilization and, in some cases, decline of pesticide use. The increased adoption of IPM strategies over time is also a likely cause for Carrasco-Tauber's findings of higher marginal productivity of pesticides in 1984 than in 1963.

[7]Headley's original study used a Cobb-Douglas production function. A recent study by Carrasco-Tauber (1989) found that the use of a damage function approach with Headley's data yields similar results.

Studies show that 800 million pounds of pesticides are applied in U. S. agriculture annually. Seventy percent of the herbicides applied are used on corn, soybeans, and cotton to substitute for labor and capital. Sometimes the herbicides are used as part of a low-tillage strategy. Almost all of the fungicides applied are used in fruits and vegetables. Cotton is, by far, the heaviest user of insecticides. When applied on fruits and vegetables, insecticides have a significant impact on quality which, in some cases, exceeds the benefits from yields. Fungicides affect both yield and quality. In a study of the effect of fungicides on North Carolina apples, Babcock, Lichtenberg, and Zilberman (1988) found that quality improvements accounted for one-third of the benefits of fungicide use and that pruning was an excellent substitute for fungicides in reducing both yield losses and disease damage.

V. Impact of Restricting Pesticides

After examining the effects on agricultural production and payoffs from pesticide use, the report now turns to the results of restricting pesticides.

Pesticide restrictions commonly ban the use of certain chemicals while allowing the use of others. If substitutes exist that are slightly more expensive than the banned chemicals but equally effective, the restrictions are likely to have very small effects on productivity and overall pesticide-use levels and may slightly increase pesticide expenditures. If there are no close substitutes, the regulations may cause considerable reduction in production, reflecting the productivity of pesticides as a production input.

The economic impact analysis of restricting pesticides needs to include effects not only on production, but also on prices, trade patterns, and the welfare of different groups (consumers and producers) affected by the regulations. The Lichtenberg, Zilberman, and Archibald chapter identified a number of approaches to assessing the impacts of restricting pesticides. The partial budgeting approach, used by EPA and other regulatory agencies, is based on the summation of cost and revenue effects of regulations across crops, ignoring possible price and land-use changes. This approach tends to overestimate the impacts on growers and underestimate those on consumers, especially when there are not high price elasticities of demand for affected products. One alternative is to employ a general equilibrium approach to predict changes in prices and quantities and estimate impacts on consumer and producer welfare.

An alternative, the marginal analysis approach, has been employed by several recent policy studies. First, the effects of pesticide regulations on the supply of affected crops are estimated (either econometrically by crop simulations or by expert opinions). Then these supply effects are combined with demand and supply elasticity estimates to approximate changes of prices, quantities, and consumer and producer surpluses.

The chapter by Parker, Zilberman, and Lichtenberg[8] explains the marginal analysis approach and uses it to investigate impacts of the cancellation of the pesticide ethyl parathion on lettuce, plums, prunes, and almonds. It demonstrates that a pesticide cancellation would raise market prices for the products involved. The price effect estimates are small in most situations, but in two cases when parathion cannot be easily replaced, they are quite substantial (an increase of about 10 percent in the summer lettuce price and 4 percent in fall lettuce price).

The study demonstrates that the burden of a pesticide cancellation is spread unevenly. Even when the effects are rather small overall, they can be substantial in specific areas. While users of the pesticide generally lose because of increased costs and/or decreased yield, some users may actually gain because of the increase in output price. In some cases, total gains to nonusers reached 40 percent of the total losses to users. Nonusers of the pesticide gain in the form of increased revenues, while

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[8]This paper relies on Lichtenberg, Parker, and Zilberman (1987, 1988).

domestic and foreign consumers lose. Export revenues are estimated to increase with the pesticide cancellation because of the price increase.

In essence, the study analyzed short-run impacts. In the long run, however, these policies will produce two conflicting results. One will be increased foreign competition and an undermining of U. S. competitiveness, forcing an even greater adjustment in agricultural production due to adjustments in domestic markets. In contrast, increased regulation will stimulate research and development of substitutes, thus improving the U. S. technological edge. It should also be noted that, in some cases when consumers lose in terms of higher prices, they may realize a net gain because of health and safety considerations. Research into analysis of this net effect will be important to policy formulation.

The chapter by Butler and Lyons, which relies on Lichtenberg, Zilberman, and Ellis (1988) as well as Lyons and Zalom (1990), provides another illustration of the market impacts of restricting a pesticide. In this study, the effects of increasing costs or reducing yield on cotton were analyzed. The net result of either a cost increase or a yield decrease is complex and involves estimating a new long-run equilibrium for the California cotton industry as part of a worldwide market. For example, a 1 percent decrease in California cotton yields would reduce cotton production by .81 percent (32,000 bales). Other regions would increase production by 24,000 bales, and the net reduction in U. S. production would result in a price increase of 2.7 percent. Again, while overall adjustments and impacts are small, distributional impacts are significant.

Cotton (like rice and wheat) is subject to a government revenue support program. Government commodity programs affect market conditions and, in turn, the impact of pesticide regulations. For example, pesticide regulations that result in a reduction in supply of a commodity in a revenue-support program may lead to a price increase and, hence, reduced government price-support expenditures. These reductions in expenditures may be of substantial value to overall economic welfare.

Reliability of future studies of market effects of pesticide regulations will benefit from expanding the modeling framework to consider other (nonpesticide) policies affecting agriculture. Lichtenberg and Zilberman (1986) showed that ignoring commodity programs in assessing the impacts of pesticide regulations in agriculture may overestimate the overall impact of these regulations by up to 30 percent.

Siebert's chapter[9] on the economic impact of the establishment of the Medfly in California describes the estimation of increased costs and decreased yields that would be associated with restricting the application of malathion-treated bait in urban areas and establishment of the pest in commercial agricultural areas. While changes in yields and costs were considered for 22 crops, the market analysis was conducted only for 10 because of a lack of appropriate data and estimates of market characteristics. Overall, it was found that an increase in costs and decrease in yields would lead to higher consumer prices. The net effect would be overall decreases in revenues for the 10 crops analyzed, but the distribution of revenues among crops would be significantly different. Producers of some crops would actually gain revenues because of the higher prices, significantly offsetting decreases in quantity, while others would lose revenue. What is missing from this analysis, as well as others like it, is the long-run adjustment to a new equilibrium for the industries involved. Hence, further research is warranted for studies of this nature.

VI. Health and Safety Risk Considerations

Federal law[10] specifies that chemical pesticides are to be regulated so that their economic benefits outweigh any adverse effects on the environment or on human health. Lichtenberg and Zilberman explore the complexities of assessing the health risks of pesticide applications. For example, data on the health risk effects, such as

[9]See Siebert and Pradhan (1990).

[10]The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA).

human cancer, associated with exposure to a particular pesticide are derived from animal studies and are subject to major uncertainties. Studies of worker safety and water quality degradation resulting from pesticide use have revealed that risk levels vary substantially across locations, across occupations, and over time. The spraying of a pesticide over a given location and human exposure to it are affected by many random variables—weather, environmental and chemical conditions, human behavior, protective clothing, and the like. Because of this randomness and uncertainty, risk assessment studies seldom provide average or "most likely" risk estimators. Indeed, they take a conservative approach and generate uncertainty-adjusted estimators. In essence, these estimators are "upper bounds" and, for most cases, the likelihood (or statistical confidence level) that actual risk is smaller than estimated risk is very high (more than 90 percent). Unfortunately, risk assessment studies differ in the extent to which they adjust their estimators for uncertainty, and these differences make comparative risk analyses and design of consistent regulations of health risks very difficult.[11]

The chapter introduces a framework for assessing trade-offs between costs and risks. This approach[12] emphasizes the use of equally conservative risk estimates in the construction of trade-off relationships and attempts to identify efficient policies, namely, the ones that will contain environmental health risks with minimum costs. Results of several case studies of the use of this approach are presented.

One of the studies analyzed alternative drinking water quality regulations in an area (Fresno County) contaminated by a pesticide (1,2-dibromo-3-chloropropane, DBCP) residue.[13] Another study examined shellfish sanitation in an estuary (North

[11]For a more complete discussion of this difficulty, see Archibald and Winter (1990).

[12]Presented in detail in Lichtenberg and Zilberman (1988).

[13]For a more detailed analysis of the case, see Lichtenberg, Zilberman, and Bogen (1989).

San Francisco Bay) contaminated by dairy waste runoff.[14] Results from these two studies show that the additional costs of containing risk increase substantially when increasingly more conservative risk measures are used. The outcomes also demonstrate that imposing uniform standards to contain risk results in excessive cost; efficient regulations recognize differences between producers and regions and vary accordingly.

Harper and Zilberman[15] compute cost-risk trade-offs associated with alternative pest control policies in Imperial Valley cotton. Assessing the impacts on outputs and farmers' income requires an explicit evaluation of the implications of biological complexities, such as secondary pest infestations and pest resistance to pesticides. The results demonstrate that prevailing procedures of making adjustments to account for uncertainty in risk assessment are (implicitly) excessively conservative and lead to substantial overestimation of pesticide health risk. The analysis suggests that in this case a change in cultural practice (e.g., transition to short season) and elimination of the use of a carcinogenic pesticide (e.g., chlordimeform, which has since been withdrawn) would substantially reduce yield but slightly reduce farm income. In modeling of the health effects of alternative policies, it is necessary to recognize differences in exposure and vulnerability to pesticides among different worker groups. For example, mixer loaders are much more vulnerable to the health effects than pilots or flaggers.

The results of both chapters demonstrate the vast degrees of heterogeneity and variability of populations affected by health risks. Heterogeneity and variability may be caused by differences in physical constraints as well as in beliefs and attitudes that lead to differences in behavior. Baumol and Oates (1974) found when variability and

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[14]Detailed analysis of this case appears in Lichtenberg and Zilberman (1987).

[15]This paper relies on Harper and Zilberman (1989) and Harper (1987).

heterogeneity exist, environmental objectives are attained at least cost by flexible policies.

Taxation of pesticides is one form of a flexible policy. Individuals who do not gain much from the use of pesticides will stop (or reduce) their use to decrease their tax payment, while the use of pesticides can continue where it is beneficial. Similarly, with respect to food safety problems, differences in individual attributes as well as perceptions are major sources of heterogeneity. Existence of a system of markets for products differentiated by chemical input use, such as organic or residue-free, allows freedom of choice. The government's role may be in establishing and monitoring performance criteria in the differentiated product markets.

Lichtenberg, Spear, and Zilberman[16] discuss pesticides and farm worker safety through reentry regulation. They point out that, while residues in food command the public's attention, the group most vulnerable to health and safety problems associated with pesticide use are farm workers and applicators. Hence, the authors studied the restriction of reentry into treated fields until enough of the residues degrade into nontoxic by-products. They investigated the use of organophosphate insecticides in Washington, Michigan, and California to protect apple crops from infestations of codling moth larvae resulting from moth flights shortly before harvest. Appropriate estimates were made by applying the economic theory that the optimal preharvest interval is found by equating the additional cost of harvest delays in terms of revenue lost with the increased benefits associated with reductions in the number of poisoning incidents. In the case of California, the interval was estimated to be 15 days, close to current EPA regulations. In Washington and Michigan—where rainfall is greater, and thus residue levels lower—a shorter preharvest interval of 12 and 9 days, respectively, was estimated as optimal. Integrating farm-level pesticide-use decisions, industry-level

[16]This paper is based on Lichtenberg, Spear, and Zilberman (1989).

market operations, and the environmental and human health effects of pesticide exposure can contribute to more informed and efficient decisions about pesticides.

VII. Summary and Conclusions

The economic evaluation of the use and restriction of pesticides has progressed from a very simple estimation of their impacts on production cost to identification of impacts on markets and consumers to consideration of trade-offs of market benefits and environmental and health and safety risks are increased. The application of models has led to increasingly complex analysis. The lessons learned from the cases presented here demonstrate that no single conclusion results from considering the economic consequences of regulations and policies restricting the use of pesticides on crops in California. The following points, however, seem appropriate:

1. There are significant payoffs to using pesticides, in both quantity and quality and it is not clear that pesticides are overutilized from the grower's perspective.

2. Environmental implications of pesticide use justify government regulation. Determining whether or not existing levels of regulation are sufficient requires comparing environmental health benefits with market costs.

3. Estimates of overall market impacts of pesticide bans are difficult given the variability in producer, crop location, pesticide-use patterns, season, and market characteristics. This difficulty is increased by data gaps about alternatives to the banned chemicals and particularly their relative efficacy and efficiency. While no attempt is made to provide an overall estimate of the impact of restricting pesticide use, the studies discussed in this overview provide valuable insight into some likely outcomes when economic theory and practice are combined with accurate and reliable sources of data. Great care should be taken in attempting to extrapolate and generalize conclusions from these individual studies because of the variations in assumptions and economic models used.

4. The effects of restricting or removing a pesticide will be unstable and depend on a number of factors. Gains and losses will vary in their distribution among commodities, producers, and regions. A short-run increase in cost or decrease in yield will depend on alternative chemicals, technologies, and cultural methods available as substitutes. The longer run effect on cost and yields will depend on the development of new technologies through increased research and development. The largest economic loss from the elimination of a chemical is for those crops that are dependent on it, and in which no close substitutes are available.

5. Short-run impacts of pesticide regulation on producers, industries, regions, and consumers (foreign and domestic) are likely to vary and usually will take the form of higher production costs and consumer prices. Technological change coupled with an expanded out-of-state supply tends to increase long-run supply and mitigate some of the short-term price effect of the regulation. The impact on the consumer is likely to be smaller in the long run, but, for some producers, the loss may be larger in the long than the short run because of lower prices. The estimation of long-run outcomes is quite complex and may require data and analyses that are not yet developed.

6. Environmental health impacts of pesticide use vary across locations according to their physical features, economic activities, and protective measures. Efficient policies have to recognize this variability and modify regulations accordingly. However, the estimation of these impacts is a growing field that involves the development of reliable data sources.

7. Uncertainty about health effects increases the cost of making decisions on pesticide policies and regulations. This uncertainty has to be treated consistently in policy assessment and in the modeling process. Reduction of the uncertainty through research and monitoring of health effects and environmental conditions enhances the efficiency of environmental health and safety decision making.

8. A policy consisting of a complete ban of specific chemicals will achieve environmental health and safety less efficiently than one that targets the crops and locations where the damage is greatest. Such a discriminatory policy is particularly effective when coupled with market mechanisms that provide incentives for achieving certain goals and penalties for activities not in conformance. In particular, user fees on pesticide use is a mechanism for achieving environmental objectives more efficiently than a complete ban. A tax rate per unit of active ingredient could be assigned to chemicals known to pose environmental or health risks. Pesticides could be taxed according to their chemical content. Such a tax would serve as an incentive to reduce the use of hazardous chemicals and to adopt alternative pest control methods. This policy can be targeted to encourage environmentally sound practices as well as to generate other benefits, such as investment into research of alternative technologies.

9. Increased research is needed and should be part of policy and regulatory decisions. Specifically, research on new alternative technologies and products to replace or modify current undesirable pesticides should be undertaken. In addition, research needs to address environmental and health effects and methodologies to ensure improved and effective monitoring and implementation of regulations.

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AN OVERVIEW OF CALIFORNIA AGRICULTURE: TRENDS AND ISSUES

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California is the leading agricultural state in the United States with gross farm income valued at nearly $17 billion in 1988. The contribution to the California economy is estimated to be 2.5 times farm value.[1] The next largest farm state is Texas which has a gross farm value of $10.3 billion. California produces over 50 percent of the nation's fruits, nuts, and vegetables on only 3 percent of its farmland. Over 250 crops and commodities are produced in California on 31.6 million acres with most produced on about 8.5 million irrigated acres from a total of 84,000 farms. Agriculture uses about 85 percent of the water supply in California. While utilizing high levels of capital, California agriculture also depends on significant amounts of farm labor with employment averaging up to 400,000.

California agriculture is characterized by high value cash crops which utilize high levels of technology, capital, and management. Its success is attributed to a blend of climate, water, soil, technology, and management that produce and market a high quality product. Whether California agriculture can continue to maintain its historical leadership role will depend on many factors. The purpose of this chapter is to provide an overview of the many dimensions of California agriculture and identify those issues that are important to its long-run health and vigor.

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[1]This multiplier varies by commodity. For further details, see California Department of Water Resources (1980).

I. Overview of California Agriculture[2]

A summary of the major crop and livestock commodities is contained in Table 1 in order of major grouping and 1988 gross sales value. Where California is traditionally known for its production of speciality crops (fruits, nuts, and vegetables), the consistent leaders in terms of gross value are milk and cream and cattle and calves. These two commodities amount to $2.1 billion and $1.6 billion, respectively; both account for over one-fifth of the gross farm income. Overall, the livestock and poultry sector has a gross farm product of over $4.7 billion. This sector was followed by fruits and nuts with $4.0 billion, vegetables with $3.7 billion, field crops with $3.0 billion, and nursery with $1.6 billion.

California is the nation's leader in the production of many fruits and nut crops, and is the exclusive supplier of almonds, clingstone peaches, dates, figs, kiwifruit, olives, pistachios, pomegranates, prunes, raisins, and walnuts. In terms of value, grapes account for nearly one-third of fruit and nut production. Citrus accounts for an additional 16 percent and almonds 14 percent. Significant changes have taken place in the fruit and nut industries over the last three decades. Statewide acreage has increased dramatically as new acreages were opened up from State Water Project deliveries and as farmers shifted from lower value field crops. For example, bearing acreage in almonds increased from 100,000 in 1950 to over 400,000 and wine grapes increased from less than 50,000 to over 300,000 during the decade of the 1970s. Shifts in acreage also took place from urbanized coastal areas to the San Joaquin Valley as well as between crops as profitability changed due to shifts in demand; changes in cost; and availability of water for irrigation, land prices, and susceptibility of different areas to pest and disease problems.

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[2]For a good description of the commodities produced in California agriculture and their overall production value, see Carter and Nuckton (1989).

TABLE 1

California's Leading Agricultural Commodities

Commodity	1988 value	Total harvest	Share of U.S. production	Total exports
	thousand dollars	thousand acres	percent	percent
Field crops	2,994,182	5,257.0		
Cotton	1,026,633	1,336.8	18.3	69.9
Hay, alfalfa, other	817,614	1,680.0	6.8	6.3
Rice	197,583	420.0	18.5	47.3
Sugar beets	178,080	212.0	21.4	
Wheat	164,860	519.0	2.4	50.8
Beans, dry	104,473	150.0	15.0	
Corn for grain	86,768	187.0	.6	
Barley	46,116	280.0	3.7	1.0
Alfalfa seed	41,665	67.0		24.8
Safflower	32,000	115.0		
Fruits and nuts	4,040,253	1,954.0		
Grapes, all	1,356,250	654.2	91.6	24.5
Almonds, shelled	600,075	407.0	99.9	68.1
Oranges, all	458,446	172.0	26.0	20.9
Avocados	205,200	74.8	86.1	10.4
Walnuts	190,962	174.0	100.0	33.0
Peaches, all	177,880	53.7	58.7	7.2
Lemons	171,436	48.9	82.3	36.2
Apples	117,750	23.0	6.9	
Prunes, dried	113,925	76.7	100.0	29.6
Pistachios	104,340	44.1	100.0	23.1
Plums	102,661	40.8	80.6	21.0
Nectarines	78,861	24.2	97.0	
Pears	74,540	23.0	35.1	9.7
Grapefruits	55,404	20.6	13.0	36.7
Olives	50,449	31.5	99.9	2.6
Apricots	29,613	17.8	92.9	12.2
Cherries, sweet	20,040	10.3	14.0	51.2
Vegetables	3,701,745	1,117.0		
Lettuce	632,424	159.5	73.0	7.2
Strawberries	388,998	17.6	73.9	8.1
Processing tomatoes	385,669	226.1	88.4	2.2
Broccoli	265,954	101.1	90.9	10.7
Fresh tomatoes	264,075	37.5	25.0	12.4
Carrots	247,366	51.1	65.1	6.1
Cauliflower	161,514	48.0	79.2	12.5
Celery	147,740	20.3	68.4	10.1
Potatoes	143,673	47.2	4.8	4.4
Cantaloupe	114,075	84.5		
Mushrooms	110,189	.5	17.8	
Onions	104,082	40.5	32.1	6.7
Asparagus	83,431	40.1	48.0	18.0
Honeydew melons	47,435	21.3	69.1	
Sweet potatoes	15,329	7.1	10.5	

(Continued on next page.)

TABLE 1—continued.

Commodity	1988 value	Total harvest	Share of U.S. production	Total exports
	thousand dollars	thousand acres	percent	percent
Livestock & poultry	4,703,771			
Milk & cream	2,080,739		13.0	2.7
Cattle & calves	1,613,819		4.8	3.1
Chickens	343,090		5.1	5.7
Eggs, chicken	297,786		11.1	
Turkeys	200,340		11.3	1.6
Sheep & lambs	66,547		10.5	4.4
Hogs & pigs	22,146		.2	
Nursery products	1,573,996			
Nursery products	919,049		27.6	
Flower & foliage	654,947		28.6	2.8
TOTAL	17,013.947	8,328.0		

Source: *California Agricultural Directory,* 1990. Published by California Agricultural Service Agency, Sacramento, California. Data provided by California Department of Food and Agriculture, Statistical Review, 1988.

Increases in yields have taken place as new varieties are developed and new technologies adopted. In addition, newer varieties have lengthened the season for many crops and provided improved quality. Many fruit and nut crops are assisted in new research through marketing order check-off funds designated for research and development. Recently, much of this research and development money has been allocated to Integrated Pest Management (IPM) programs.

One recent development that has taken place is the importation of fresh fruits, particularly from the southern hemisphere, to fill in voids left by the seasonality of California fruit production. These imports generally have been complementary to California production with a limited amount of competition due to overlaps in seasons.

Many of California's fruit and nut crops are exported. Growth in these export markets has been significant over the past six years.. Leading to the improvement in this situation has been a relatively weak dollar against other currencies, the introduction of subsidized promotion programs through the Targeted Export Assistance (TEA) program, and the use of marketing order and commission funds in market promotion. The leading crops exported are almonds, walnuts, oranges, lemons, grapefruit, raisins, prunes, cherries, plums, and pistachios. New markets in the Pacific Rim have opened up through negotiations, particularly for citrus and nectarines.

California is the principal producer of vegetables in the United States with 54 percent of the 10 major fresh market vegetables and 57 percent of the five major processing vegetables. Lettuce is, by far, the largest commodity in terms of value with nearly 17 percent of total vegetable production. Processing tomatoes and strawberries account for another 10 percent each; and broccoli, fresh tomatoes, carrots, cauliflower, celery, potatoes, cantaloupe, and mushrooms combined account for an additional 36 percent. California vegetable production has expanded in response to consumer demand with acreage and production up over 30 percent during the past decade.

Important shifts have taken place in vegetable production as traditional areas of production in the coastal areas have been removed due to urban pressures and replaced by the desert areas and the San Joaquin Valley. The central coast area dominated by the Salinas Valley, also known as the "salad bowl of the world," is still a significant factor in California vegetable production due to state-of-the-art production and postharvest practices as well as year-round seasons. Nevertheless, the San Joaquin Valley has become the production leader in vegetables in California with 538 thousand harvested acres in 1987 compared to 322 thousand acres on the central coast.

California fruit and vegetable grower-shippers are highly integrated and frequently multi-regional and multi-commodity in scope. They have increasingly expanded into other regions and countries either through joint ventures or purchase arrangements that enable them to become year-round marketers, thereby increasing their risk. Significant expansion has taken place in Mexico where there is lower labor costs and less stringent environmental regulation. While further expansion may be limited due to a number of factors, the high degree of integration of the Arizona, California, and Mexico vegetable industries has dramatically changed the face of the vegetable industry.

While California is not known for its production of field crops, it nevertheless grows significant quantities of cotton, rice, sugar beets, dry beans, and alfalfa. Many of these quantities, such as alfalfa, are used as inputs into livestock production. Overall, while the value of field crops accounts for only 15 percent of the total farm value of commodities in California, harvested acres account for almost two-thirds of total acreage. In addition, significant amounts of field crops are exported—notably cotton, rice, wheat, alfalfa seed, and safflower.

Market conditions for California field crops depend largely on conditions elsewhere, particularly international markets and federal farm and trade policy. While federal crop subsidies account for less than 2 percent of the total value of farm production, or about $279.9 million, in California, they account for significant percentages of farm income for producers of rice, cotton, and wheat. In particular, federal subsidy payments in 1988 amounted to 18.1 percent for cotton, 19.3 percent for barley, 25.2 percent for rice, and 28.8 percent for wheat. These payments do not take into account water subsidies for California agriculture.

Cotton, grown largely in the San Joaquin Valley, is the leading field crop and principal agricultural export. It is grown on 16 percent of the state's cropland and consumes about 8 percent of available water supplies. Because it is such a strategic crop, the profitability of cotton has dramatic impact on other crops planted in California, particularly the San Joaquin Valley. While essential inputs such as water increase in price, farmers tend to look for higher value crops such as fruits, nuts, and vegetables. Hence, during the last decade field crops have experienced a significant shift.

Alfalfa is another significant field crop utilizing over 20 percent of the state's total acreage. In addition, it uses large amounts of water, consuming about 16 percent of total available water supplies in the state. Alfalfa is an important feed ingredient to the state's livestock, dairy, and horse industries. Even with the large amount of alfalfa hay production in California, the state must still import significant quantities of feed from other western states.

The livestock, dairy, and poultry industries have long been heavy contributors to the California farm economy. However, significant changes have taken place during the last two decades. First, California—due to its large population—has traditionally been a net importer of livestock, dairy, and poultry. For example, although California is the second largest dairy state next to Wisconsin, it still must import nearly 50 percent of its cheese requirements. Additionally, the industry has changed dramatically from producing primarily for a fluid market to one that produces over 50 percent into butter, nonfat dry milk, and cheese; with about 20 percent going into government sales; and another 15 percent marketed outside of California.

California has traditionally imported most of its chicken and broiler products. This situation will likely continue even with a tripling of broiler production due to population increase. Population growth has also increased production of turkey products. However, the egg industry, while still a national leader, has shrunk dramatically due to a decrease in demand.

California beef production centers on cow-calf operations that take advantage of the abundant range resources in the state. Most of the beef that is consumed in California is finished outside of the state and then slaughtered and shipped back in. Only 30 percent of the beef consumed in California is slaughtered in the state due to high labor costs. One area that is undergoing expansion is the growing Japanese market for California beef as companies from that country have purchased feedlots and slaughtering facilities.

As far as other livestock products are concerned (lamb and pork), most of California's consumption will continue to be imported from other areas.

Nursery and floral products account for a growing share of California agriculture's gross farm product. In 1988, the value of these products was nearly $1.6 billion. Exports do not account for a significant part of income. However, the industry is facing increased competition from low-priced and often subsidized imports. Competition is especially intense on the eastern seaboard and for cut flowers.

The $17 billion generated by California agriculture in farm sales has been a significant factor in the state's economy. To this amount, a multiplier of 2.5 is factored in to allow for value-added to the raw product produced on the farm. This factor reflects the additional processing, packaging, transportation, storage, and marketing costs that take place for farm products to reach the consumer. Hence, the value of agricultural products is estimated to be $42.5 billion in terms of value added to it.

The role of the farm economy as part of the California state economy is significant. Historically, the value of farm production, as a percent of the California Gross State Product, has averaged over 3 percent.[3] During the past decade, however, this percentage has been decreasing and reached a low of 2.3 percent in 1985. This trend is likely to continue as California becomes a more urbanized state placing increased pressures on land, air, and water resources used in agricultural production.

California agriculture is increasingly turning to world markets to sell many of the crops it produces. Exports of agricultural products amounted to nearly 25 percent of that produced in 1988, or $4 billion. This amount is an increase from 1987 in which exports amounted to $3.3 billion.

California agriculture has benefited from several federal and state marketing programs. In the past two years, California agriculture has made heavy use of the Export Enhancement Program and TEA funds from the U. S. Department of Agriculture (USDA) to assist in export marketing. These programs have provided great assistance in marketing California products in export markets, particularly those where California products have faced subsidized competition. In addition, school lunch purchases have become a mainstay of many commodity marketing programs. There are 48 state and federal marketing order, and commission programs that include various provisions for research, promotion, advertising, education, information, market allocation, grades, standards, and quality.

California agriculture currently is a healthy and vigorous contributor to the California economy. Whether it can continue to maintain its prosperity and leadership role will depend on the resolution of a number of issues. These issues cover a broad

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[3]For details, see California Statistical Abstract (1989).

spectrum—from the role of California in a global market and economy to water, land use, environment, food health and safety, and labor concerns.[4]

II. California Agriculture in a Global Economy

California's markets are influenced by changes in economic forces and conditions on a worldwide basis. Government actions concerning inflation, interest rates, exchange rates, and monetary and fiscal policies have an impact. High inflation and interest rates in the late 1970s, coupled with a rise in the value of the dollar, led to a significant shakeout in California agriculture in the 1980s. Agriculture did not turn around until inflation subsided along with interest rates and the dollar weakened in the mid-1980s to allow U. S. products to become more competitive.

Government actions have a significant impact on world agricultural markets. A current concern is the use of production and marketing subsidies to promote industries that compete with U. S. agricultural products both in export and domestic markets. In many cases, these subsidies are also coupled with import barriers that restrict entry of U. S. products. The question of these subsidies and trade barriers is currently being negotiated under the General Agreement on Tariffs and Trade (GATT). The United States is proposing elimination of trade-distorting subsidies and barriers which, if enacted, poses both opportunities and problems for California agriculture. Elimination or reduction of trade barriers by countries that have restricted California products promises increased export opportunities. However, removal or reduction of U. S. barriers will mean increased competitive pressures for some domestic agricultural industries.

A significant number of changes are taking place in agricultural markets. One such change involves an increase in the value-added component of food and fiber. The lessening importance of the raw product component means that other factors will

[4] Much of the following material is taken from Siebert (1990).

influence decisions regarding food product marketing than production. This trend toward value-added food and fiber products is not only true in the United States but throughout the rest of the world. More countries are looking to compete in the world markets on a value-added basis rather than in marketing the raw component, particularly those countries that have relatively inexpensive labor supplies. For California, this development has serious implications as far as its markets are concerned.

Quality is a factor in which California has traditionally been a leader in the world. It has been established through the use of advanced technology as well as appropriate management systems which coordinate activities for quality enhancement from production through retailing. However, the rest of the world is catching up—both through the applications of technology developed in California and through technological advances of their own.

Technology today is truly international. Where California once had a decided edge through its University research and extension, coupled with an active and viable private research and development effort, other countries have made major advance, and, in some cases, are recognized world leaders. For some commodities, California must go to foreign companies for state-of-the-art technology. The University of California is well known for its basic research and is placing an increasing level of priority on biotechnology; however, a growing gap is taking place in applications research and development activities which are essential to continued leadership in technology. A fierce struggle is occurring worldwide for control of technology, particularly among multinational companies that view this as a way of controlling the market.

Significant changes have taken place in the structure of the food and fiber industry in the world. In the United States, the number of food processing companies has been steadily declining since the late 1940s with the survivors even larger. This trend is no more evident than in the California canning industry. The implication of this change is that the larger companies are more likely to be multinational and global in their outlook. They will look to market requirements first and then access products from sources where the quantity, quality, price, and market delivery meet their specifications. In addition, they will develop and have access to market information that is not available through public mechanisms. Finally, fewer processors and sellers will also mean fewer buyers which will shift bargaining power in their favor.

III. Water and Land Use

Water is the lifeblood of California agriculture. There is adequate land in California for production of crops but, without water, not many crops would be economically feasible. Agriculture utilizes about 85 percent of the available water supplies in California. Because it is the state's largest water user, pressure is increasing from many directions. With an increasing population in California and little development of additional water supplies in the foreseeable future, water now being used by agriculture is an inviting target for reallocation to industrial and municipal uses.

One major issue regarding the use of water by agriculture is conservation. Agriculture is accused of wasting water. Many contend that more water supplies could be made available if agriculture would shift to crops that require less water as well as utilize irrigation methods such as drip irrigation that are more efficient. Many crops are grown because they are profitable in the marketplace and not because they are water efficient. The shift to more efficient irrigation methods is limited by the kind of crop grown and its water requirements and the soils structure. For example, some crops and soils require a leaching of salts beyond the root zone that can only be accomplished with furrow irrigation which is less efficient compared to drip irrigation. Another related factor is that conversion to drip or sprinkler irrigation is costly and requires higher levels of energy. Hence, agriculture is in a real dilemma regarding water conservation, but pressure is likely to increase.

Another issue is water pricing. Compared to the delivered price in urban areas, many agricultural irrigation districts have less expensive water supplies. The reasons for this difference are many. However, many critics of agricultural water use allege that it is unduly subsidized and that it ought to pay a price for water more nearly in line with the true costs of delivery. The critics further maintain that, if agriculture would pay a higher price, it would develop necessary conservation measures. Water costs for agriculture have been increasing, and water conservation measures have been adopted. These measures have included more efficient delivery methods such as sprinkler and drip irrigation, return flow systems to reuse waste water, and irrigation management systems to improve time water applications to coincide with weather conditions and plant stress.

Another related issue is drainage. Because of the nature of many agricultural soils, they must have adequate drainage in order to avoid the buildup of damaging salts. The San Joaquin Valley drain was planned and partially built. However, construction was stopped with the result that lands that are irrigated on the west side of the San Joaquin Valley do not have a place to drain water containing high levels of salts. As a result, "perched" water tables are building up into the root zones of many crops, and productive land is being lost. At risk may be land totaling 1 million acres.

Agricultural land is coming under increased pressure from development as California's population expands. About 44,000 acres of land are being lost to urbanization each year with most of it prime agricultural land. If this trend continues, nearly 1 million acres of land could be lost during the next 20 years. Deferrals in the conversion of agricultural land have occurred under use of the Williamson Act which assesses it on the basis of agricultural use and not market value. However, many counties that utilize the Act are finding that the subvention funds used to offset the loss in tax revenue are not sufficient and are considering suspension of the Act. Removal of the Williamson Act provisions in many counties would hasten the conversion of agricultural land.

IV. Environmental and Food Health and Safety

California agriculture uses chemicals to increase efficiency by controlling pests and diseases and to enhance quality. Among the chemicals used are pesticides, fertilizers, and fuels. Increased pressure is being placed on agriculture to use less chemicals, particularly pesticides, through environmental and food health and safety regulation. Concerns have been expressed in the areas of water quality, detection of toxics in food supplies, and worker protection. As a result of these concerns, more restrictive regulations and policies have emerged to control the use of chemicals and avoid unsafe levels of toxics in the food and fiber supply as well as to protect the environment.

California agriculture is already the most regulated industry in the United States, if not the world, in the production of food and fiber. Many chemicals have been banned from use with increasing restrictions on applications of many others. These chemicals that have been prohibited from use are not being replaced as companies are finding that the costs of developing new ones are not profitable, particularly given increased risk associated with bringing new products into a market. In addition, because of the speciality crop nature of California agriculture, the market for new chemicals is limited in terms of revenues needed to offset product development costs. Hence, California agriculture is seeking new alternatives to its current arsenal of pest and disease controls.

In order to reduce its dependence on chemicals, four areas are emerging to meet agriculture's needs: (1) the development of pest and disease-resistant varieties through biotechnology research, (2) the development of improved pest control and environmentally compatible compounds through biotechnology and other research, (3) the use of IPM systems which utilizes a broad spectrum of technologies from biological to pest monitoring and improved management information to reduce chemical use, and (4) sustainable agriculture which looks at farming systems that are more compatible with natural resource use and environmental concerns. Continued pressure will be placed on agriculture to develop programs that will be more compatible with environmental and food health and safety concerns. Unless feasible alternatives are found, costs will increase, and California agriculture will become less competitive in the marketplace.

V. Farm Labor

While California agriculture is an intensive user of capital, it also is highly dependent on farm labor. Farm labor accounts for about 25 percent of overall farm production costs. Hence, California agriculture must not only be concerned with adequate supplies of labor, but also the cost of labor as it relates to overall production costs. In relation to other competing countries, California has substantially higher labor costs.

Farm labor rules have changed. Passage of the Immigration Reform and Control Act of 1986 (IRCA) has placed new rules on the availability of farm labor to agriculture. While adequate supplies now exist, it is expected that the historical transition from farm jobs to urban jobs will continue to take place with farm laborers. Unlike the past, replenishment of workers who leave the farm workplace is now highly controlled by IRCA. A significant test will take place in the years ahead as to whether the mechanisms now in place can meet the needs to fill farm labor vacancies not only in terms of quantity but also in terms of timeliness of harvest.

The spin-off from this prospective supply situation will be twofold. One is in the form of economic incentives needed to keep people in the farm labor ranks. These incentives will take place in the form of higher wages and improved benefits. Since California is already a high labor cost agricultural producer compared to its worldwide competitors, pressure will be on to increase efficiency through adoption of technology and management to offset increased labor costs. A second challenge to farmers will be to increase their management skills related to labor not only to provide increased efficiency but also to provide a workplace environment that is conducive to retaining farm laborers.

VI. Conclusions

California agriculture is a dynamic industry which has maintained its world leadership through innovation and management skills. However, a number of changes are taking place that, coupled with some critical issues, pose a challenge to this leadership. The restructuring of food and fiber markets means that increasingly California firms must think of themselves in the context of global competitors. If the U. S. status of decreasing government influences in the production and marketing of food and fiber succeeds, agriculture will find itself not only in a position to take advantage of opportunities now denied because of trade barriers but also in a position where it might face increased competition for the same reason. Pressures from water and land-use issues could well lead to a reduction in land available to grow crops as well as to increased costs. Cost increases will also occur in complying with increasing environmental and food health and safety regulations. It also is likely that increased costs will occur in assuring adequate supplies of farm labor. To offset these cost pressures, California agriculture will increasingly turn to a mix of high value and value-added food and fiber products. In addition, it will need improved technologies and management skills in order to offset its increased costs with improved efficiencies. In spite of the adversity identified with the future of California agriculture, it is located in a rapidly growing market in its home state (nation) as well as sitting at the doorstep of the largest market in the world in the Pacific Rim. California agriculture will be changed because of the forces identified. Its ability to provide quality goods and services to the marketplace will depend mainly on its ability to quickly adopt new technologies and apply a high level of management skills.

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3

PESTICIDE USE IN CALIFORNIA AGRICULTURE

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Pesticide use in modern agriculture has helped account for increased output of high quality food. This has helped release labor from menial tasks such as weeding, pruning, and produce sorting. Use of pesticides in California crops is somewhat unique compared with much of the remainder of the United States in that the crops are relatively high value per unit area, there is more use of high technology and management, and there are favorable weather and pest conditions. In addition, California farmers produce large shares of the U. S. production of fruits and vegetables which have special pest management problems because they are "minor pesticide" markets.

This chapter summarizes data from farm surveys of pesticide use in California and elsewhere in the United States. Four major points are developed:

- Use levels of pesticides in California per acre and per dollar of farm output is low relative to the remainder of the United States for most crops and pesticide types.
- Use levels of most pesticides over the past decade are stable or declining especially when adjustments are made for dosages per application.
- Many of the crops grown in California are "minor use crops" which means that the cost of safety and efficacy studies for pesticide registration is relatively high per acre.

- California agriculturalists have been world leaders in developing pest management practices and substituting information and labor for pesticides.

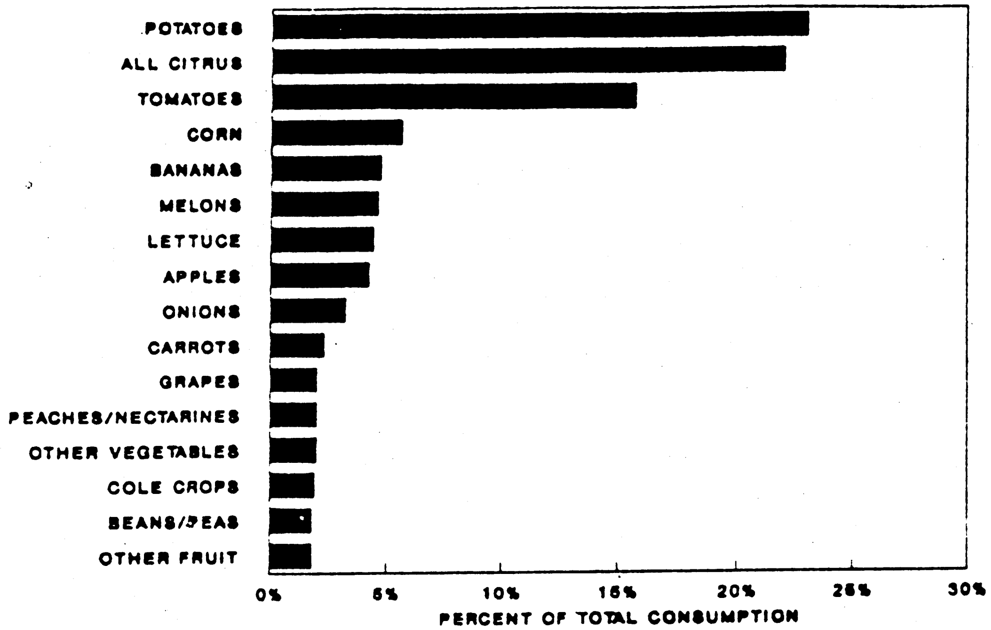
I. A Perspective of Pesticides in California Agriculture

Farmers who routinely come into contact with pesticides can easily see their benefits in production in terms of higher yields, increased quality of produce, and capabilities for extending the growing season to provide produce through much of the year. Farmers must continuously weigh the value of the extra produce which pesticides provide with their costs. The costs include the farmers' and his laborers' safety as well as the direct costs of the pesticides. However, food consumers and the typical voters have a difficult time associating food quality and food prices with pesticide use.

For California farmers, the $8.5 billion fruit, nut, and vegetable industry accounts for about one-half of the total agricultural receipts in the state. On the consumer side, these products represent an important share of the diet. Total fruit, nut, and vegetable consumption relative to all food consumption (weight basis at retail) is about 30 percent in the average American diet (*Agricultural Statistics*, 1988). California growers account for about 55 percent of the U. S. production of fruit and nuts and about 50 percent of all vegetables. Net imports account for about 5 percent of the value of production for vegetables. Most all types of fruit and vegetables are grown in California and, in some cases (processed tomatoes, canned peaches, avocados, almonds, walnuts, apricots, lemons, prunes and plums, and grapes), large proportions (greater than 90 percent) are produced in California.

Figure 1 shows the consumption shares for fruits and vegetables based on fresh produce equivalent weight basis (*Agricultural Statistics*). With the exception of potatoes and bananas, California growers account for a large share of this food. For California consumers, even higher percentages of the produce would originate in

FIGURE 1 U.S. CONSUMPTION SHARES FOR FRUITS AND VEGETABLES, 1987



California fields. Therefore, it is critical for consumers to be aware of the costs of changes in production practices as well as food quality originating in California.

II. Pesticide Use in California Relative to Other Regions

Use levels of pesticides by California farmers are low relative to those in other parts of the United States. This is partly due to the dry weather in California and partly to advanced pest management techniques developed and widely adopted by growers. The relatively low use of pesticides per acre and especially per dollar of crop revenue indicates that California growers have already adopted most of the more advanced pest management techniques. Additional restrictions on use are likely to result in major short-term disruptions in agricultural production with associated higher consumer prices.

Figures 2 to 12 show pesticide applications (product acres = applications *x* number of different products in an application) per acre grown for 11 of the major California crops relative to other regions based on farmer surveys for 1987 and 1988. This survey is conducted by a firm which has been collecting pesticide-use data from farmers each year for about 20 years; 4,683 fruit and nut growers were surveyed in 1988 while 5,019 vegetable growers were contacted in 1987. The "West" region includes some producers from other states, especially in the case of potatoes and apples; but in all cases the data for the "West" closely represent California pesticide-use practices. The same type of survey data for 2,000 cotton growers is summarized in Figure 13.

Except for a few cases (fungicides for grapes and fumigants in potatoes, apples, grapes, and oranges), the number of product areas per acre grown are much lower in the "West" than in other regions. It is not uncommon for major crops such as peaches, apples, citrus, and tomatoes to receive 10 to 15 times the level of fungicide treatments in other regions as that in California. Plant disease levels are much higher

FIGURE 2

APPLE PESTICIDE USE PER ACRE GROWN

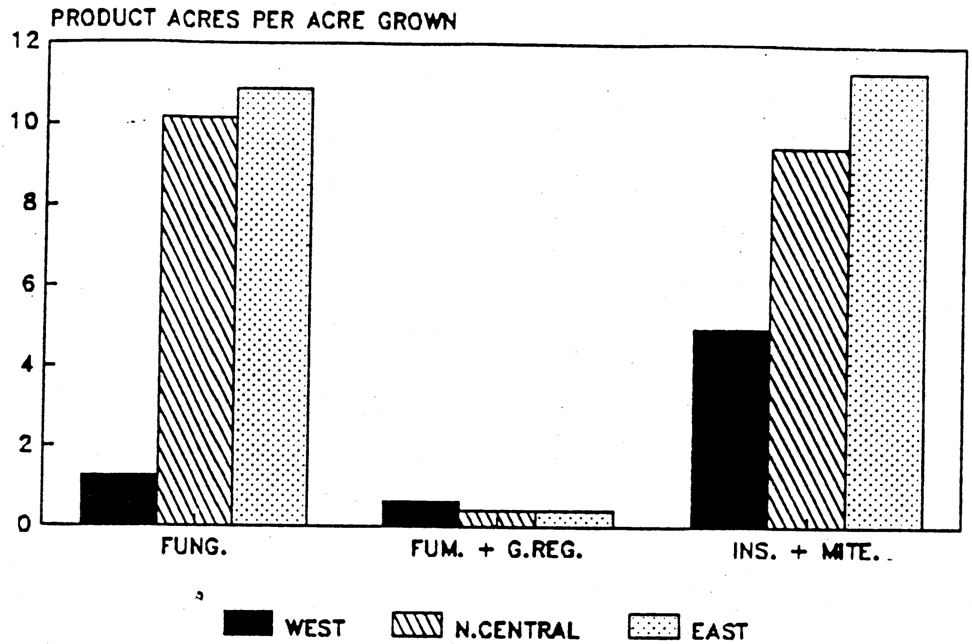


FIGURE 3

CHERRY PESTICIDE USE PER ACRE GROWN

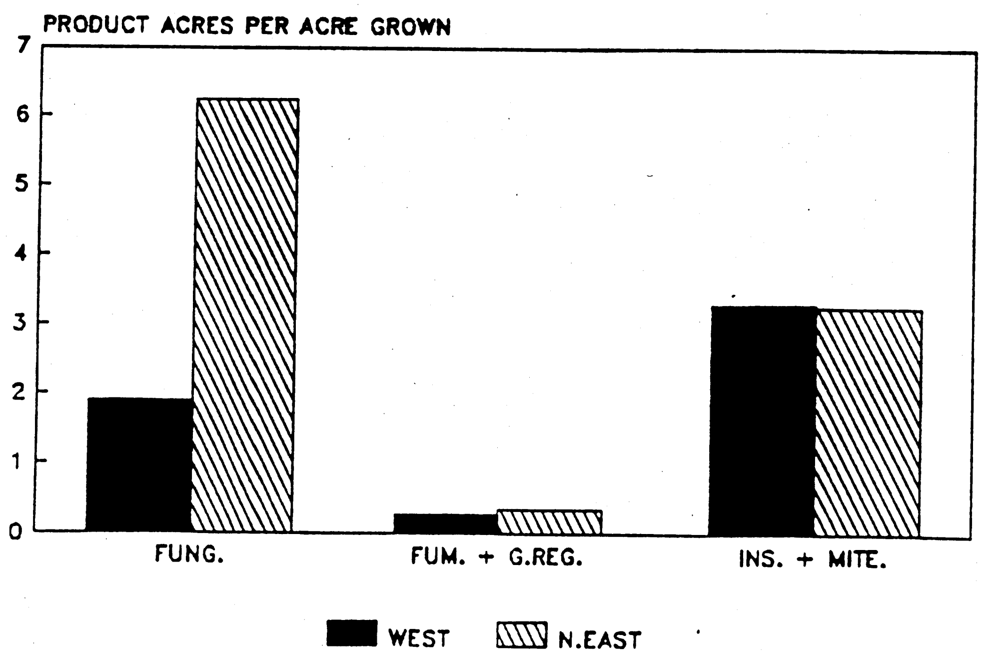


FIGURE 4

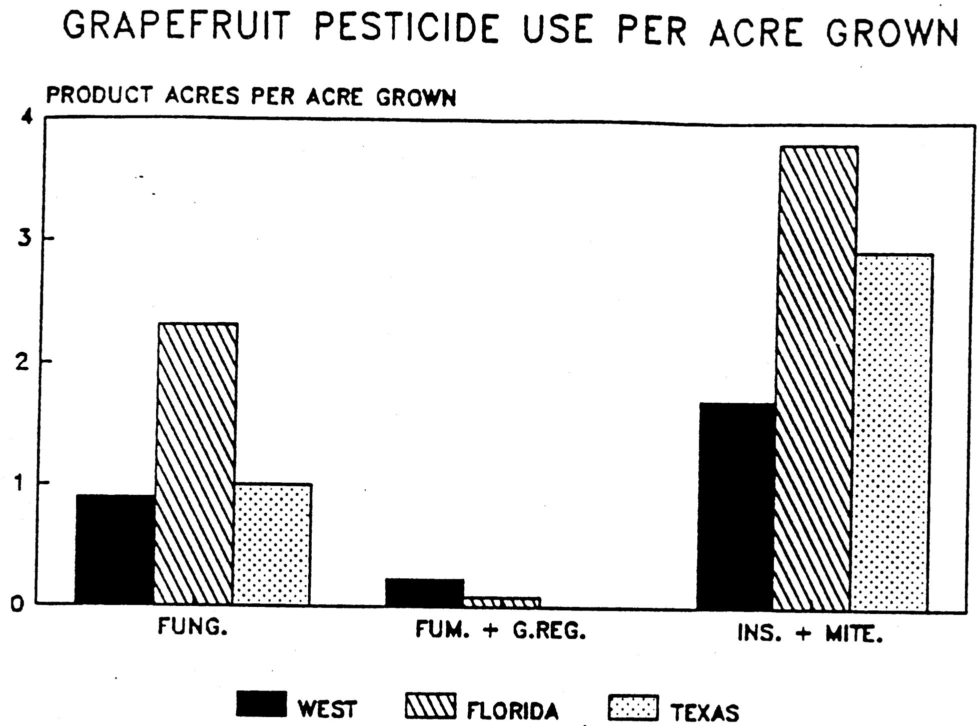


FIGURE 5

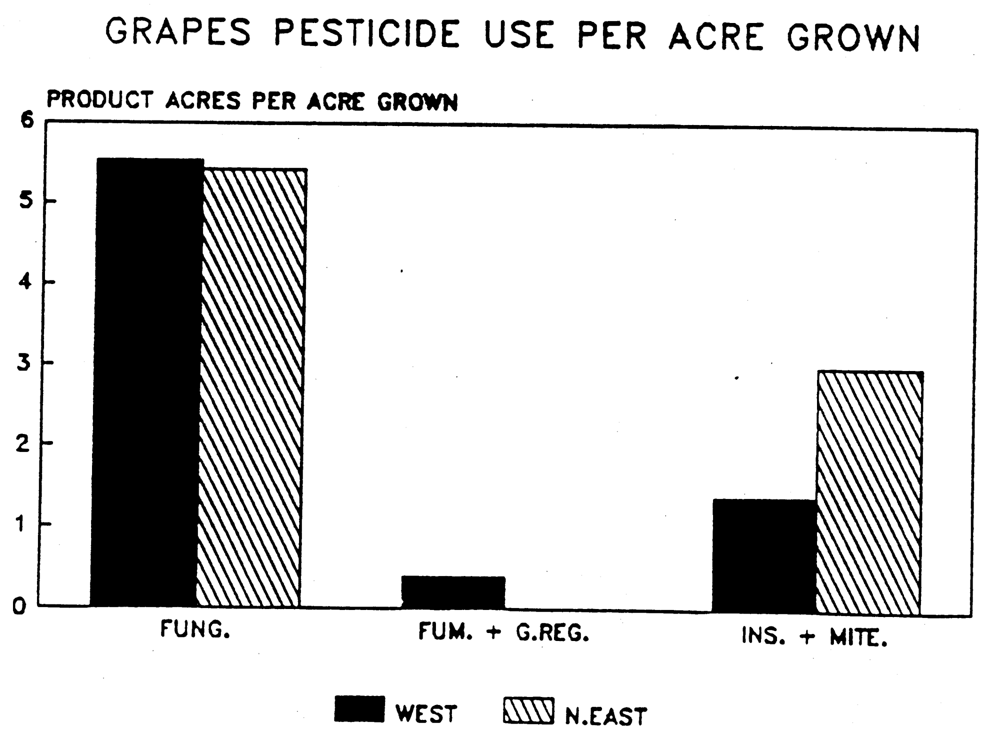


FIGURE 6

LETTUCE PESTICIDE USE PER ACRE GROWN

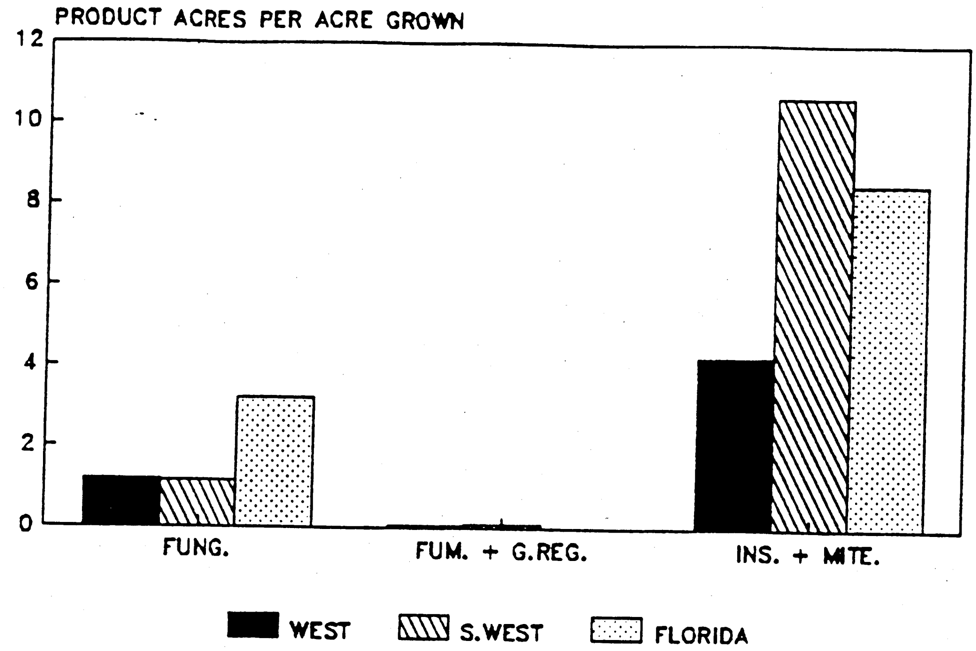


FIGURE 7

MELON PESTICIDE USE PER ACRE GROWN

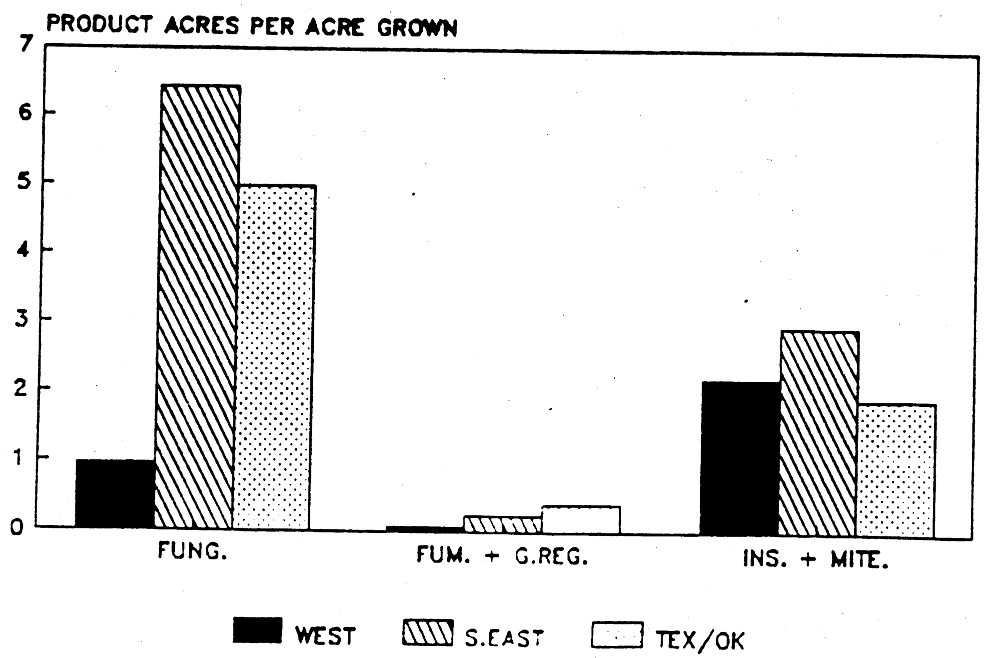


FIGURE 8

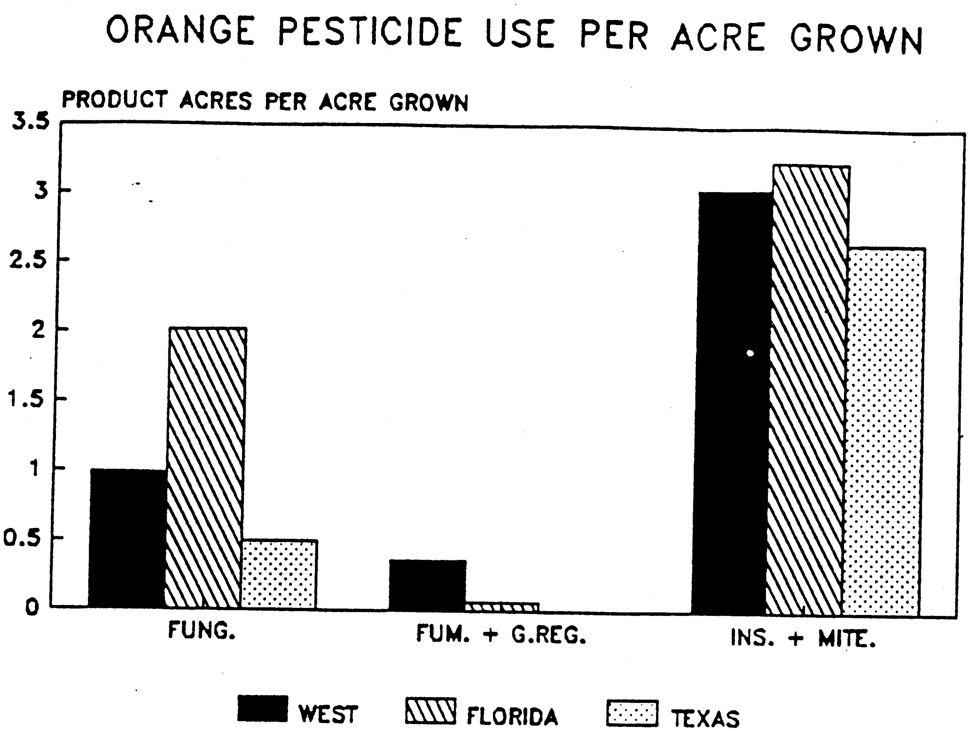


FIGURE 9

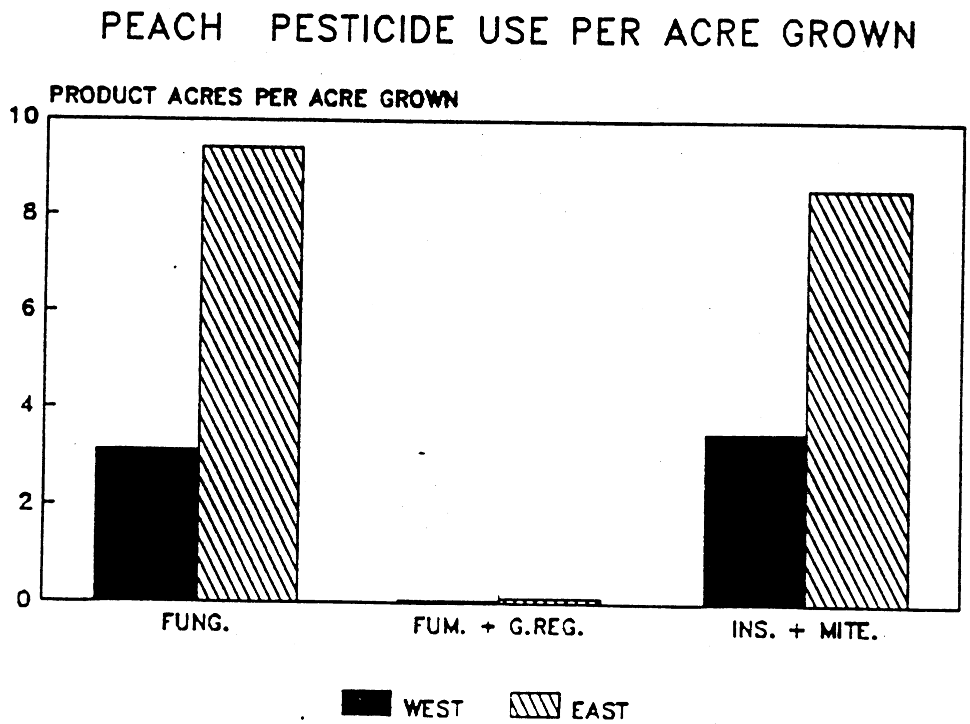


FIGURE 10

POTATOE PESTICIDE USE PER ACRE GROWN

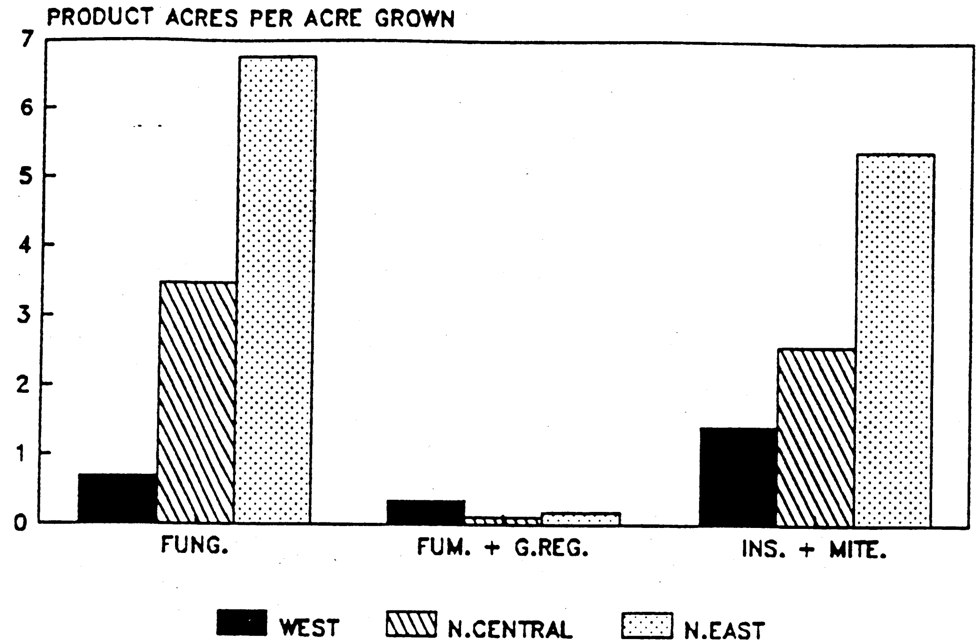


FIGURE 11

SUGAR BEET PESTICIDE USE PER ACRE GROWN

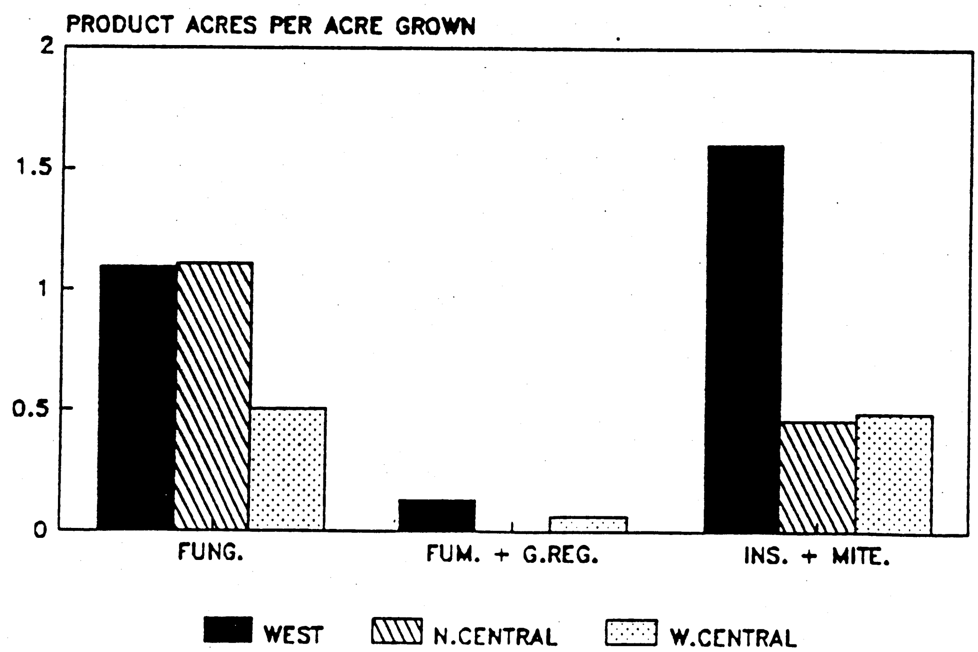


FIGURE 12

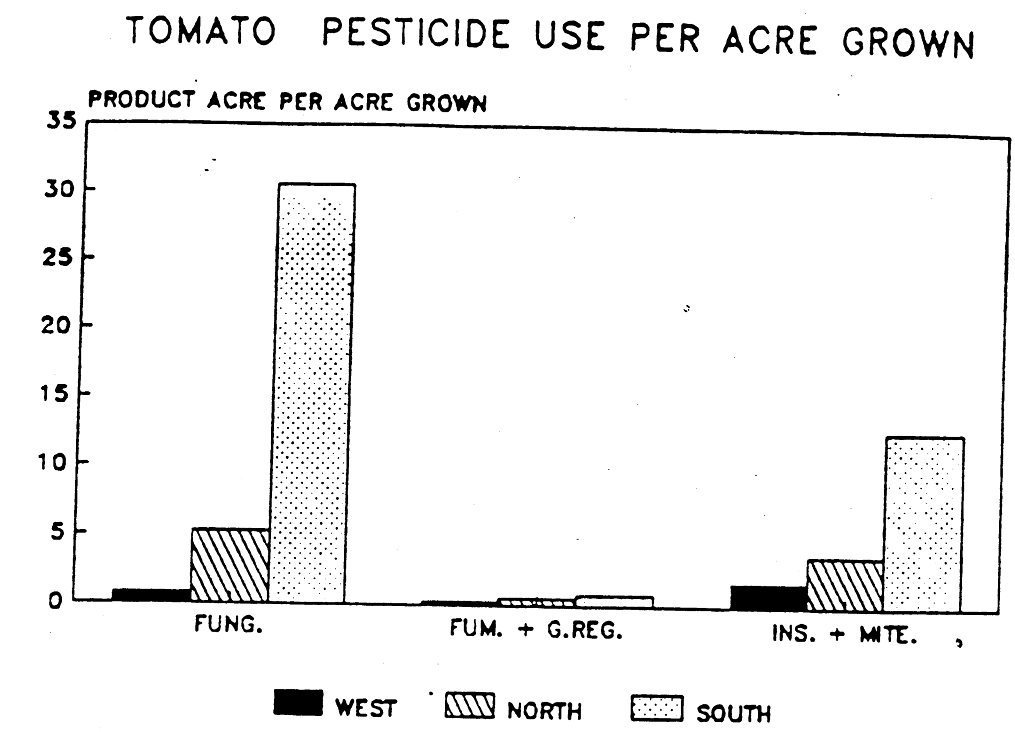
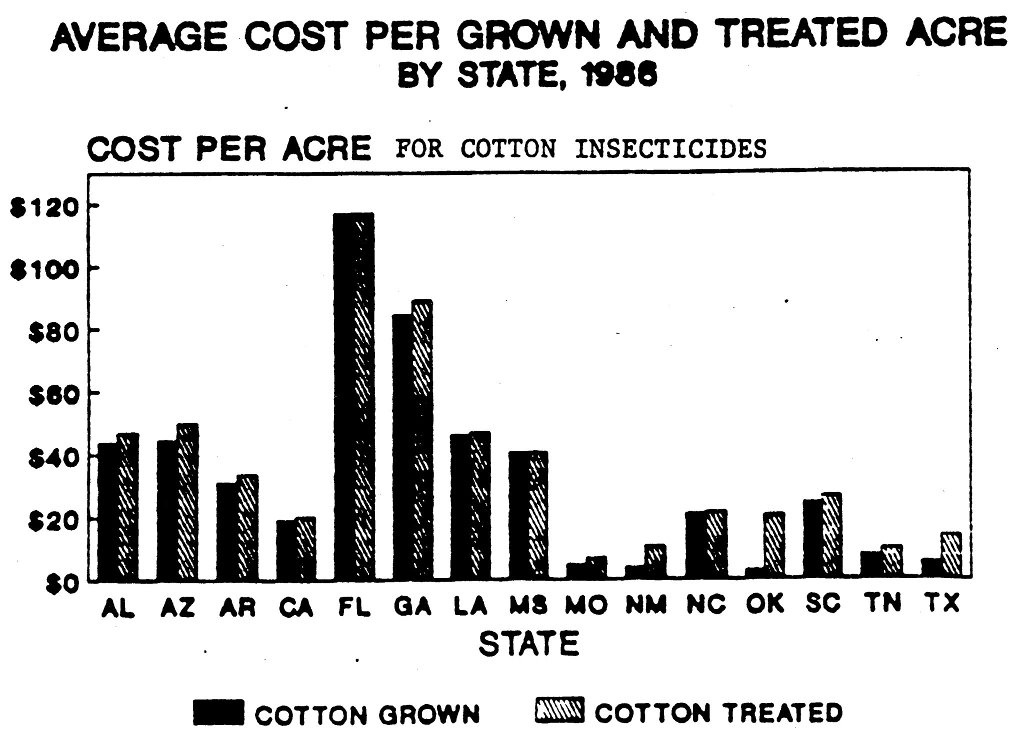


FIGURE 13



in more humid areas. In some cases mites and insects are also higher in midwest and eastern regions than in California. The largest acreage vegetables (tomatoes, potatoes, and lettuce) all have lower insecticide use than do other regions. The crops with equivalent insecticide use across regions are oranges, cherries, and melons. Only sugar beets shows a higher use rate for insecticides. California cotton growers have lower insecticide use rates (in dollars per acre) than most states (Figure 13).

Some crops are more susceptible to certain pest categories than are others. Figures 14 to 16 show fungicide, fumigant (primarily nematicides), and insecticide expenditures per dollar of crop revenue. Fungicide expenditures are much higher on almonds and peaches than on grapes or potatoes. For most vegetable and fruit acres, only about \$.005-\$.01 of fungicides are needed per dollar of crop output. In the case of fumigants, potatoes and sugar beets receive the highest treatments but, even on these crops, less than \$.01 per dollar of output is expended. A typical insecticide protection program costs about \$.01 for tomatoes, grapes, and potatoes and as high as \$.04 for oranges. These expenditures are low, but it does not mean that they can be easily reduced even more.

III. Trends in Use Levels of Pesticides

The usual assumption by agriculturalists is that pesticide use is increasing over time. Over the 1950-1980 period, this upward trend in use was driven by new pesticide discoveries and falling pesticide prices relative to labor, machinery, and land. However, in the past 5 to 10 years, prices of pesticides have risen relative to land and labor. Energy costs for cultivation also have fallen relative to herbicide costs. In this environment pesticide use has been stable or in some cases declining.

Trends in pesticide use over the past 10 years for four major fruit and vegetable crops are shown in Figures 17 to 20. These data are based on total pesticide applications (product acres) for the entire United States. They do not correct for the

FIGURE 14

FUNGICIDE EXPENDITURES RELATIVE TO CROP REVENUE

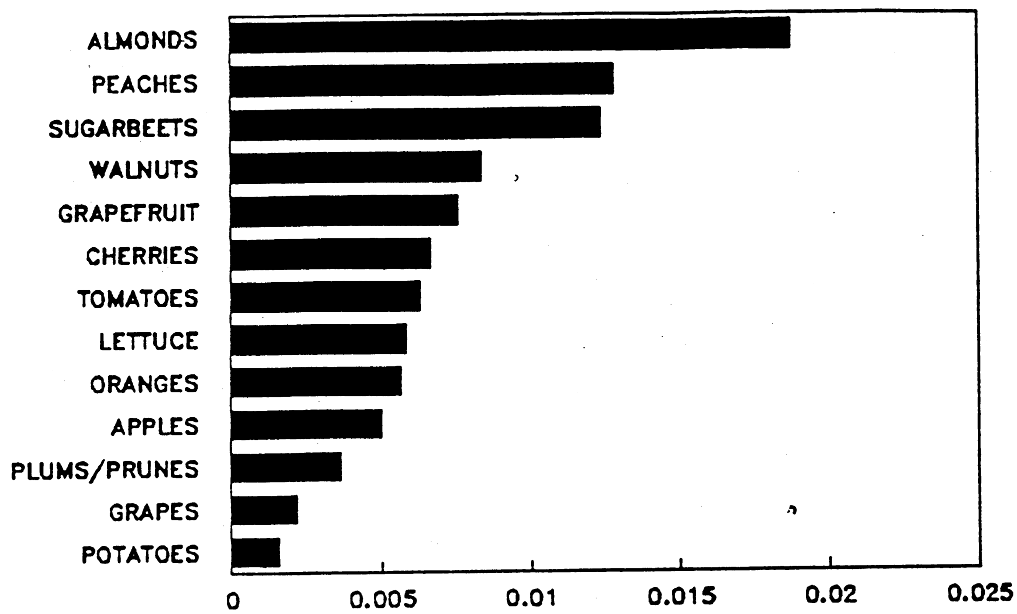


FIGURE 15

FUMIGANT & GROWTH REGULATOR EXPENDITURES RELATIVE TO CROP REVENUE

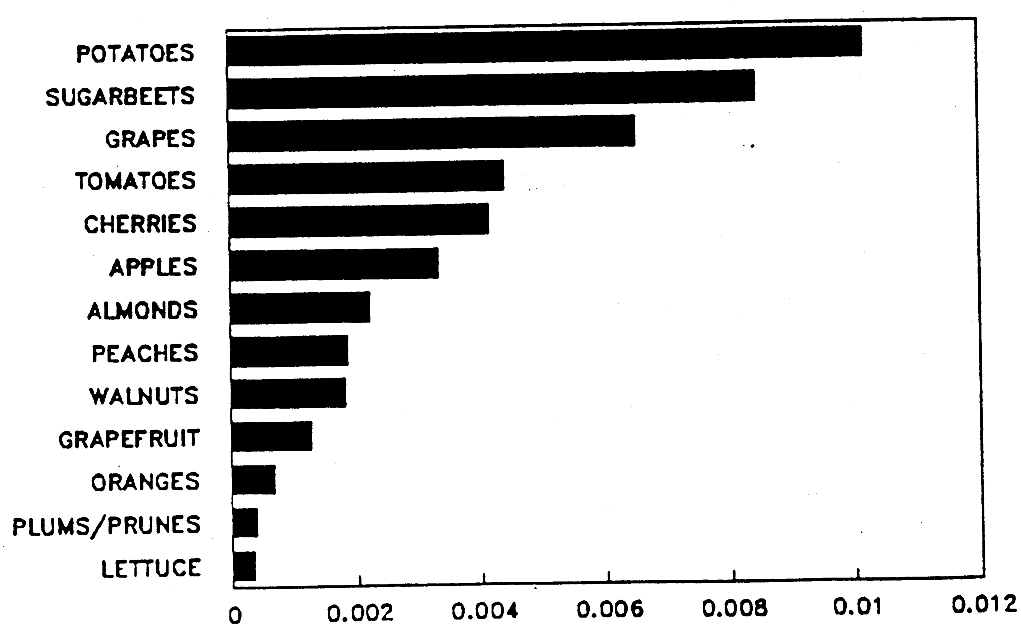


FIGURE 16

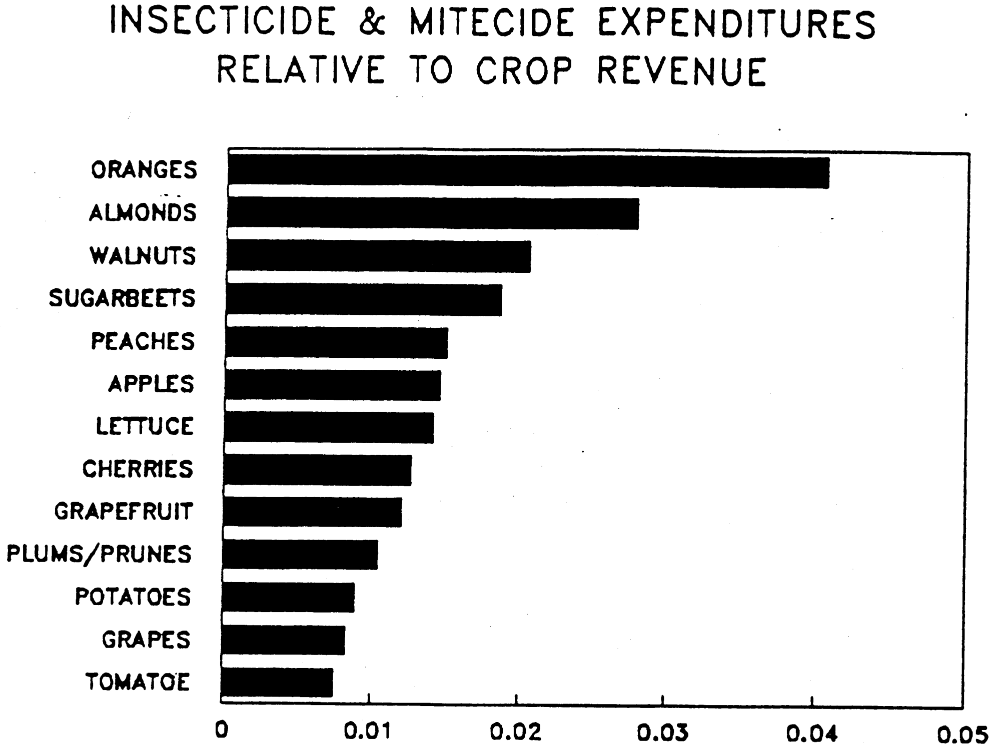


FIGURE 17

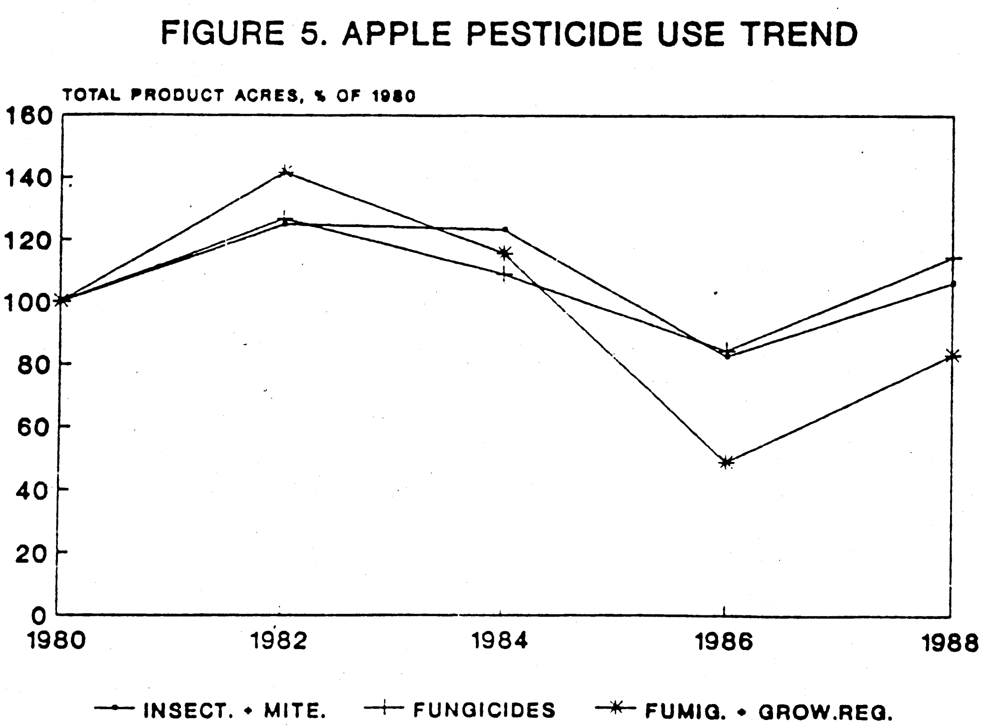


FIGURE 18

FIGURE 6. GRAPE PESTICIDE USE TREND

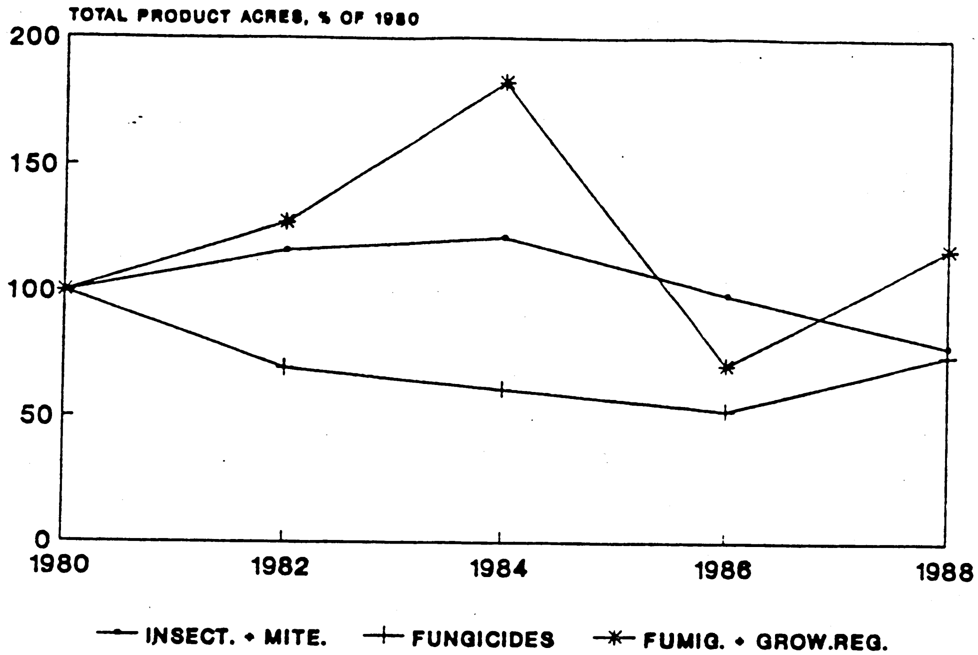


FIGURE 19

FIGURE 7. POTATOE PESTICIDE USE TREND

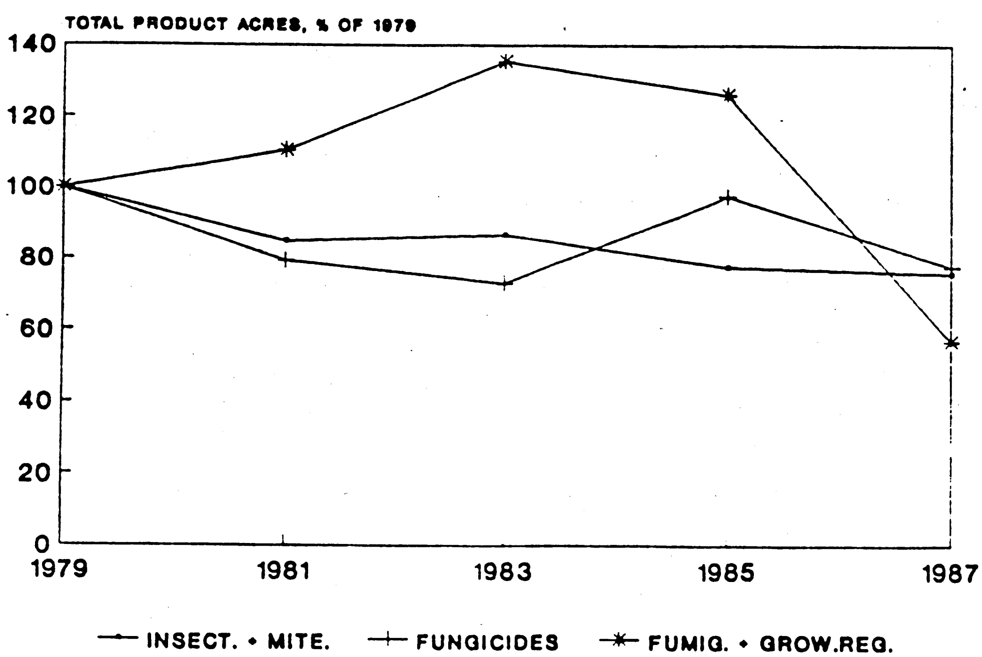
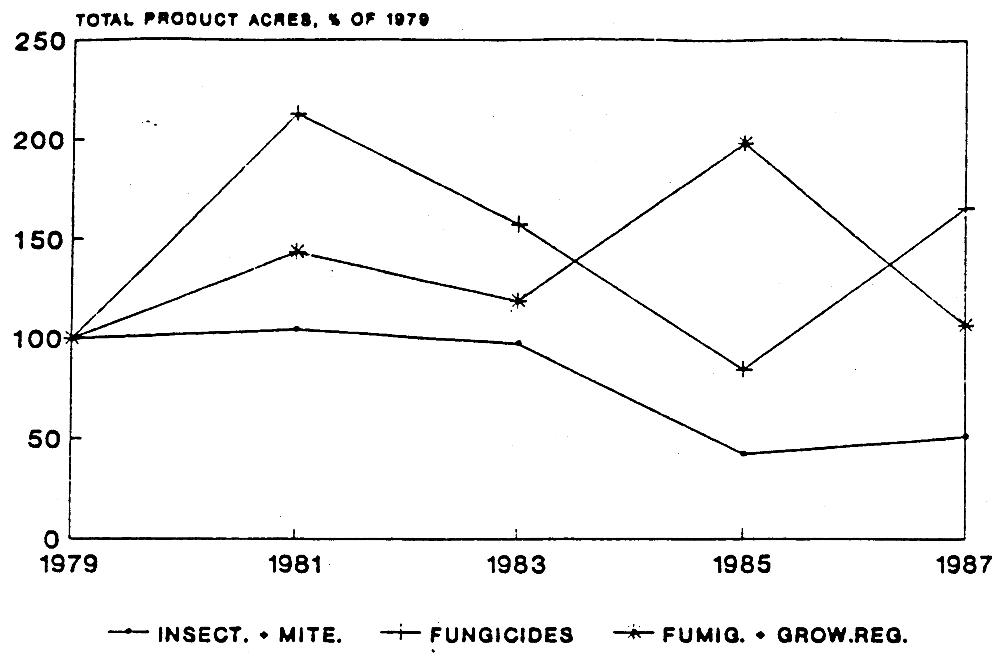


FIGURE 20 TOMATOE PESTICIDE USE TREND



changes in planted acres. Except for fungicides used on tomatoes (mostly outside of California), use rates in the late 1980s were equal to or lower than 1979-80 levels. The pesticide use is measured in number of applications. However, dosages per application have declined as well. Many insecticide treatments with synthetic pyrethroid materials (introduced about 1980) are applied at .1 pound per acre instead of the .8 to 1.0 pounds for older compounds. The same is true for many of the new herbicides. Dosages per treatment have not declined as much for fungicides, fumigants, and plant growth regulators. Though not shown, the trend in cotton insecticide use in California is very stable at about 2.5 to 3.5 treatments per year since the 1980s.

IV. Minor Use Pesticides

The development of new pesticide products is slow because of the necessity to conduct safety as well as pest efficacy studies prior to registration and use. Most pesticides are first developed for soybean, corn, and cotton pests because costs of development can be spread over large market sales. After a new product is introduced on the major crops, it is expanded to other crops if they have similar pests to the major crops. Many pests on fruit and vegetable crops are different from the major crops so that product development is slow and in some cases only one or two pesticide are effective against particular pests.

Another factor preventing development of pesticides for fruit and vegetable crops is the high potential liability loss in cases of worker safety, pesticide drift, or nonperformance in pest control. Fruit and vegetable crops have high revenues per acre and high potential levels of damage relative to that for row crops. A nonperformance loss for a fruit or vegetable pesticide would mean a large ($2,000-$4,000 per acre) potential liability for a pest infestation that was not controlled. The potential loss for a wheat insect may only be $10-$20 per acre. In California the close proximity of pesticide use to honey bees or another crop susceptible to drift can also result in large liability losses. Potential losses such as these will deter pesticide companies from developing and registering pesticides for minor use crops.

When there are only a few pesticides registered for use, the potential yield and quality losses from pesticide cancellation can be more drastic. There are fewer substitute pesticides and, if there is a substitute material, it may be difficult to use, expensive, and not as effective. Thus, higher percent yield losses from cancellation of pesticides on fruit and vegetables than on other crops can be expected. The costs from cancellation of a pesticide may last several years as growers and pest management advisers devise alternative chemical and nonchemical management practices.

V. Pest Management in California

California farmers, pest control advisors, extension service workers, and university researchers have been in the forefront of pest management research and development. Part of the reason crops like cotton, tomatoes, citrus, and other tree crops receive such low pesticide treatments is the high level of use of advanced management techniques. Use of pest resistant crop varieties (sugar beets, potatoes, and alfalfa); release of biological control agents (olives, citrus, and almonds); and use of pest monitoring in most all crops in California are the envy of researchers and farmers in all other parts of the world.

Development of plant growth models, computer models of insect and mite development especially in cotton, alfalfa, and citrus, have lead to lower insecticide use. Researchers at the University of California were leaders of a major integrated pest management consortium during the 1970s. The study of pesticide-resistance development, along with methods to slow its progress, has also been led by California researchers.

The final component of pest management, which is more developed in California than in other regions, is the use of private pest management advisors. These advisors who monitor crop and pest status through the year can help farmers apply pesticides only when the crop loss prevented exceeds the costs of the pesticide application. Choosing low dosages and the correct pesticide type to preserve natural pest enemies is a critical function of these advisors. But they also must know application technology to prevent drift, nonpesticide crop management practices, and other practices to lower food and water residues. Most pest control advisors are not "count and spray" managers because they want to maintain farmers as repeat customers.

VI. The Future of Pesticides in California

The dry, fertile valleys of California (San Joaquin, Salinas, Napa, and Sacramento) are world renown for their high production of fruit and vegetables. The use levels of pesticides are lower than for producing these crop in most regions of the United States. Only 4 to 5 cents per dollar of produce is expended on all pesticides in California. The trend in total pesticide use is stable or slightly lower on a per-acre basis. Pest management advisors and an active research program have brought new developments in pest management to California prior to most regions of the world.

However, there are several vulnerable points to the California pest management practices. The pesticides which are used cannot be easily and rapidly replaced. The federal pesticide laws require long periods of testing and, in many cases, there are few pesticide or nonpesticide substitutes for the specialized or "minor use" products. Secondly, the pesticide-use practices are more interdependent between species and crops in orchard, vegetable, and vineyard crops than in land-intensive crops (corn, soybeans, small grains). This occurs because of the low levels of cultivation, close distances, and low levels of noncrop refuges. Finally, because of the high crop values, the potential losses from inadequate pest control can be large when unusual pest conditions arise. As an example, the Central Valley provides an ideal climate for peach, almond, and other fruit production because of low summer rainfall. However, a minor sprinkle of rainfall can induce fungal rot (brown rot) that can damage 5 to 50 percent of the crop in a few days if protective fungicides are not used. Such rainfalls only occur about once in 10 years. Similar conditions can lead to large losses in other California crops. It is for these unusual conditions that pesticides can provide a highly valuable service to farmers and consumers alike.

4

CALIFORNIA AGRICULTURE IN TRANSITION TECHNOLOGICAL RESPONSE TO ENVIRONMENTAL REGULATION

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I. Introduction

California agriculture has a long history of adapting to changes that have been stimulated by shifts in technology, products, resources, and markets. We are now entering an era where environmental constraints on production have to be added to this list. Currently, it appears that the impact of environmental constraints will be stronger than all the factors, except markets, in determining the development of California agriculture in the future. Even if the initiatives on the forthcoming ballot do not result in changed production conditions, the shift in environmental concern of the average voter is clear.

The costs of these changes to California agriculture can be summarized as: (1) the cost of a changed comparative advantage if California adopts different standards of production unilaterally (this cost could be offset if other states and importers adopt similar production as opposed to residue standards); and (2) the costs of adjusting to the new production equilibrium. Given the high proportion of fixed investment in agricultural production, the costs of adjusting over a short period may be the greater of the two costs.

This chapter examines how California agriculture has adjusted to past shifts in technology and attempts to draw some lessons whether it can adjust to this new source of production change.

Innovation in agriculture, as in other industries, is driven both by economic conditions and institutional factors that influence economic returns. There's a large demand for technological development. This represents an evolutionary process that responds to changes in resource value reflected in the relative prices of inputs and in the restrictions imposed by regulatory authorities. Past examples of technological change in California agriculture show the creative ability and resiliency of California farmers, and rural farm workers to adapt to new conditions. For instance, tractors, tomato harvesters, cotton pickers, chemical fertilizers and pesticides, irrigation, and computers have now—as in the past—significantly influenced the state's agriculture.

New technological challenges are confronting agricultural producers in California. The heightened public outcry concerning both the known and unknown dangers of many synthetic chemical pesticides requires that agricultural interests either provide information supporting the reasonable safety of their chemicals or develop and adopt alternatives.

II. Diffusion or Confusion: Understanding Transition in Agriculture

Industry-based technological change can be categorized as supply push or demand pull. Supply-push change is when a new technique or product is spawned by the advance of basic science in the exploration of the frontiers of knowledge. Demand-pull technology arises in response to increased scarcity, a response that is reflected in the saying that "necessity is the mother of invention." In both cases the rate of adoption of the technology is driven by its value. The recent development of genetic technologies provides examples of both types of innovation. An example of a supply-push advance is the bovine somatotropin (BST) which enhances the production of milk in some cases by as much as 25 percent per cow. To many producers, taxpayers, and consumers this advance—that is clearly not a response to any apparent demand to increase dairy efficiency—compounds the stress on an industry that is already trying to cope with surplus production. In contrast, the research and development of genetically pest-resistant plant varieties are a demand driven search for ways of decreasing the reliance on costly pesticides. These two simple examples illustrate how adoption will depend on perceived values. A demand-pull innovation which arises out of on inherent need or a response to prevailing economic conditions has a recognized value that immediately affects the acceptance of the technology and its adoption, whereas innovations without a demand base, even if they clearly increase efficiency, may be met with less acceptance and adoption may be slowed by vested political interests threatened by accommodating the innovation.

The introduction of more stringent regulations on agriculture will create an increased demand for environmentally benign production technologies. How fast will it take to evolve? And once evolved, how fast will they be adopted by the industry? The cost to the industry will depend on the rate and extent of required adjustments.

The process in which potential users are converted into actual users is known as diffusion. In a pioneering study of the diffusion of technology, Griliches (1957) studied the percentage of U. S. corn acreage planted with hybrid seed. Griliches found that over time the penetration of hybrid technology followed the well-known S-shaped curve (Figure 1a), and the rate of diffusion could easily be estimated by the cumulative density function of the logistic distribution. Differences in the "ceiling" level of penetration and the speed of diffusion are attributed to demand factors and the profitability of shifting varieties. This pattern has been repeatedly shown in study after study and gives rise to Rogers' (1960) description of innovators, early adopters, late adopters, and laggards commonly used to describe technological change within an industry (Figure 1b).

Figure 1-a

S-Shaped Diffusion Curve

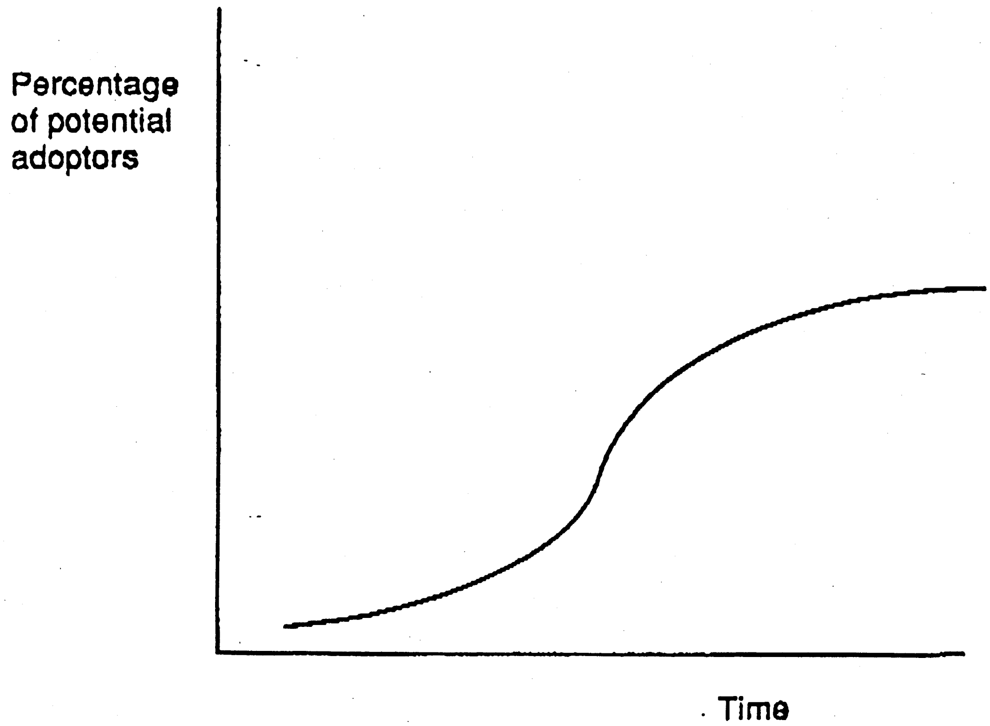
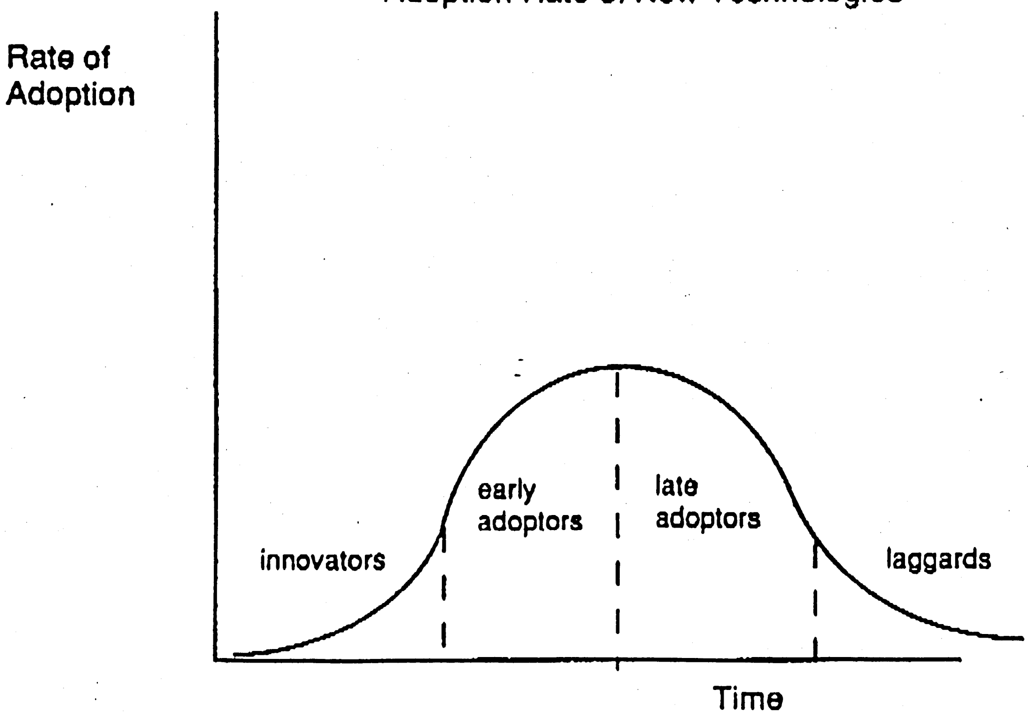


Figure 1-b

Adoption Rate of New Technologies



As for the spread of an infectious disease, the diffusion process is frequently modeled as an epidemic in which information concerning the profitability of the innovation is spread by word-of-mouth. At the time of the innovation, few of the potential users are aware of the benefits of adoption but, as time goes on and as successful users have contact with potential users, the rate of conversion grows at an increasing rate. Eventually, as the innovation begins to saturate its potential market, the likelihood of a current user contacting a potential user begins to fall as the number of potential users relative to users falls and the diffusion process begins to level off at some level of saturation (Thirtle and Ruttan, 1987). New technology has a downside; this is commonly called a "technological treadmill" that can force changes in the structure and scale of production. New technology may have characteristics that favor larger or smaller production units. In response to environmental regulations, alternative pest control technologies, like many agricultural innovations in the past, may favor larger farm units due to economies of scale associated with management practices. Producers must continually be mindful of new technologies that serve to lower prices, and threaten to undermine their profits if they delay adoption.

III. California's Legacy of Innovation: Tractors

In the history of technical innovation in California agriculture, none has had a more profound impact on rural life than the tractor. Tractors worked faster, freed farmers from the labor of caring for their horses, and freed acreage from hay and oats. Just before World War I, a small tractor was introduced and, by 1920, 11 percent of California farms had a tractor. This number continued to grow to one-third of the California farms by 1930 and, by 1945, it had risen to 57 percent (Ankli and Olmstead, 1981). Capital constraints, a developed market for custom tractor services, and the importance of specialized crops with distinctive cost and production characteristics likely contributed to the slow diffusion of the tractor technology. Unlike future innovations, the introduction of tractor technology was met with little opposition except perhaps from the industry of farriers.

Improvements in tractor technology added to the attraction. Berck (1985) notes how these improvements, primarily horsepower, worked to lower the costs of tractor horsepower over a 10-year period. His evidence supports the view that technical innovation in tractors served to proportionally lower costs of a given horsepower. The lowering of tractor costs, as well as the introduction of pneumatic tires and a variety of implements, enhanced the adoption rate and accelerated the diffusion of the technology. Sensitivity to costs is a strong incentive driving both the development and the adoption of new technologies but, unlike the tractor, the development of the tomato harvester required an intense coordinated effort by the entire industry.

IV. Tomato Harvester

California has been at the leading edge of many technological innovations; foremost among them has been the tomato harvester. The coordinated efforts of industry and University scientists and engineers in developing the mechanical harvester and a suitable tomato hybrid led to a revolution in the tomato industry. The innovation required joint adaptation by each segment of the industry. Growers adapted to new plant varieties and harvesting methods (processors accommodated these new varieties), and farm laborers were forced to change the type and quantity of labor. Schmitz and Seckler (1970) estimated that farm workers lost 19.5 million man-hours of labor due to the tomato harvester by 1973.

Diffusion of the harvester technology was swift and certain due to the dramatic and significant decrease in harvesting costs. The discontinuation of the Bracero program of imported Mexican labor was an early example of regulation generating a demand for new technology. The initial reaction of growers without the foresight of new technology was pessimistic. Tomato growers argued that, "the use of braceros is absolutely necessary for the survival of the tomato industry. . . . It is the consensus of opinion among tomato growers that without Mexican National help we would have to discontinue operations" (California Senate, 1961). Instead of these dire predictions, tomato mechanization improved California's comparative advantage in tomato production. Between 1961 and 1987, California tomato acreage increased by 34 percent whereas labor used in harvesting tomatoes dropped by 43 percent (Martin, 1990).

The first 25 harvesters were introduced in 1961. In 1964 there were 75; by 1967, there were 1,000 harvesters in use on 80 percent of the tomato acreage in California. Competitiveness in agricultural markets can be unforgiving both to late adopters who are unwilling or unable to adopt and, in this instance, to farm laborers who are displaced at the hands of technology. Schmitz and Seckler attempted to estimate the net social returns of the harvester by taking into account the value of the displaced labor. Depending on the estimated cost savings and the percent of the displaced wage bill paid in compensation, the net social returns range from -8 percent to 1,288 percent—suggesting that, with the exception of the most pessimistic scenario, if those who benefited from the innovation compensated those who were displaced, society as a whole would have been better off.

As is true for many innovations, the rewards of a technological advance are unequivocally reaped by consumers who benefit from the fall in food prices and possibly by the innovators, and early adopters who can profit by the temporarily increased margin due to the fall in costs. However, producers who are late jumping on the technological treadmill—either because they lack access to capital markets (or they face information constraints on the supply and use of the innovation) or because the innovation is scale sensitive—may find themselves at a competitive disadvantage that threatens their economic viability. For these producers, with real and binding constraints to adoption, technological change may be an unwelcomed advance that threatens them with economic dislocation. An example of a technological advance that has met with a decidedly cool reception is the development of bovine somatotropin (BST).

V. Bovine Somatotropin

In an ongoing effort to study the acceptance and attitudes of California dairy people to the potential introduction of BST, Butler, Carter, and Zepeda (1990) are in the third year of conducting a survey of over 100 dairy producers. Their results show a consistent need by 60 percent of the producers to increase milk production. In response to questions concerning their preferences to increasing milk production, which has shown a declining interest (from 47.4 percent in 1987 to 37.5 percent in 1989), California producers prefer to increase milk production through breeding techniques, followed by improved feed management, and lastly by adding more cows. The desire of respondents to use BST has been low but is increasing (from 0 percent in 1987, 5.6 percent in 1988 and 6.3 percent in 1989). However, when asked whether they would use BST immediately once it became available, the group which said they would has dramatically and steadily fallen over the three years (10.6 percent in 1987, 4.3 percent in 1988, and 3.1 percent in 1989) and, during this same period, the group that said they would not use it at all has increased by 12 percent from 36.5 percent in 1987 to 48.5 percent in 1989. Overriding concerns about negative consumer response and milk quality were strongly stated by both potential users and nonusers as well as the concern for the adverse effect on prices that increased production would support. This research suggests that California producers are sensitive to the market consequences and inherent risks of new technologies. The potential adoption and diffusion of BST, if and when it is commercially introduced, appear uncertain since concerns regarding its health and price effects remain. BST is an example where the concern about food safety and contaminants is slowing or preventing technological adoption. The recent concern over "ice minus," the frost-resistant bacteria experiments in strawberries, is another example.

VI. Computers

Computer use in agriculture is an example of a technology that is neither crop or animal specific or activity specific. The adoption and use of micro computers has enhanced management and record keeping of many agricultural firms in California. Putler and Zilberman (1988), in a study analyzing the factors influencing computer use by farmers in Tulare County, showed that the likelihood of computer adoption increases as farm size increases (but at a decreasing rate) and as education level increases and is influenced by the age of the operator. Computer adoption did not appear to be sensitive to the crops and activities of the operation. However, with respect to software applications that aid in management decisions, livestock producers appeared more likely to adopt than crop producers, possibly reflecting inadequate supply of crop models or more discretion and complexity in the response to changed food and breeding inputs.

VII. Irrigation

Advances in the technology of irrigation (i.e., drip irrigation) hold promise to increase the conservation of an increasingly valuable input. However, the incentives to embrace this technology are limited by the lack of appropriate pricing signals reflecting real opportunity costs of water use. Caswell and Zilberman (1985) investigated the selection of irrigation technologies (sprinkler, drip, and furrow) for perennial crops grown in California's Central Valley. Their results suggest that factors such as water source, soil type, and crops grown affect the decision to employ water-conserving technologies. More recently, the decision to adopt water conservation technology seems to have been driven more by environmental constraints on drainage disposal than the value of the conserved water. Initial response to salinity and selenium drainage problems in the San Joaquin Valley was to use evaporation ponds and reverse osmosis filters. However, once the magnitude of the problem and the enormity of the costs of this solution became clearer, regulations and constraints on regional irrigation practices were embraced and, consequently, fed the demand for new irrigation technologies.

VIII. The Challenge of Developing and Adopting Alternatives to Pesticides

The development of chemical agents to control insects, weeds, diseases, and other pests began to take off at the close of World War II as chemical warfare research tried to convert to more civilian applications. As a new technology, it [illegible] hailed as the beginning of a new prosperity. No longer would food producers [illegible] subject to the random decimation by ravenous pests. Both cheap and apparently effective, pesticide development and use spread quickly as growers seized [illegible] pesticides as an economic alternative to other existing forms of pest control that [illegible] seen both as more costly and less effective than the miracle of chemistry. Driven primarily by their short-run economic advantage, chemical pest control diffused quickly and thoroughly throughout the U. S. agricultural system.

The pest problems, however, appeared more resilient than first imagined, and the unanticipated problems with persistent and ecologically damaging pesticides began to express itself. Researchers at the University of California, as early as [illegible], began to consider and formulate pest management problems within a broader context. Termed "integrated control," their idea [illegible] of pest management within a system of agricultural production that re[illegible] ecological foundations that underlie agriculture. However, it would be a[illegible] 15 years before the integrated control concept received further attention.

Research on the feasibility, use, and economics of integrated pest management (IPM) has become wide and varied over the last 20 years. Efforts have primarily focused on insect pests and ways to interrupt their life cycle and reproductive habits with much less effort aimed at weed, fungus, and disease problems. In tomatoes the development of worm sampling methods has formed the foundation of IPM in the processing tomato industry. An economic analysis of the effects of the tomato IPM program has been conducted by Antle and Park (1986) who concluded that mean damage and risk of fruit damage by worms were significantly reduced on program fields while monitored labor costs increased only slightly. The quantity of pesticides applied (in pounds of active ingredients) were reduced slightly; however, differences in the quality of materials used caused total pesticide costs to remain equal across program and nonprogram fields. Ignoring the value of risk reduction, Antle and Park conclude that growers could expect to increase net returns about $7.10 per acre by using the IPM methods. The effect of decreasing the risk of worm damage would unquestionably increase the value of the program to a particular grower depending on the risk aversion of the grower.

In a related study of the adoption of IPM by tomato growers, Grieshop, Zalom, and Miyao (1988) found that, in spite of the economic evidence supported by Antle and Park, many growers were reluctant to incorporate the IPM methods into the production process. In their investigation they considered what factors, in addition to economic payoff, influence the adoption decision of a grower. As suggested by Rogers (1960), they investigated the individual characteristics of growers, the lines of communication that they have established, and the properties of the innovation that may affect the diffusion of a technology. Their findings, applied to the growers who had adopted the IPM program over a five-year period, supports the S-shaped diffusion curve described earlier in Figure 1a. The curve shows an increasing number of adopters initially, followed by a decreasing number. Beginning with less than five growers (from their sample of 82) who had adopted in 1981, the number of growers who were using the worm sampling methods had grown to 47 (57 percent) by 1986. Characteristics which appeared to significantly affect adoption rates include landownership, organizational structure of the enterprise, experience with previous IPM innovations, and perception of risk associated with IPM. Sources of information also were found to contribute to the adoption of IPM. Adopters were found to rely more heavily on contacts with pest control advisors and Cooperative Extension farm advisors, whereas nonadopters depended more on friends and neighbors for information. Attributes or properties of the innovation are also a major category affecting the adoption decision. Perception of the complexity of employing the IPM methods were found to differ between adopters and non\adopters. They found that perceptions of benefit and risk of using IPM were not significantly different between adopters and nonadopters and concluded that "much more than economics is at work as growers consider these innovations and make their decisions."

An example of the long-run benefits of IPM technology adoption for California agriculture can be seen in the production of cotton, California's most valuable plant crop. Initially planted in the Imperial Valley area of the state as early as the 1920s, cotton has grown to encompass over 1.2 million acres of the state's agricultural lands. As recently as 1978, acreage in the Imperial Valley numbered close to 145,000 acres producing tremendous yields with the long growing season that permitted the production of a second set of cotton (much like the second wind of a marathon runner). Yields four and five times the national per acre yield were common. However, by 1988, cotton acreage in the Imperial Valley was under 12,000 and falling. Finally, hit by a wide range of pesticide-resistant cotton insects, Imperial Valley growers could no longer profitably grow the crop with pest control expenditures rising to $500 an acre in some cases. The pink bollworm was the primary culprit. It was able to thrive on the long growing season of the cotton. The mild winters aided their survival, and by spring they returned in greater force. Growing resistance to chemical controls made battling the "pinkie" increasingly difficult and, adding to the problem, the use of broad spectrum pesticides decimated the host of natural pest controls (predatory insects and parasites) that kept other pest problems in check. Consequently, other pest problems began to inflict heavy damage on the fields as well, driving the production of cotton in the Imperial Valley down by 90 percent (Archibald, 1984).

San Joaquin Valley (SJV) growers, witnessing the devastation that the pink bollworm had brought to their neighbors in Imperial, initiated a series of measures and restrictions to prevent the pink bollworm from successfully invading their valley. A $2.00 per bale assessment has been collected from SJV growers to fund the Cotton Pest Control Board that has set up an extensive monitoring and control effort aimed at preventing pink bollworm from establishing itself in the Valley. In addition, by emphasizing shorter season practices and mandating thorough cleanup of crop residues after harvest (plow-down restrictions), SJV growers have been successful in avoiding the devastation that affects other growers who face the pink bollworm and the boll weevil.

Hope is on the horizon for the Imperial Valley cotton growers. With the introduction of IPM methods and techniques, the possibility of reviving the cotton industry is promising a recovery. Through the use of shortened growing seasons, pheromone traps, and with the release of sterile pink bollworm moths, researchers are optimistic about the recovery of Imperial Valley cotton. In the Coachella Valley an experimental project has reduced the number of pesticide applications from 414 to zero in four years (*California-Arizona Farm Press*, 1990). If these practices can be adopted on a regional wide scale, the cycle of the pesticide treadmill may be broken.

IX. Conclusions

There is a history of technological change affecting the structure of agriculture. The changes have not always been welcomed and some have brought with them significant economic dislocation. In earlier instances technological innovation induced structural changes within the industry. However, the approaching changes in the regulation and use of chemical technologies diverges from this pattern. We find that structural change in the form of input regulation is a major impetus for technological adoption. From the structure of chemical prices and restrictions to the formation of state and federal agricultural and environmental policies, incentives facing agricultural producers will increasingly require adoption of nonpesticide technologies. However, trade-offs between the gains from policies that increase the rate of adoption but distort resource allocation decisions will have to be considered carefully (Miller and Tolley, 1989).

Given the long history of technologically driven change in California agriculture and the adaptations that it has required, there is evidence to support an optimistic outlook to the current transitional period now facing producers. This is not to suggest that the transition to less chemically intensive methods will be without some economic dislocation, but as with the dawn of the tractor and the tomato harvester, it is our opinion that California agriculture will survive and continue to thrive with a lessened adverse impact on the welfare of the environment.

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5

ECONOMICS AND PESTICIDES

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Widespread use of chemical pesticides in agriculture is a relatively recent phenomenon, dating back only about 40 years to the introduction of synthetic organic chemicals after World War II. In that span of time, chemical pesticides have become integral to modern agricultural production. At the same time, they have become increasingly controversial because of the risks they pose to human health, to the environment, and, in many cases, to agricultural productivity in the long run. One of the principal aims of the sustainable agriculture movement, for example, is to effect drastic reductions in pesticide use.

Economists have produced a sizable literature dealing with pesticide policy in the broad sense, examining issues ranging from micro-level assessments of appropriate on-farm use to macro-level assessments of market welfare costs of registering or canceling registration of specific chemicals. Both micro- and macro-level studies have made contributions to knowledge and to the conduct of policy, but in both cases those contributions have been limited by the historical agendas and the institutional constraints within which they have operated.

The micro-level literature dates back to the late 1960s. It emerged as part of the integrated pest management (IPM) movement, which was itself a response to the recognition of the serious problems caused by pesticides on and off farms popularized by Rachel Carson and Robert van den Bosch. The economists involved were located mainly in departments of agricultural economics and the agricultural experiment station network and were thus oriented mainly toward farm management issues. As a result, this literature focused largely on central on-farm operating problems of IPM, beginning with how to determine economic thresholds for pesticide application and evaluating the cost effectiveness of alternative pest management strategies. Later, they moved on to broader microeconomic problems such as evaluating market performance and the need for public intervention in the presence of factors such as mobile pests, pesticide resistance, predator-prey interactions, uncertainty, and behavioral barriers to adoption of IPM methods.

The macro-level literature is more recent, dating back only to the early 1980s. It arose out of problems encountered by the U. S. Environmental Protection Agency (EPA) in the course of registration and special review of chemical pesticides. Because of the restrictions EPA places on the role of economic analysis in pesticide regulation, this literature focused on problems of benefits assessment, including adjustment for agricultural commodity programs, estimation of market welfare effects from limited entomological and farm budget data, and consideration of distributional effects and impacts of multiple cancellations.

This chapter briefly reviews the main accomplishments and limitations of these two strands of economic investigation of pesticide use. We do not intend to be thorough in our survey of the literature. Rather, our goal is to examine the strengths and weaknesses of economists' contributions to the policy process overall and to identify key areas needing further investigation. In particular, we focus on some new approaches to integrating the micro- and macro-level approaches with each other and with the work of entomologists, toxicologists, and other scientists into what we term the system for [illegible] integrated management models for assessing pesticide policies. We argue that this interdisciplinary approach is the most productive for additional research.

I. Micro-Level Studies of On-Farm Pesticide Use

When pesticides were first introduced, they were believed to be "magic bullets" that could be used to eradicate disease and create completely sanitary, pest-free conditions in agriculture without risk of adverse effects. By the late 1950s these illusions were rudely dispelled by the recognition that pesticides could wreak havoc on wildlife, notably predatory birds. In addition, by the mid-1960s, it became evident that pesticide use was creating serious problems on farm as well. Suppression of invertebrate predator and competitor populations by broad-spectrum insecticides created target pest resurgence problems and led to a spiral of ever-increasing application rates and frequencies. Pest populations began to exhibit resistance to heavily used chemicals like DDT. In some cases, farmers achieved adequate control over a target pest only to find that its niche was taken over by a pest less susceptible to control.

In response, entomologists began to fashion what came to be known as IPM strategies. IPM advocated an ecosystem approach to pest control in which chemicals were considered one tool among many in manipulating crop ecosystem conditions to reduce pest damage and enhance harvested yield. Central to the IPM effort were (1) collecting information about key components of the crop ecosystem such as pest population sizes, predator population sizes, weather conditions, time of year, etc.; (2) projecting crop losses on the basis of that information; and (3) deriving flexible pesticide use recommendations to replace the rigid application schedules typically used. The goal was to reduce chemical applications to the lowest reasonable level and, thus, reduce the scope of the on- and off-farm problems associated with pesticide use.

The first economic studies of pesticide use were part and parcel of the effort to fashion and promote IPM. The economists involved—J. C. Headley, Richard Norgaard, Uri Regev, Darwin Hall, Gerald Carlson, Hovav Talpaz, and Darrell Hueth—were all located in departments of agricultural economics and worked closely with entomologists in the context of the agricultural experiment station network. As a result, their research was very much micro-level, farm-management oriented.

The first task undertaken was that of devising flexible schedules for efficient pesticide use. Before IPM, and even today, farmers typically followed rigid application schedules, applying a fixed dosage at fixed intervals without regard of the actual conditions prevailing in the field. Headley (1968) combined simple entomological models of exponential insect pest population growth and damage per insect with the familiar profit maximization model of economics to derive an optimal pesticide application rate and desired pest population level given a single known time of application, showing that eradication of the pest was not economically advantageous. Hall and Norgaard (1973) generalized Headley's model by endogenizing the time of application and were thus able to derive the economic threshold, that is, the pest population level triggering the need to apply insecticides. Talpaz and Borosh (1974) generalized this model further by allowing multiple-pesticide applications.

A closely related task which economists undertook was that of evaluating and promoting IPM strategies. In this task they worked closely with extension service personnel—economists, entomologists, plant pathologists, agronomists, horticulturists, and agricultural engineers. Initial efforts focused on scouting. Lawrance and Angus (1974) compared the standard chemical control strategy for cotton in Arizona with an IPM strategy involving scouting and reduced chemical use. They found that yields under the two strategies did not differ significantly but that costs were lower under the IPM program. Hall (1977) analyzed the profitability of similar alternatives for cotton in the San Joaquin Valley, California. He found that yields and costs under the two were quite similar because the cost of hiring professional scouts balanced the savings from reduced chemical purchases. Using data from a California mosquito abatement district, Lichtenberg (1987) examined the impact of using biological controls on chemical use for controlling rice field mosquito populations. He found that full use of the biological control allowed reduction in chemical applications of over 75 percent and that full use of the biological control was cost efficient even at the current high cost of the predatory fish used.

More recently, crop ecosystem simulation models have proven to be a powerful tool for projecting the impacts of a wide variety of alternative pest management strategies. There have been numerous studies using biological simulation models to evaluate sets of alternative pest management strategies for various crops and growing conditions. Examples include: Reichelderfer and Bender, 1979 (comparison of biological and chemical control methods for Mexican bean beetles); Zavaleta and Ruesink, 1980 (comparison of resistant alfalfa strains and chemical use for control of alfalfa weevil); Lazarus and Dixon, 1984 (comparison of crop rotation and chemical methods for control of corn rootworm in the Corn Belt); Lazarus and Swanson, 1983 (comparison of crop rotation and chemical methods for control of corn rootworm in the Corn Belt under uncertainty); Zacharias and Grube, 1986 (comparison of crop rotation and chemical methods for control of corn rootworm and soybean cyst nematode on Illinois farms); and Harper and Zilberman, 1989 (comparison of shortened growing seasons and chemical methods for control of pink bollworm on cotton in the Imperial Valley, California).

As time passed, economists began to examine pesticide policy at the micro-level more broadly, looking at questions using the traditional tools of microeconomic theory, in particular, theories of market failure. They began with issues arising from pest population dynamics, beginning with the phenomenon of resistance. As is well known, application of pesticides can be viewed as a form of selective pressure that promotes the spread of resistant strains in a pest population, leading to declining effectiveness of the pesticide. Hueth and Regev (1974) argued that susceptibility to pesticides should be treated as an exhaustible resource. They showed that resistance implied that the economic threshold should change from year to year. Regev, Shalit, and Gutierrez (1983) showed that optimal pesticide use in the presence of resistance would be less than the myopic level that failed to take resistance into account and that it might be optimal to rotate chemicals with different modes of action as a means of delaying the spread of resistance. Using a crop ecosystem simulation model focusing on the alfalfa weevil, they found, however, that the difference between optimal and myopic pesticide use was not very great.

A second factor considered was pest mobility. When pests are mobile, infestation is a regional problem and cannot be dealt with efficiently at the farm level. In essence, the pest population is the common property of the infested region. Regev, Gutierrez, and Feder (1976) showed that uncoordinated control efforts by individual farmers is suboptimal in terms of both amounts of chemicals applied and the timing of application. The problem of common property implies a need for collective action, either voluntary or through government intervention. In the United States, pest control districts provide such a vehicle for collective action. They have been used in such contexts as eradication programs for the boll weevil in cotton in the southern United States, using a shortened growing season to control pink bollworm on cotton in the Imperial Valley, California, and dissemination of introduced predatory wasps on citrus in California.

A third factor considered was predator-prey interactions. Feder and Regev (1975) undertook a theoretical comparison of optimal and myopic pesticide use when these interactions are important. They showed that pesticide use is excessive when these interactions are ignored and that the result may even be higher long-run equilibrium pest population levels. Harper and Zilberman (1989) later showed that other biological interactions, such as secondary pests and their predators, affect the use of pesticides and other inputs as well.

Economists also began to examine behavioral factors affecting pest management practices, primarily uncertainty about infestation levels and damage. Carlson (1970) used a Bayesian approach to derive optimal fungicide use patterns for brown-rot control on peaches. He showed that the chemical chosen and the number of applications should depend on observable factors such as fruit maturity, predicted rainfall, and spore density. Using an expected utility approach, Feder (1979) showed that an increase in pure uncertainty about infestation levels, damage per pest, or the effectiveness of the pesticide will reduce the economic threshold and increase the number of pesticide applications and volume of pesticides applied.

Risk was also examined as a potential disincentive for IPM adoption. IPM is believed to be more risky than chemical controls because it is less familiar and because the effectiveness of nonchemical controls varies more than that of chemical controls. As a result, one would expect risk-averse farmers to rely more on chemical controls and be less prone to adopt IPM. This argument has led some to suggest that crop insurance subsidies could be used to induce farmers to adopt IPM or at least to reduce the total volume of pesticides applied (see, for example, Carlson and Main, 1976; Norgaard, 1976). Empirical evidence regarding the impact of risk aversion on chemical use and IPM adoption is, however, extremely scanty. As far as crop insurance is concerned, a simulation study by Miranowski, Ernst, and Cummings (1974) found that extremely large subsidies would be required to induce any real changes in pesticide use and that improved information about pest population sizes would reduce chemical usage more than insurance subsidies.

Low human capital has also been cited as a key obstacle to IPM adoption. IPM requires an extremely sophisticated approach to crop production as management of a complex crop ecosystem. Farmers with little skill and a low educational level may be unable to cope with the information processing needed for successful IPM. Pingali and Carlson (1985), for example, found that North Carolina apple growers with less education and experience made greater errors in estimating pest infestation levels and, as a consequence, relied more on chemical controls and less on cultural controls than they should have.

The informational requirements of successful IPM programs have led, as one might expect, to the emergence of professional pest control consultants. The economics of marketing professional pest management services have been studied only scantily. Carlson (1980) presents evidence that publicly provided pest information tends to "crowd out" private pest management consultants. Tsur's (1983) dissertation found that cotton growers in California with smaller operations or less education were more likely to hire pest management consultants. Overall, however, the determinants of the decision to hire a professional consultant deserve further study. One might expect growers with very low or very high human capital to tend not to use private consultants. Those with low human capital would not recognize the advantages of IPM, while those with high human capital would be able to formulate an adequate IPM program by themselves. It would also seem likely that large operators would hire their own specialists rather than private consultants, while small operators would be unable to afford private consultants. Thus, one might hypothesize that growers with average human capital and medium-size operations would have the greatest demand for private pest control consultant services.

In studying pesticides, economists have focused on demand-side issues, largely ignoring the supply of pesticides. Yet, the phenomenon of resistance and the fact that the types of pesticides available clearly influence the types of IPM programs that are feasible suggest that the pace and scope of research and development (R&D) of new chemicals are extremely important. To date, little has been done in this area. Carlson (1989) has noted that research conducted by pesticide manufacturers tends to have a "large crop" orientation, focusing on chemicals with large potential demand. Sarhan et al. (1981) looked at this issue empirically by estimating the profitability of developing narrow-spectrum mosquito larvicides. They found that development of narrow-spectrum chemicals was likely to be unprofitable for mosquito control and recommended "orphan pesticide" legislation to correct the problem. Further studies applying the techniques and findings of the large literature on R&D to pesticide issues, however, have not been performed. Among the questions deserving investigation are (1) the appropriate pace of R&D given the spread of resistance to any given chemical; (2) appropriate spectrum of a pesticide, given predator-prey and other biological interactions; (3) impacts of chemical industry market structure on the pace and scope of pesticide R&D; and (4) the role of public policy. Initial efforts to apply genetic engineering techniques to pesticides have raised numerous related questions, a case in point being Monsanto's attempts to introduce resistance to a proprietary herbicide into tomatoes and other crops that currently use herbicides very little.

II. Macro-Level Studies of Market Welfare Effects

The IPM movement, and the economists associated with it, had little interest in macro-level studies. Because of its entomological base, the IPM movement focused on ecological phenomena for which farm-level or regional analysis was relevant. Analysis of the society-wide effects of the diffusion of IPM or of policies limiting pesticide use were largely ignored.

There were a few exceptions. Headley (1968) used state-level data on production of major crops and expenditures on pesticides and other inputs in 1963 to estimate the marginal productivity of pesticides. He found that the marginal value product of pesticides exceeded their marginal cost by a factor of 4 and concluded on that basis that, from a farm productivity point of view, pesticides were actually being underutilized. Lichtenberg and Zilberman (1986a) later argued that this and similar econometric findings of underutilization of pesticide use were suspect on methodological grounds. They pointed out that the Cobb-Douglas functional form used in these studies violates structural conditions imposed by the fact that damage is limited by potential yield. An empirical study of North Carolina apple orchards by Babcock, Lichtenberg, and Zilberman (1988) confirmed their suggestion that Cobb-Douglas estimates of pesticide productivity exceed by a large margin estimates derived from more reasonable functional forms.

The impetus for macro-level economic studies of pesticides came from an institutional change. When EPA was created, responsibility for regulating pesticides was transferred to it from the U. S. Department of Agriculture (USDA). At about the same time, a rewrite of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the principal statute governing pesticide regulation, transformed it from a law concerned with ensuring product efficacy to one concerned with balancing agricultural productivity against damage to the environment and human health. Shortly thereafter, EPA began canceling the registrations of the most harmful known pesticides, beginning with DDT in 1976 and continuing through the remainder of the chlorinated hydrocarbons (aldrin, dieldrin, lindane, heptachlor, chlordane) in the late 1970s and early 1980s.

Under FIFRA, a pesticide must pass a risk-benefit balancing test to be registered, i.e., the benefits of using it must outweigh the risks it poses to the environment and human health. The procedure used by EPA runs as follows. The manufacturers of any unregistered new chemical or any old chemical needing re-registration is required to contract for a battery of environmental fate and acute and chronic toxicity tests conforming to specific protocols. The data from these tests are then provided to EPA, whose scientists use them to construct human health and ecological risk assessments. If the estimated risks are negligible, EPA will register the chemical. If the estimated risks are nonnegligible, EPA goes on to estimate the benefits of using the pesticide. The first stage of this benefits assessment is a "biological analysis" performed by entomologists, plant pathologists, agronomists, and other crop scientists. The biological assessment consists of a review of the pest-crop complexes treated with the pesticide, identification chemical and nonchemical alternatives, and estimation of differences in yields and treatment costs associated with these alternatives and their likely extent of use. The biological assessment is then fed as raw material to EPA's economists who are charged with estimating benefits. The estimated benefits are then used in a risk-benefit balancing procedure.

The use of economics in EPA's regulatory process is actually even more restricted than this description might indicate. Pesticides that are shown to have relatively high risks, e.g., likely or probable human carcinogens with reasonable exposures, will not be registered (or, if they are currently in use, will have their registrations canceled), regardless of the benefits. The economic analysis will be used solely to decide the pace and timing of their withdrawal from the market.

To estimate the benefits of using a pesticide or, put another way, the market welfare costs of disallowing its use, EPA has relied primarily on accounting methods. The data typically provided are estimates of the changes in per acre costs and yields associated with alternative treatment methods and of the extent to which each alternative is likely to be used. EPA's analysts have generally relied on what is known as partial budgeting. This approach estimates welfare costs first by adding the cost increases and yield losses (valued at the current price) associated with each alternative, multiplying by the acreage expected to be treated with each alternative, and then summing up overall alternatives to obtain a total cost figure.

Partial budgeting has some significant advantages. It requires information on changes in costs and yields and on current or likely prices, the kinds of data usually provided by entomologists and other crop scientists about the impacts of cancellation.

It also offers considerable flexibility in treating regional heterogeneity in those impacts and identifying differences in impacts on growers in different areas, which is important because specific pest problems may vary considerably even within recognized crop areas.

On the negative side, partial budgeting ignores demand and the possibility of price changes. It thus ignores potential losses transferred to consumers and potential gains obtained by growers not currently using the chemical under threat of cancellation and overestimates losses suffered by growers currently using the chemical. These shortcomings were criticized heavily in a National Academy of Sciences (1980) report, and EPA was urged to abandon partial budgeting and substitute standard welfare economic methods in their place.

One alternative is to use econometric supply and demand models to predict changes in prices and quantities and estimate impacts on consumer and producer welfare. A good example of this is TECHSIM, a regionally disaggregated econometric simulation model of the major crop and livestock sectors developed by Collins and Taylor (19) that is capable of using cost and yield change data. Unfortunately, development of such econometric models is feasible only for major crops. Moreover, models like this are not flexible enough to allow disaggregated analysis of pest problems affecting subregions, for example, weed problems affecting only part of the Corn Belt.

A second alternative is to employ marginal analysis to calculate first-order approximations of changes in price, quantity, and consumer and producer welfare. This approach requires assuming (1) a market-clearing system in which growers equate marginal cost and price and consumers' demand and price and (2) changes in marginal cost equal changes in average cost per unit of output. Given data on equilibrium price and quantities and elasticities of supply and demand, one can solve the differential of the system for changes in price and quantity. These changes in price and quantities can then be used to obtain first-order approximations of changes in the income of consumers and nonusers of the chemical. The impact on users of the chemical can then be derived under the additional assumption that cancellation results in a parallel shift in supply. Lichtenberg, Parker, and Zilberman (1988) proposed this approach and demonstrated its applicability to pesticide regulation problems in case studies of several tree crops. They also showed that partial budgeting significantly overestimated both the total social costs of cancellation and the losses incurred by current users of the pesticide.

Investigations of macro-level effects of pesticide policy have raised several major issues. The first is that of heterogeneity. The impacts of canceling a pesticide will vary substantially from place to place because pest problems do. Thus, one of the principal effects of pesticide policy will be to redistribute income among producers. Studies by Lichtenberg, Parker, and Zilberman (1988) on tree crops; Osteen and Kuchler (1987) on major grain crops; and Lichtenberg, Zilberman, and Harper (1988) on cotton showed that the dominant effect of canceling a pesticide on those crops was to shift production regionally and thus redistribute income among farmers. These results imply that, to be useful in pesticide regulation, a methodology for estimating benefits must be able to generate estimates of the distribution of gains and losses, especially among growers.

A further finding of these studies was that the total market welfare cost of canceling a pesticide tends to be negligible—precisely because cancellation has such strong redistributive effects. This suggests that any single chemical contributes relatively little to agricultural productivity. The same inference cannot be drawn, however, for large classes of chemicals. For example, Osteen and Kuchler found that, while canceling any single pesticide had a negligible effect on the major grain crops, canceling a whole class reduced agricultural productivity and income significantly.

A second issue is the impact of agricultural subsidies. In the United States, government programs such as price supports, deficiency payments, and set-asides exert considerable influence on the markets for major crops, as do marketing orders on many fruit and vegetable crops. Lichtenberg and Zilberman (1986b) argued that EPA should consider these programs as a predetermined feature of the market environment and should thus estimate market welfare costs conditional on their existence. From the viewpoint of pesticide regulation, reductions in deadweight losses from overproduction caused by such subsidy programs count as social benefits and thus serve to reduce the social costs of canceling a pesticide. Analyzing a simple deficiency payment scheme without set-asides, they showed that standard market welfare cost estimates, that is, estimates made under an assumption of competitive market clearing, overstate the true costs by as much as 50 percent for some major crops. The magnitude of the distortions involved suggest that refining this approach to incorporate other features of agricultural commodity programs such as price supports and set-asides is well worthwhile.

The macro-level literature has largely ignored a number of other key factors, especially those that arise in the context of specialty crops. One is product quality. As Pimentel and Pimentel (1980) have pointed out, one of the main motivations for the use of some pesticides is to prevent cosmetic damage to fruits and vegetables, allowing a greater fraction of the crop to be sold as high quality produce at premium prices. A micro-level study of North Carolina apple production by Babcock, Lichtenberg, and Zilberman (1988) showed that maintaining product quality accounted for about 20 percent of optimal fungicide applications. Further study in this area is needed.

Another weakness is a concentration on productivity issues to the exclusion of all other uses of pesticides. One major use of fungicides, for example, is to increase the storability of commodities by controlling rots and molds; increased storage life was also a major motivation for the use of alar. A recent study by Lichtenberg and Zilberman (1990) examined the impact of changing the cost or effectiveness of fungicides used on commodities that are stored for future sale, like apples or grains. They show that altering storability is akin to changing the term structure of interest rates and results in changes in storage strategies and temporal patterns of consumption, for example, reductions in late-season consumption of apples and increases in harvesttime consumption. When this occurs, it becomes possible that the income of consumers of the commodity may increase, i.e., that the welfare gain from increased consumption in some periods may outweigh the welfare loss from decreased consumption in others. This suggests that there may exist situations in which consumers have everything to gain from further restrictions on pesticide use and nothing to lose. A further implication is that restrictions on pesticide use will make price stabilization policy more costly, a policy conflict that deserves some scrutiny.

Pesticide use may also be motivated by seasonality. For example, one reason for pesticide use may be to permit production of a crop in an area where harvest takes place exceptionally early or exceptionally late, so that growers can take advantage of the high prices owing to short supply. This kind of effect is not easily modeled as a simple shift in yield or quality and deserves further study.

III. Integrated Management Models

We have seen that micro- and macro-level investigations of the economics of pesticides developed quite differently because of the needs to which they were responding and because of the institutional contexts in which they were working. One negative consequence of this course of development is that economists have neglected the topic of micro-macro linkages. This oversight has become problematic. Over the years, IPM projects have developed farm-level data bases for a number of important crops in key production regions across the United States. These data bases can provide valuable micro-level information about pesticide productivity and the productivity of no-chemical alternatives that can be brought to bear in benefits assessments. At present, EPA analysts are dependent on expert opinion for estimates of cost and yield effects of alternative chemical and nonchemical controls. At a minimum, this farm-level information can be used to validate expert opinion. At a maximum, it can be used to obtain more precise estimates of productivity impacts than experts can provide. However, to be useful in pesticide regulation, this farm-level information must be translated into aggregate impact terms. Thus, a key research need is developing models for linking micro- and macro-level impacts, i.e., translating changes in marginal productivity at the farm level into changes in marginal cost at the regional or national level.

Modeling micro-macro linkages is also important because it may offer insights into likely effects of regulatory policy on pest management strategies and, therefore, on risks posed to wildlife and/or human health. Take the example of reentry regulation. EPA sets reentry intervals, i.e., the length of time after pesticide application during which workers cannot reenter treated fields, to reduce the risk of acute pesticide poisoning to an acceptable level. (It sets preharvest intervals, the earliest time after pesticide application that a crop can be harvested, to keep health risks from residues on food to an acceptable level.) Lichtenberg, Spear, and Zilberman (1989) study reentry regulation using a model that combined a crop ecology model of crop growth and pesticide population dynamics, an economic model of optimal pesticide use, and a risk assessment model of acute organophosphate poisoning as a function of the length of the reentry interval. The structure of the crop ecology model implied that growers should apply fixed amounts of pesticides. Analysis of the economic-ecologic model showed that reentry regulation may induce farmers to adopt a preventive strategy for pesticide application even for observable pests because of the rigidity it introduces into treatment scheduling. This result suggests that EPA should assess benefits using models that endogenize growers' reactions to possible regulatory actions. Such models must be constructed via cooperative interdisciplinary efforts between economists who supply the behavioral and regulatory framework and crop scientists who supply a framework for capturing the key biological dynamics.

Such an approach can also produce insights into risk estimation. Olson (1990) presents a Bayesian model of optimal toxicity screening. Applying the model to pesticide regulation using standard estimates of the value of lifesaving, he shows that mutagenicity tests are suboptimal for chronic toxicity testing under a policy where only a single test is allowed. Lichtenberg (forthcoming) critiques current practices for producing "conservative" risk assessments because of the unintended biases they create. He discusses three types of problems: (1) risk estimates that are noncomparable, ruling out the application of cost effectiveness or cost-benefit analysis; (2) arbitrary imposition of functional forms that alter the optimal timing of regulatory restrictions; and (3) ignoring potential reductions in uncertainty, leading to underutilization of policies like monitoring in favor of usage restrictions.

More broadly, interdisciplinary modeling efforts that incorporate risk analysts, as well as economists and crop scientists, can be used to illuminate the full range of trade-offs involved in making pesticide regulatory decisions. The types of regulatory options currently considered are quite limited, largely because risk estimation and entomological assessments are made independently and are drawn into analysis of risk-benefit trade-offs only ex post. This narrow vision can be overcome by establishing a unified, interdisciplinary process led by analysts focusing on assessing the *trade-offs* between agricultural productivity and the safety of humans, wildlife, and ecological systems, that is, the costs of achieving any set of environmental goals through pesticide regulation. Such an approach has several further advantages. It provides more comprehensive estimates of risk-benefit trade-offs than EPA currently obtains. It permits economics to be brought to bear without the distraction of arguments about the validity of monetary valuation of environmental amenities such as wildlife and human safety. Also, estimates of marginal cost derived from such analyses can be used to assess consistency across regulations and thus to improve overall regulatory performance.

Lichtenberg and Zilberman (1988) have developed a methodology for building such trade-off assessments. Noting that current risk assessment methods provide estimates of human health or wildlife impacts that are subject to a great deal of uncertainty and that regulators and the general public are quite sensitive to that uncertainty, they argued that safety rules provide an attractive, practical way of incorporating uncertainty into trade-off assessments. They begin with a probabilistic risk assessment, i.e., a model that treats the incidence of an adverse health or environmental effect as a random variable and estimates its probability distribution. They then posit as a decision criterion that the goal of regulation is to minimize the cost of keeping the probability that the incidence exceeds some predetermined acceptable risk level below a given frequency. Formally, let $r(x)$ be the measure of risk as a function of policy variables x. Let r_0 be the acceptable risk level and $1 - \alpha$ be the maximum allowable frequency with which risk exceeds the acceptable level so that α is the *margin of safety* with which the allowable risk standard is met. Let $C(x)$ be the total social cost of adopting the policy vector x. Then the social optimization problem is to minimize $C(x)$ subject to the constraint that $Pr\{r(x) > r_0\} < 1 - \alpha$. Solving this optimization problem over the full range of allowable risk standards r_0 and substituting the optimal policy vector into the cost function yields an *uncertainty-adjusted cost curve*, or trade-off curve. Following such a procedure over the range of reasonable margins of safety yields a family of such cost curves which can be used to estimate the trade-offs between enhanced human safety/environmental quality and other social goals.

This approach can be viewed as an extension of the Baumol and Oates (1974) standards-and-charges approach to cases where there is uncertainty about environmental pollution. It can also be viewed as an expression of preferences characterized by disaster avoidance, which are often ascribed to politicians and government agencies. Moreover, because it takes a classical statistical approach to uncertainty (it essentially relies on confidence limits), it is more amenable for working with natural resources scientists, for whom Bayesian methods like expected utility are an anathema.

The margin of safety α expresses the decision maker's level of aversion to uncertainty, that is, his or her willingness to tolerate violations of the allowable risk standard. Greater aversion to uncertainty can be expressed by a higher margin of safety. The incremental cost of meeting a higher margin of safety can be viewed as an uncertainty premium, akin to the risk premium of the standard economic literature on decision making under uncertainty.

The (absolute value of the) slope of the uncertainty-adjusted cost curve for any given margin of safety gives the marginal cost of risk reduction, again adjusted for uncertainty. It decreases as the margin of safety rises, so that greater aversion to uncertainty implies more stringent risk-reduction policies. It can be used to compare policy decisions for consistency and suggest more efficient ways of enhancing overall safety.

Lichtenberg, Zilberman, and Bogen (1989) applied this methodology in an empirical examination of excess cancer risk from contamination of drinking well water in California by the nematicide, 1,2-dibromo-3-chloropropane (DBCP). They estimated uncertainty premiums ranging from 20 percent to 30 percent of the total cost of meeting alternative standards for DBCP in drinking water, which implies that greater precision in estimating risk has substantial value. The marginal cost of risk reduction under a 99 percent margin of safety was as much as 35 percent lower than the marginal cost of reducing risk on average, which implies that the degree of aversion to uncertainty exhibited by regulators has a substantial effect on policy choice.

IV. Concluding Remarks

Pesticide economics has developed largely in response to the problems facing specific institutions. The micro-level literature comes primarily from the need of the land-grant university system to formulate and promote IPM strategies. The macro-level literature comes primarily from the needs of EPA's Office of Pesticide Programs to estimate benefits for regulating pesticides under FIFRA. Meeting these needs remains an important task for economists. However, in recent years policy concerns regarding pesticides have become increasingly broad, encompassing issues ranging from residues on foods to protection of endangered species and other wildlife to cosmetic uses to productivity. The ramifications of pesticide policy decisions are, correspondingly, increasingly complex. As a result, the narrower concerns of the past no longer suffice. More and more, the issues facing policymakers require analysis using integrated management models that take into account these broad ramifications. On the scientific side, many of the questions of greatest interest from a scholarly point of view have to do with the interactions between macro- and micro-level concerns, with health risk outcomes versus productivity, and the like, i.e., which require integrated models to study. To us, then, it seems that development of such integrated models is the key task facing the discipline—both for the contribution that economists can make in improving policy and for scientific interest.

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6

PESTICIDE PRODUCTION: A SURVEY

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I. Introduction

The number of chemical pesticides (insecticides, fungicides, herbicides, nematocides, and bactericides) used in the United States has increased substantially since World War II. Statistics indicate that in 1935, before DDT was tested in the United States, about 50 million pounds of pesticides were used. Since the discovery of DDT, about 600 different types of chemicals aimed at killing diseases, insects, and weeds have been registered for legal use in the United States (Prokopy, 1986).

With the introduction of synthetic chemicals, most entomologists adopted DDT and other chlorinated hydrocarbons into their pest control programs. As a result, by 1945, farmers expanded chemical pesticide use to about 100 million pounds at a cost of $77 million (Prokopy, 1986). Today there are approximately 55 thousand pesticide products formulated from about 600 active ingredients which are used in the United States (U. S. General Accounting Office, 1986).

The above statistics reveal an amazing growth in the amount of pesticides used in the United States since World War II. Unfortunately, other figures reveal a darker side to this transformation of pest control practice. For example, despite the substantial increase in pesticide use, pests reap an unacceptably higher proportion of the harvest than before the arrival of DDT. It is estimated that in 1945 the level of crop losses was 32 percent; by 1980, losses attributed to pests were 37 percent of the potential crop harvest in the United States (Prokopy, 1986).

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economists have been toward developing static and dynamic models and theories of damage-control agents. Among the major contributions related to decision framework, those most commonly discussed and applied are the Economic Threshold Model, Decision Theory Model, Marginal Analysis, Dynamic Programming, and Simulation.

These models attempt to characterize agricultural production, utilizing several inputs into the production process (land, human labor, water resources, capital, etc.) in addition to those synthetic compounds usually referred to in a generic manner as pesticides. Pesticides themselves are composed of subcategories such as fungicides, insecticides, herbicides, nematocides (used to control nematodes), and rodenticides (used to control rodents). Another agrochemical input used in agriculture is fertilizers. Its use has been increasing steadily in the United States. Fertilizers are used by growers mostly on crops which depend on the cash value of the crop per acre, since the growers' expectations are to have oversized, rapidly grown crop plants. The use of fertilizers, as in the case of pesticides, has adverse effects on the ecosystem (e.g., water contamination, pollution).

The literature review of empirical studies presented in sections II and III deals mainly with the first three subcategories of the pesticides named above. Fungicide compounds are used primarily on fruits and vegetable crops; the purpose of fungicides is to control disease during crop development, to improve the storage of the products, and to lower dependence on crop rotation. Insecticides are broadly classified according to their chemical nature or their effect on the pest insect; among other crops, the most significant use of pesticides have been on cotton, corn, and soybeans. Herbicides had experienced the most rapid growth in agriculture; these chemicals are used to control weeds and other wild vegetation in major food crops.

The conceptualization of input productivity within the production process is very controversial as applied to inputs such as pesticides in agricultural production.

Pesticides have been used in agricultural production for the purpose of reducing the incidence and severity of crop losses due to pests (insects, fungus, weeds, etc.); thus, the benefits from pesticides are derived from their ability to control damage agents. By the 1950s, pesticide use was already showing its external effects on the environment and, by the 1960s, some evidence showed not only effects at the farm level but also increasing resistance, resurgence, and secondary outbreaks of the pest themselves. In response to the attention focused on the usage of chemicals on commercial agriculture, the major concern of entomologists became a search for alternatives to control the pests and to reduce the quantities of chemicals used. It was they who introduced the concept of integrated pest management (IPM) as an ecological concept. One particular IPM objective is to utilize chemicals as effectively as possible with the goal of reducing total chemical use and preventing the problems derived by its use. Flint and van den Bosch state that ". . . IPM uses pesticides, but only after systematic monitoring of pest population, and natural control factors indicates a need" (Flint and van den Bosch, 1987, p. 6).

At the same time economists developed theories and different approaches associated with IPM. The main theoretical development was the concept of "economic threshold." This entomological concept was first introduced by Stern et al. (1959) and was consistent with the principles of Headley (1972). In pest management decision, two branches of economics are considered useful by entomologists—one is the descriptive (positive economics) and the other is the prescriptive (normative economics). The viewpoint of Mumford and Norton is cited in this regard: "The economics of decision making in pest management is not just concerned with the dollars and cents of pest damage and control but with the goals and behavior of those who make pest management decisions" (Mumford and Norton, 1984).

Several techniques have been developed in the last two decades for the purpose of implementing IPM in an economic framework. Efforts by agricultural

In the next two sections, the literature dealing with this type of model will be reviewed—first at an aggregate level (i.e., models which lump all the available input variables) and secondly at a micro-level (in which some models that are specific to one crop or a pesticide subcategory is included). In the last section, some conclusions and comments are presented.

II. Aggregate Level Data Empirical Studies

All of the applied studies on aggregate agricultural productivity have lumped all synthetic compounds into one input category, pesticides. But some micro-level studies do offer estimates of productivity by chemical compound (e.g., fungicides, herbicides, and insecticides).

The paper by Headley (1968) can be considered the first macro-level empirical attempt estimating the marginal productivity of pesticides to U. S. agricultural production. He used state-level data for the production of 59 major crops and expenditures on pesticides and other inputs in 1963. This study did not consider resistance and externalities which are inherent to pest and pesticide use, respectively. He found that the marginal value product of pesticides in 1963 exceeds the marginal factor cost by a factor of $4.00 : $1.00.

A later contribution by Pimentel et al. was done in 1978. They estimated the cost of chemical control in U. S. crop production to be around $2.2 billion annually and calculated a gross return of $8.7 billion implying that the average value of a $1.00 expenditure for pesticide control is about $4.00. In a related study Pimentel et al. (1980) examined the indirect costs which pesticide usage poses to the rest of the ecosystem. He found that the ratio of average value/average cost declines by $3.00 : $1.00.

Another study which attempts to estimate the marginal contribution of pesticide expenditures in U. S. agriculture is the one done by Roth, Martin, and Brandt

The measurement of pesticide productivity is a twofold concept since it implies a trade-off between agricultural productivity on the one side and human health and environmental quality on the other side. Moreover, the optimal pesticide application (where resistance is present) depends on pesticide productivity; the latter is a function of the population dynamics of the pest which varies with climatological conditions, soil types, cultivation practices, and other natural practices (Lichtenberg and Zilberman, 1986a).

Several techniques for assessing the productivity of pesticides in agricultural production have been developed in the last two decades. The ability to offer alternative approaches to pesticide policy regulatory decisions has been the major concern of most researchers in the field.

The most common method used to estimate the value of pesticide productivity has been the use of marginal analysis; in particular, the standard production theory model which uses the Cobb-Douglas specification (i.e., Headley, 1968; Fischer, 1970). These studies are mainly focused on the effect of pesticide use on increasing expected profit; thus, pesticide productivity has been measured without considering the social benefit. Other studies have used alternative specifications such as quadratic, linear, and demand theory.

In the early 1970s economists began proposing models of economic decision rules for pest management and incorporating mathematical modeling of entomological knowledge (Hall and Norgaard, 1973; Talpaz and Borosh, 1974). In particular, Lichtenberg and Zilberman (1986b) made an important theoretical contribution in showing that the marginal productivity of damage-control agents (pesticide) is overestimated by the standard Cobb-Douglas specification. They propose an alternative econometric model where pesticides are not included as a directly productive input into the production function but, rather, as a function called "damage abatement" or "kill function."

TABLE 1

Marginal Productivity of Pesticide Input

Source	Results	Year of study
Headley (1968)	\$4.16 : \$1.00	1963
Pimentel et al. (1978)[a,c]	\$4.00 : \$1.00	1978
Pimentel et al. (1980)[b,c]	\$3.00 : \$1.00	1980
Roth, Martin, and Brandt (1982)	\$1.19 : \$1.00 \$4.47 : \$1.00	1969 1974
Carrasco-Tauber (1989)	\$6.38 : \$1.00	1984

[a]Applies when no indirect costs are being considered.

[b]Applies when indirect costs are being considered.

[c]The results are average returns of pesticide.

(1982). The methodology used was the same as in Headley (1968); the results show that the estimated marginal value product of pesticides for an additional dollar of expenditures is $1.19 for 1969 and $4.47 for 1974.

A recent aggregate study by Carrasco-Tauber (1989) provides an empirical utilization of the alternative econometric model "damage abatement" proposed by Lichtenberg and Zilberman (1986b). This study is based on the productivity study done by Headley (1968). Carrasco-Tauber (1989) finds that, for the year 1984, the calculation of the pesticide productivity using the Cobb-Douglas specification results in an estimated return of $6.15 for each dollar of pesticide spent and, when an alternative "damage control" specification is used, the estimated return is $6.38; thus, the two specifications result in virtually identical values for the pesticide productivity. The author also discusses the probability of an inappropriate application of the "damage control" model for analysis of macro-level data.

Table 1 summarizes the estimates obtained on pesticide productivity from the above studies. Virtually all of these results suggest that the value of the marginal product of pesticide exceeds marginal factor costs by several times or more. These results are particularly surprising since there is an abundance of anecdotal and other evidence suggesting that pesticides are essentially "overused" in agriculture.

An important contribution of the difficulties of aggregation can be found in Antle (1986). In a later empirical study, he develops an empirical model based on the theory of induced innovation (Antle, 1988a). This model, based on the use of a time trend to represent technological change, is used to measure the rate and bias of technological change and to test the induced innovation hypothesis.

Antle's 1988 study examines the empirical evidence of the dynamic structure of U. S. agricultural production and is based on U. S. data for the years 1910-1978. The four aggregate inputs used were machinery, chemicals, labor, and land; the chemical inputs include fertilizers and pesticides. Some of the following conclusions can be

Few of the existing studies evaluate the productivity of insecticides or herbicides used in cotton production. The work of Carlson (1977) is limited to insecticide use for some cotton-producing regions in the United States. He found that the marginal productivity of insecticides decreased over time by approximately 50 percent from 1964 to 1969. He attributed much of this fall to the increased resistance to insecticides. In a subsequent study, Carlson (1979) included the factor resistance. The resistance to insecticides is responsible for a decrease in cotton yield by 26 pounds per acre in 1973 and by 99 pounds per acre in 1974.

An examination of the most suitable specification of the functional relationship between input and output leads Miranowski (1975) to base his empirical study on a quadratic form of the production function which differs from previous studies done by Headley (1968), Fischer (1970), and others. The model includes information on infestation, and dummy variables are introduced into the production function of cotton to account for the wide disparity of insects between states. With the purpose of verifying the performance of the biological response function, which is of importance in determining the demand analysis, he proceeds to estimate the value of the marginal product per dollar of insecticide (and fertilizer) as well as herbicide inputs in cotton production; the results are \$0.09 and \$1.82, respectively, for the year of research (1966) and using farm level observation. These results can be compared with the ones obtained by Carlson (1977). For example, the marginal physical product of cotton insecticide in the Southeast declines from \$1.85 in 1964, to \$1.07 in 1966, and to \$0.24 in 1969.

The study by Archibald (1984) attempts to analyze optimal pesticide use with resistance. In this study the author remarks that, while insecticide use has increased in cotton, the probability of all insects surviving the level of materials used increased, indicating resistance development. The study shows economic losses from resistance in the early 1980s to be in the range of \$45 to \$120 per hectare of cotton.

drawn from this study: (1) There is evidence of dynamical evolution of input and output variables and of exogenous technical change and (2) there is evidence that firms use lagged prices to form expectations or that technological change is endogenous or both. Other results include measures of the effects of exogenous factors (represented by the time trend) and scale changes (represented by output) on cost shares. These results show that both effects lead to higher shares for chemical and machinery inputs and smaller shares for labor and land.

III. Microlevel Data Empirical Studies

Statistics show that more than 75 percent of agricultural pesticides and 70 percent of the inorganic nitrogen are applied to seven crops in the United States. These crops are corn, wheat, barley, cotton, rice, peanuts, and sorghum (Knutson et al., 1990).

Most of the reviewed empirical literature of the last two decades has addressed the issue of cotton production (evaluating and comparing the pest control practices used on this crop) and the impact of insecticide use on several factors such as yield, output (quantity and quality) and costs, assessment of the level of pest resistance, the risk of crop loss occurred by farmers, and the trade-off between the private and the social benefits.

Empirical Studies on Cotton

Perhaps one of the main reasons for attracting attention to research on this crop is due to the historical significance of insecticide use. Cotton accounts for 35 percent of total users, and the cumulative application on cotton nationally has been over 200 pounds of active ingredients (National Research Council, 1982) per acre. Statistics in aggregate cotton yields and pest control inputs for Imperial Valley indicate that average yields per acre declined over the 20-year period (1960-1980) by about 1.6 percent per year over the same period (Archibald, 1988).

TABLE 2

Marginal Productivity of Pesticide Input for Cotton Production

Source	Results		Year of study
	Insecticide	Herbicide	
Carlson (1977)	Decline by 50 percent		From 1966 to 1969
Miranowski (1975)	\$0.09 : \$1.00	\$1.82 : \$1.00	1966
Archibald (1988)	\$3.50 : \$1.00[a] \$2.50 : \$1.00[b]		From 1968 to 1972

[a]Value obtained under "present regulatory policy."

[b]Value obtained under the "IPM tax policy."

In a more recent empirical study, Archibald (1988) shows that under two different regulatory policies different results on insecticide use are achieved. Thus, for producers under the present regulatory policy and for producers who follow the IPM externality tax policy, the figures are the following: The rate of decline in cotton yield per acre is 0.4 and 0.3 percent per year, respectively; the rate of change in resistance is estimated to increase by 5.5 and 1.3 percent per year, respectively; and a private economic return for a dollar invested is 3.50 and 2.50, respectively. Also, it is noted that, under the second regulatory policy, IPM practices lead to a higher social benefit.

Table 2 presents estimates of the marginal productivity of the pesticide input found in the studies mentioned above. The following studies do not offer measurements on pesticide productivity; however, they evaluate and compare between IPM and non-IPM practices. Additionally, they provide figures and qualitative information on the impacts of risk faced by producers (whether the programs adopted reduced pesticide use) as well as increases in producers' welfare (how costs, output, and yield are affected by producers' pest control choice).

Casey, Lacewell, and Sterling (1975) examine pesticide-use practices and cotton yield on farms using traditional methods and new IPM strategies. They find that IPM techniques result in significant benefits in two regions studied in Texas, and the study notes that the new pest management strategy would increase cotton output by over 27 thousand bales and reduce the quantity of insecticides applied by 1.4 million pounds while increasing producer net returns to over $5 million.

Lawrence and Angus (1974) examine the comparative costs of inundative pesticide application versus IPM practices. They note that inundative suppression with pesticides has been the main method of pest control for cotton (e.g., DDT was extensively used until it was banned). They find that adopters of IPM had slightly higher pest damage; compared to the nonadopters, they used a smaller amount of chemicals. The average costs of application were $9.25 for the producers under the

Another substantial body of literature is concerned with chemical use on specific types of food and fiber (e.g., vegetables, fruit/nuts, and grains). In the study by Miranowski (1975) which is also described in section cotton, a marginal return value of $2.02 per dollar spent on insecticides and of $1.23 for herbicides was estimated in corn production. With respect to the insecticide productivity estimate, the author notes that "the average quantity of insecticides applied per acre of corn did increase from 0.35 to 0.40 pounds between 1966 and 1971, indicating a limited response by corn farmers" (p. 56).

Hawkins, Slife, and Swanson (1977) present an economic analysis of herbicides used in corn and soybean at the farm level. The methodology used was the same as in Pimentel et al. (1978). The findings show that the average rate of return in herbicide expenditures ranges from $3.30 to $4.89 per dollar spent. This return is seen as not being affected greatly by crop sequence practice (e.g., soybean and wheat). They pointed out that the probability of financial loss is lower with herbicides than without them.

Results of an economic analysis of IPM practices used in 1980 in 10 major corn-producing states conducted by Hanthorn and Duffy (1983) show the average return for corn insecticides to be $1.03 per acre ($1.05 for herbicides). Also, the authors note that farmers who applied a no-till practice used a greater amount of insecticides and incurred higher herbicide costs than the conventional till farmers. The linear production function used in this study and in a later study included pest infestation. In a later study Duffy and Hanthorn (1984) estimated that, for 1980, the average returns for soybean were $0.57 per dollar spent for insecticides and $1.13 for herbicides.

A summary of the results obtained about marginal productivity of pesticide in corn production in presented in Table 3.

new strategy and $13.5 for the others; the average pest control costs were $30.85 compared with the nonadopters ($41.31) who tended to utilize more chemicals.

An evaluation of the impact of IPM on cotton and citrus growers in California is presented by Hall (1977). This study arrived at the same conclusions as the above-mentioned study on the Arizona cotton fields. IPM strategy helped producers to reduce pesticide use by between one-third and two-thirds; IPM reduces total pest management expenditures and also reduces risk by substituting knowledge and information.

Cotton growers have used chlorodimeform to improve the control and development of resistance by heliathus (Campanhola and Plapp, 1987); yet, this compound has been banned because of potential health risks. The difficulties in assessing the human health implications from chemical use by the workers' exposure in cotton fields is discussed in Harper (1987). In addition, Harper and Zilberman (1990) suggest techniques that could assist in rationalizing pesticide regulation on the health side as well as on the economic side.

In a very recent study on the economic impacts of reduced chemical use (Knutson et al., 1990), the authors predict that there will be a decrease of exported grain and cotton by 50 percent if pesticides and inorganic nitrogen fertilizer are removed from the market.

Empirical Studies on Food and Fiber

Statistics show that 800 million pounds of pesticides are applied to agriculture annually. Of the herbicidal material, 70 percent is used on corn, soybean, and cotton, while almost all the fungicidal material is applied to fruit and vegetables crops with only a small amount used on field crops. As for insecticides, 64 percent is applied to cotton and crops (Pimentel and Pimentel, 1980b).

Two pest control practices are evaluated for an Illinois cash grain farm by Lazarus and Swanson (1983). The first one, crop rotation, is considered to be a way to reduce expected pest damage and is a diversification against risk since reduced risk aversion causes farmers to specialize in corn. The second practice is insecticide threshold which also reduced risk aversion and increases the total insecticide use if no insecticide is used on the rotated crop.

Soybeans are subject to sporadic or episodic pest infestation, and chemical herbicides are increasingly being used in soybean weed control. Regionally, the Corn Belt accounts for a substantial share of the herbicides used, which is more than 40 percent of the U. S. total (Schroder, Headley, and Finley, 1981). The latter study measures the contribution of herbicides and other applied technology variables to soybean yield in the cited region for the period 1965-1979. The authors' findings are consistent with other studies, namely, that the marginal private benefit/cost return is higher ($2.30) per dollar of herbicide. Their research indicates that the yield increase would be 5 bushels per acre.

A more detailed study of insecticide productivity on soybean production in Indiana was conducted by Cashman, Martin, and McCarl (1980). The authors estimate the farm level impact of selected soybean insecticide with respect to bans placed by the U. S. Environmental Protection Agency. The benefit/cost ratio found by insecticide types were $2.00, $2.20, and $2.70 for malathion, methomyl, and carbaryl, respectively. Additionally, the study finds yield gains of 3.4, 2.9, and 2.5 bushels per acre, respectively; the authors note that these figures reflect exclusively private and not social benefit-cost ratios since possible external costs from insecticide usage were not included.

An evaluation between conventional chemical control and biological control by a parasitic wasp to control Mexican bean beetles was done by Reichelderfer (1979). Her study shows that the profitability of biological control is highest in the Delmarva

TABLE 3

Marginal Productivity of Pesticide Use in Corn Production

Source	Results		Year of study
	Insecticide	Herbicide	
Hanthorn and Duffy (1983)	\$1.03 : \$1.00	\$1.05 : \$1.00	1980
Hawkins, Slife, and Swanson (1977)		From \$3.30 to \$4.89 : \$1.00[a]	1966-1975
Miranowski (1975)	\$2.02: \$1.00	\$1.23 : \$1.00	1966

[a]The findings are ranges of average rates of returns.

TABLE 4

Marginal Productivity of Pesticide Use in Soybean Production

Source	Results: Insecticide	Results: Herbicide	Year of study
Duffy and Hanthorn (1984)	\$0.57 : \$1.00	\$1.13 : \$1.00	1980
Schroder, Headley, and Finley (1981)		\$2.30 : \$1.00	1965-1979
Cashman, Martin, and McCarl (1980)	\$2.30 : \$1.00[a]		1975-1977

[a]The value is an average obtained from three types of insecticides.

Peninsula. By using this technique, the insect control cost would lower by an average per treated acre of $1.47; and this would increase net revenue per soybean acre by $0.71 over that expected for conventional control.

Other nonmentioned cases on alfalfa weevil control have also found an alternative nonchemical pest control to be very profitable and to reduce pesticide usage (Shoemaker and Onstand, 1983; and Zavaleta and Ruesnik, 1980). The estimations found in the above studies on marginal productivity of pesticide in soybean production are summarized in Table 4.

From the "reduction scenario" of no chemical option, corn yield and soybean are expected to decline by 53 percent and 37 percent, respectively. If herbicides and pesticides used in corn were eliminated, then the result would be a 30 percent reduction in yield per acre and 32 percent in yield reduction, respectively (Knutson, et al., 1990).

Empirical Studies of Fruit and Vegetables

Chemicals like fungicides (e.g., alar) are used to improve or maintain quality by reducing spoilage and by extending the time of storability. Insecticides are used for yield enhancement by preventing fruit drop before maturing. In spite of the growing pesticide use in fruit and vegetables not only for preventing yield reduction but also in large proportions for preserving taste and appearance, IPM is only practiced sporadically in contrast to the prevalent use of IPM in soybean and corn production (Greene et al., 1984). For example, for tomatoes grown for processing, about two-thirds of the insecticides used is to control the tomato fruit worm, a "cosmetic pest." The cosmetic appearance of fruit and vegetables is generally alleged to reflect consumer preference (van den Bosch et al., 1975).

Antle's (1988b) application for the study of pesticide use in California processing tomatoes verified that farmers in the region had risk-aversion behavior.

decision. IPM growers, compared with non-IPM growers, applied 30 percent less insecticides, 46 percent less miticides, and 10 percent less fungicides. They also note that quality differences between the groups rarely varied by more than 2 percent. The per hectare cost is lower ($237.2) for IPM users than for non-IPM ($333.04). They recognize that, when IPM practices are being adopted, the public and the environment benefit.

Some of the literature concerned with estimates of pesticide input productivities comes from countries other than the United States. Using the same approach as Headley (1968) for pesticide productivity analysis, Fischer (1970) estimated the marginal productivity of pesticide application on apple production to be higher than its marginal cost (they range from $2.00 to $12) for three regions in Canada. Campbell (1976) provides another similar estimate for the same tree fruits in different regions of Canada; the research results indicate that the marginal value product of pesticide was between $2.00 and $13 for every dollar spent.

The commercial implementation of the Integrated Mite Management (IMM) program began in 1984 (Headley and Hoy, 1987). These authors found that the IMM program benefits almond growers in California; the adopters of the program can save from $60 to $110 per hectare, even though no yield increases occur. The study shows that the annual return on the investment in this program is anticipated to be between 280 percent and 370 percent.

In a previous study by Croft (1976), five alternatives of the cost of adopting integrated control techniques for deciduous fruit pest control were reviewed and examined. It was shown that IMM improved spray, timing, and application and was observed as the most effective technique.

Statistics have shown that the trend in pesticide use in citrus pest control has been upward (Lee and Langham, 1973). Moreover, its use has increased due to citrus rust mites causing the "rustering" or "bronzing" of oranges in Florida. For example, The study shows that, for producers with a low degree of risk aversion, the per acre cost is low; when IPM is adopted by those farmers, their benefits are $24 per acre. In contrast, for a highly risk-averse grower, the program's benefit is about $60 per acre.

Pesticides are used in apple production to maintain and improve the quality and quantity of apple production. Apple production is one of the major sources of farm income within the state of Virginia. The marginal productivity of pesticides in that state's apple production for the year 1982 was studied by Patroch and Taylor (1985). The authors used an approach similar to that of Headley (1968) to evaluate both the marginal value product and the marginal product in bushels; they are found to be $2.80 and $0.64, respectively, for every dollar spent in pesticides. The study also evaluated the marginal rate of substitution between inputs, concluding that there is considerable scope for substitution between pesticide and labor to maintain the same level of output. On the other hand, the study shows that it is less costly to the grower if pesticides are used instead of labor. However, the authors admit that their study has some limitations—one of them being that biological and IPM practices were not considered as a close substitute to pesticides and that an examination of different management techniques was not examined.

The importance of quality impacts of pesticide use in apples was illustrated by Babcock, Lichtenberg, and Zilberman (1989). They show that quality effects matter. Insecticide use was found to have a higher impact on quality compared to yield. Fungicides were detected to improve both yield and quality. With reasonable prices, the analysis suggests that quality counts for about one-third of benefits associated with pesticide in the sample. The study also shows that pruning is also an excellent substitute for fungicides, reducing both yield losses and disease damage.

An evaluation of whether IPM adoption reduces pesticide use in apple production is presented in Kovach and Tette (1988). The study finds that 80 percent of the apple growers in New York state adopted IPM practices in their pest control

TABLE 5

Marginal Productivity of Pesticide Input in Fruit Production

Source	Results	Year of study
Fischer (1970)[a]	\$2.00 to \$12 : \$1.00	1965-66
Campbell (1976)[a]	\$2.00 to \$13 : \$1.00	1970
Lee and Langham (1973)[b]	\$0.82 : \$1.00	1964-1968
Patroch and Taylor (1985)[c]	\$2.80 : \$1.00	1982

[a]The studies are for the case of apple production in Canada.

[b]The study is for the case of citrus production.

[c]The study is for the case of apple production in the state of Virginia.

during 1973, about 87 percent of the citrus acreage in Florida was sprayed for rust mites (Pimentel et al., 1977). Lee and Langham (1973) conducted a study using data for 1964-1968 for the major citrus-producing areas of Florida. This study includes a kill efficiency relationship and shows that marginal returns to pesticide use in citrus were less (e.g., 8.2 cents) than marginal cost, implying that pesticides are overused in the sample citrus production units. The same qualitative results apply for fertilizer. It is also noted that pesticides increase citrus production and decrease pest infestation.

Table 5 presents a summary of results on marginal productivity of pesticides for fruit production.

IV. Summary and Conclusions

Pesticide use in agricultural production has increased significantly in the last three decades; this fact is shown in statistics and various studies of pesticide usage in different cases. The increase in pesticide usage can be attributed to the following reasons:

1. Pesticide prices have increased at a slower rate than either labor or machinery. This characteristic is important because pesticides constitute a mechanism for substituting capital for labor and for equipment services in agriculture. For example, herbicides and insecticides are used to replace farm labor and management input, and they are also substitutes for mechanical cultivation in activities such as hand weeding, tillage, and others including crop rotation with weed competitive crops. But the practice of weed control using chemical control can cause soil erosion (e.g., where weeds are important in containing soil moisture and keeping wind erosion at a minimum).

2. All aggregate-level empirical studies support the belief that pesticides are highly productive in agriculture, thus, implying that pesticides are being underutilized by farmers in terms of private costs and returns. An average return of $4.00 for each

With few exceptions, all of the above empirical studies reviewed show that the private return to pesticide use (at an aggregate crop level as well as for a single crop), exceeds their cost. This particularity is attributable to the fact that environmental and social costs cannot be quantified and thus included in the farmer's decision making concerning the level of pesticide use. Thus, much of the research among agricultural economists lately has been about the appropriateness of the production function specification to estimate the productivity of chemical inputs.

Reevaluation of other previous studies of pesticide productivity in conjunction with new empirical work may shed further light on the source of the discrepancy between perception and econometric results regarding pesticide productivity.

dollar spent in pesticides can be derived from the studies done between 1963 and 1984. However, it must be noted that aggregation studies have certain limitations such as the assumption of homogeneity throughout the region. Furthermore, many other "important" variables are not being included in the model such as entomological variables concerned with pest population, pest resistance, and others of that kind. However, the most important fact that remains to be addressed is that indirect costs are not considered at all, and in many cases certain costs cannot be assigned a value (e.g., human life).

3. Farmers' use of pesticide is a behavioral characteristic of risk aversion: Pesticides may be viewed by some as an insurance policy protecting growers from potential pest damage and as a form of reducing income variability.

While the use of herbicides and insecticides has increased, particularly in certain crops such as cotton, studies which evaluate IPM practices versus non-IPM control practices (e.g., relying on pesticide use only) show that pesticide usage is responsible for a decrease in its own efficacy, as reflected by the decline in yield obtained for that crop in the year of research, the increase in pesticide use and expenditures (because of resistance and resurgence problems), and in some cases by the increase of the farmer's risk behavior. In the case studies of grain production (particularly in soybean and corn), the use of herbicides and insecticides together with other technologies is believed to increase the yield crop to some degree. But it is also noted that non-IPM practices incurred higher herbicides costs and a greater use of insecticides and herbicides.

In this review an attempt is made to present a sample of empirical studies, both at an aggregate level (i.e., for the United States) and at a micro-level (i.e., for different crops). The results obtained in both studies represent a partial measurement of the private benefits of pesticide use.

With few exceptions, all of the above empirical studies reviewed show that the private return to pesticide use (at an aggregate crop level as well as for a single crop), exceeds their cost. This particularity is attributable to the fact that environmental and social costs cannot be quantified and thus included in the farmer's decision making concerning the level of pesticide use. Thus, much of the research among agricultural economists lately has been about the appropriateness of the production function specification to estimate the productivity of chemical inputs.

Reevaluation of other previous studies of pesticide productivity in conjunction with new empirical work may shed further light on the source of the discrepancy between perception and econometric results regarding pesticide productivity.

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on pesticide use may harm some growers, make other growers (nonusers) better off, and increase consumer price and affect international trade patterns.

This study shows how the distributional and cumulative effects of a pesticide restriction may be analyzed for the case of a hypothetical cancellation of a pesticide used on vegetables and fruits. Drawing on past studies done for the U. S. Environmental Protection Agency (EPA), we show that the total economic effect of a pesticide ban on society is often less than that projected using the old methodologies, especially in domestic markets; that the economic consequences are uneven and some growers lose substantially; and that some groups actually gain from restrictions.

I. Methodology

The consequences of the removal of any pesticide from use affects several general groups of individuals. Among them are the producers who use the pesticide, the producers who do not use the pesticide, and both domestic and foreign consumers. The producers who use the pesticide may be subdivided in order to account for regional effects which manifest themselves in the form of different pests, different yields, or different times (seasons) of production. The analysis of the effects of a pesticide cancellation is performed in four steps.

The first step is to assess the farm level response from the proposed pesticide cancellation. This is done by contacting farm organizations, extension specialists, and other experts and interviewing them as to the predicted effects. This requires an interdisciplinary approach. All feasible alternatives to the pesticide must be considered, including integrated pest management (IPM), alternative chemicals, biological controls, and cultural controls. The impacts of the changes are then quantified, and predicted changes in yields and costs are made. These analyses are repeated for each subgroup which is impacted differently. These subgroups are

7

EQUITY AND ECONOMIC EFFECTS OF PESTICIDE USE RESTRICTIONS

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Pesticides are subject to regulation and study because of their possible environmental and health effects. The restriction or ban of pesticide use is one type of policy which is frequently considered. Research in agricultural economics led to the development of methodologies to assess the market impacts of these policies. This chapter demonstrates the analysis of the market effects using, as an example, a 1987 case study of a parathion cancellation on one vegetable and several fruit crops.

When studying the economic effects of a pesticide cancellation, one must separate between the production and cost impacts and market effects. This is important because the immediate changes in costs, yields, and quality cause further, less obvious impacts through the workings of markets. Thus, the overall results of a pesticide ban on farmers' profits are not immediately clear. The market adjustments which take place from reduced supplies will partially compensate farmers for some of the initial losses and increase consumer prices.

A ban on pesticides may result in a multitude of changes. One has to distinguish between the overall policy outcome and the distributional impacts. A ban total acreage treated with parathion and each alternative chemical were obtained from published data and conversations with university personnel, extension experts, and pest control advisers. It was assumed that the yields obtained by parathion users and nonusers did not differ. Information on each crop and its markets is presented in Table 1.

III. Lettuce

Although California is a large producer of lettuce, it is grown in many regions of the United States, producing differences in seasonal markets (Table 1). Parathion is used on lettuce in the Far West (California and Arizona), Florida, and New York (Toscano, 1987; Guzman, 1987; Bolts, 1987; Schuler, 1987; A. Chem Service, 1987). In California it is used in the Central Coast, San Joaquin Valley, and Imperial Valley. Equally effective alternatives exist for every use of parathion in California except for treatment of the lettuce root aphid in the Central Coastal region (Toscano, 1987). Therefore, for the rest of California, a cancellation of the registration of parathion for use on lettuce would result in a switch to a more costly alternative. In the Central Coast region a cancellation would cause a switch to a more costly alternative and/or a reduction in yields by up to 25 percent (Toscano, 1987). The alternative available in 1987 for treatment of the lettuce root aphid was only available on a one-year emergency use registration and, due to the lengthy reentry interval, there were doubts as to the viability of its use (Toscano, 1987).

The complexities of parathion use in California are seen when we describe the effects of a cancellation on different regions. Cancellation was estimated to result in average increases in the cost of treating aphids, crickets, and beetles of $9.20 per-acre treatment in the San Joaquin Valley and $7.00 per-acre treatment in the Imperial Valley. Central Coast growers using parathion to treat insect pests other than lettuce root aphid or garden symphylan would face an estimated increase in insecticide costs generally users of the pesticide who face different alternatives due to variations in pests treated, growing regions, yields, etc.

The changes in equilibrium price and quantities produced in each region are estimated next. This is done by noting the expected changes in yields and costs and using economic supply and demand studies to estimate the resulting market effects. Increases in costs or decreases in yields cause a reduction in the quantity that producers are ready to sell at any given price. The reduction in supply leads to an increase in the product's price.

These estimates are then used to calculate the changes in profitability to nonusers of the pesticide. These nonusers generally gain additional revenues due to the rise in price which may increase production in response. The changes in welfare of consumers is also estimated. The increase in price and decrease in output implies a reduction in the well-being for the consumer as they are forced to pay more for less product.

The final step is to estimate the changes in profits for each group of producers using the pesticide. These producers face higher production costs and/or higher losses. These immediate effects will be partially offset by the higher price of the product once the market adjustments are considered.

II. Case Studies

The economic effects of the cancellation of the pesticide ethyl parathion on lettuce and on the tree crops, plums, prunes, and almonds, were studied in 1987 (Lichtenberg, Parker, and Zilberman, 1987a, b; Lichtenberg, Parker, Zilberman, and Van Steenwyck, 1987). These studies were used to design and test the methodology briefly described above. The results of the tree crop studies will be grouped and presented separately from those of the lettuce study. For each crop, information on equilibrium prices, yields, acreages, output levels, pesticide costs, and proportions of of $8.98 per acre. Those using parathion only to treat lettuce root aphid would experience an estimated decrease in insecticide plus application cost of $13 per acre coupled with a 25 percent reduction in yield. Those using parathion for both lettuce root aphid and other pests would face an estimated decrease in insecticide costs of $4.02 per acre coupled with a 25 percent reduction in yield. Those using parathion to control garden symphylan only would experience an increase in pesticide costs of $82 per acre while those using parathion to treat garden symphylan and other pests would face an increase in costs of $90.98 per acre.

The social losses were estimated for each region for each set of insects by season. These can be found in Lichtenberg, Parker, and Zilberman (1987b). Summary effects for the United States as a whole, by season, are given in Table 2. Annual U. S. lettuce production was estimated to decrease by 0.49 percent or 15,362 tons. The annual average price of lettuce would increase by $9.80 per ton or 3.98 percent. Current parathion users would lose over $37 million per year in producer profits, while nonusers would gain over $16 million per year. The total change in producer profits is a net lost of nearly $21 million. Consumers would lose over $27 million from cancellation, mainly during the spring and summer. Domestic welfare would decrease by over $48 million annually, while export revenues would increase by about $1.3 million.

Central Coast growers affected by lettuce root aphid account for most of these losses. They would lose an estimated $39 million annually, about $712 per acre per growing season. The reduction in output from these growers is so large that other growers currently using parathion would actually gain about $1.36 million per year from cancellation.

If the lettuce root aphid were not a factor (or a variance were granted for this particular use of parathion), the impact of cancellation would be relatively small. During the winter months, for example, when the Central Coast does not produce,

TABLE 1

Profile of Crops Affected

Crop/region, season	Production	Yield	Share of production for: Users	Exports'	Price
	tons	tons per acre	percent		dollars per acre
Plums	224,250	6.5	47.8	0.0	670
Almonds	202,400	0.55	39.7	56.6	1,680
Prunes					
Aggregate	547,280	6.5	46.6	30.8	220
California	480,240	7.2	48.2		
Umatilla Valley, OR	3,445	5.3	100.0		
Other Oregon	29,205	5.3	0.0		
Washington/Idaho	20,890	5.9	93.8		
Michigan	13,500	6.0	33.3		
Lettuce					
Aggregate	3,109,500	14.6	NA	5.7	232
Winter	775,525	13.6	NA		221
Spring	863,075	14.9	NA		205
Summer	754,125	15.4	NA		229
Fall	716,775	14.5	NA		271

Source: Lichtenberg, Parker, and Zilberman (1987a, b); Lichtenberg, Parker, Zilberman, and Van Steenwyck (1987).

cancellation would reduce output by less than 0.01 percent and increase price by only 0.09 percent. If root aphid were not a problem, total lettuce production would decrease by less than 415 tons annually, and domestic welfare would decrease by under $1 million (compared with the $48 million decrease predicted). Current parathion users would lose only $614,000 while current nonusers would gain $434,000. Domestic consumers would lose $785,000 and export revenues would increase by only $37,000.

The case of lettuce provides a good example of why policy decisions must be based on information which demonstrates the effects of policies on each subpopulation affected. Except for one group of growers, the effects of a parathion cancellation on lettuce is rather small. The lettuce example is also useful in showing the effects of a cancellation where no alternatives are available. This type of analysis would be particularly useful when several pesticides were considered for cancellation at once leaving no effective treatment. Such may be the case with the passage of EPA 1990. It is important that policymakers are aware of the effects on these groups so that appropriate considerations may be made.

IV. Plums, Almonds, and Prunes

Each of these tree crops provides a different emphasis in either marketing or growing conditions. In the United States plums are only grown in California and they are virtually all consumed by the domestic fresh plum market. Therefore, imports and exports are not considered for this crop.[1] Parathion was found to be used on nearly 50 percent of the acreage, solely as a dormant treatment of scale, mite eggs, leaf rollers, and aphid eggs. The remainder of the acreage received dormant treatment with either chlorpyrifos, diazinon, methidathion, or phosmet (DeBore, 1986; Marler, 1986/87; Yoshikawa, 1986). While costs vary, all of these treatments are believed to

[1]Plum exports have increased in recent years and would need to be considered if the current growth trend in exports continues.

TABLE 2

Welfare Costs of Canceling Parathion for Use on Lettuce

	Winter	Spring	Summer	Fall	Aggregate
Market impacts					
Change in price	+$0.20	+$4.60	+$20.00	+$11.80	+$9.80
Change in output	-125	-5,928	-7,838	-1,470	-15,362
Impact on current users					
Change in producers' profit	-$238,858	-$14,203,112	-$16,698,350	-$5,971,172	-$37,111,492
Impact on current nonusers					
Change in producers' profit	+$111,694	+$6,614,908	+$7,731,922	+$1,721,154	+$16,179,678
Impact on domestic consumers					
Change in consumers' surplus	-$220,360	-$9,677,465	-$14,267,811	-$3,177,128	-$27,342,760
Impact on foreign consumers					
Change in export revenues					+$1,290,622
Change in consumers' surplus					-$1,720,903
Net welfare impacts					
Change in domestic surplus	-$347,524	-$17,265,668	-$23,234,234	-$7,427,146	-$48,274,576
Change in world surplus					-$49,995,479

Source: Lichtenberg, Parker, and Zilberman (1987b).

also used in-season to control peach twig borer and oriental fruit moth on about 75 percent of prune acreage; the remainder is treated with azinphos-methyl for this purpose (Dahmen, 1986; Willet, 1986/87). In Michigan, parathion is used only in-season to control apple maggot and plum curculio. Parathion, azinphos-methyl, and phosmet are each used on about one-third of the prune acreage (Howitt, 1986; Thomas, 1987).

For plums, it was found that canceling parathion would increase current users' costs by an estimated $5.54 per acre ($0.91 per ton at average yield). For almonds, canceling parathion would increase current users' costs by an estimated $13.92 per acre ($25.31 per ton). For prunes, canceling parathion would increase current users' costs by an estimated $14 per acre ($2.64 per ton) in California, $8.74 per acre ($1.46 per ton) in Michigan, up to $17.07 per acre ($2.89 per ton) in Washington/ Idaho, and up to $52 per acre ($9.81 per ton) in the Umatilla Valley, Oregon. The estimates for Washington/Idaho and Oregon vary depending upon whether parathion is used once or twice per year. The effects of these costs, for each crop in each region, on the welfare of each group were calculated and are shown in Table 3.

U. S. plum production was estimated to decrease by 39 tons annually or 0.02 percent. The price of plums would increase by $0.18 per ton or 0.03 percent. Current parathion users would lose almost $80,000 while current nonusers would gain over $20,000 annually. Domestic consumers would lose almost $40,000 and the net loss in domestic welfare would total almost $100,000 per year.

Cancellation of the registration of parathion for use on almonds was estimated to result in a reduction in output of 136 tons per year or 0.03 percent. The price of almonds would increase by $3.42 per ton or 0.20 percent. Current parathion users would lose about $1.8 million per year while nonusers would gain about $0.5 million per year. The total effect on the industry would, therefore, be a loss of about $1.3

be of equal efficacy. Therefore, cancellation of registration for parathion on plums would increase costs of annual dormant treatments for 50 percent of the acreage.

Like plums, the entire U. S. almond crop is grown in California. However, almost three-fifths of the crop is typically exported. Parathion is used on almonds solely for dormant treatment of scale, mite eggs, and peach twig borer. It is used on almost 40 percent of almond acreage. The remaining acreage is treated with diazinon, methidathion, or phosmet (Viveros, 1987; Krueger, 1987). The chief impact of canceling the registration of parathion for use on almonds would be an increase in annual dormant treatment costs as growers switch to a more costly alternative (Wilks, 1986; Cahn, 1986; Chemeter Agricultural Chemicals, 1986; Stanislaus Farm Supply, 1986).

The situation with prunes is more complex. The bulk of the prune crop (86 percent) is grown in California; however, significant shares of crop are produced in Oregon, Washington/Idaho, and Michigan. Parathion is used differently for prunes in each growing region. In California it is used solely for dormant treatment of scale, mite eggs, leaf rollers, aphid eggs, and other insect pests. It is used on almost half of California prune acreage. The remainder of the acreage receives dormant treatment using the same substitutes as for plums (DeBore, 1986; Marler, 1986/87; Yoshikawa, 1986). In Oregon parathion appears to be used only in the Umatilla Valley, both for dormant treatments and for in-season control of leaf rollers. About 40 percent of Umatilla Valley prune acreage receives dormant treatment with parathion; the remainder, with chlorpyrifos (Darnell, 1986/87; Waliser, 1986/87). Leaf rollers have recently become a major problem in this region and parathion is expected to be used on all prune acreage for this purpose. Chlorpyrifos or azinphos-methyl could be used but would probably require an additional application to give adequate control. In Washington/Idaho parathion is used for dormant treatment on about 75 percent of prune acreage; the remainder receives dormant treatment with diazinon. Parathion is million per year. Domestic consumers would suffer small losses of about $300,000 per year. Export revenues would increase by about $262,000 per year or 0.07 percent.

The reduction in U. S. prune production was estimated to be 140 tons annually or 0.03 percent. The price of prunes would increase by $0.27 per ton or 0.12 percent. Current parathion users would lose over $236,000 per year in profits while current nonusers would gain almost $77,000. Domestic consumers would lose about $88,000. Domestic welfare would decrease by almost $248,000 while export revenues would increase by over $45,000 annually.

Prune growers in the Umatilla Valley of Oregon would be affected most heavily by cancellation. Those currently using parathion for both in-season and dormant treatments would lose over $50 per acre, while those currently using it in-season only would lose over $26 per acre. Growers in Washington/Idaho currently using parathion for both dormant and in-season treatments would also lose heavily, over $37 per acre. Those currently using parathion for either purpose exclusively would lose between $11 and $16 per acre. Current parathion users in Michigan would lose over $7.00 per acre. Current users in California would lose the least, just over $4.00 per acre. This type of regional redistribution emphasizes the need for detailed study when considering the effects of a pesticide registration cancellation. Aggregate results underestimate the impact that this type of restriction can have on subpopulations.

Several conclusions can be drawn from Table 3. First, the impact of canceling the registration of parathion on these three tree crops would be quite unevenly distributed. Nonusers' gains amount to roughly between one-fourth and one-third users' losses. While domestic consumers do suffer losses, foreign consumers lose even more. The severity of the impact of cancellation may not be discernible from aggregate loss figures, even when the latter are calculated on a regional basis. For example, the aggregate losses of Umatilla Valley growers amount to only $23,313 per year which is only about 17 percent of the aggregate losses suffered by all California

TABLE 3

Welfare Costs of Canceling Parathion for Use on Plums, Almonds, and Prunes.

	Plums	Almonds	Prunes
Market impacts			
Change in price	+$0.18	+$3.42	+$0.27
Change in output	-39	-136	-140
Impact on current users			
Change in revenue	-$16,496	-$25,152	+$7,533
Change in pesticide cost	+$97,496	+$2,029,224	+$305,133
Change in other costs	-$35,389	-$299,067	-$61,201
Change in producers' profit	-$78,603	-$1,755,309	-$236,379
Impact on current nonusers			
Change in producers profit	+$20,264	+$417,027	+$76,666
Impact on domestic consumers			
Change in consumers' surplus	-$39,542	-$299,996	-$88,124
Impact on foreign consumers			
Change in export revenues	NA	+$261,952	+$45,509
Change in consumers' surplus	NA	-$391,239	-$45,509
Net welfare impacts			
Change in domestic surplus	-$97,501	-$1,638,278	-$247,837
Change in world surplus	-$97,501	-$2,029,517	-$293,346

Source: Lichtenberg, Parker, and Zilberman (1987a); Lichtenberg, Parker, Zilberman, and Van Steenwyck (1987).

of the pesticide cancellation. It may be beneficial for cancellation to be accompanied with research and development funds. Another short-run effect is that, for crops with significant export markets, foreign consumers may bear much of the cost of restrictive policies. However, in the long run these policies will produce increased foreign competition and thereby undermine U. S. competitiveness.

The methodology demonstrated in this chapter can be used when analyzing the effects of a multiple-pesticide cancellation. This type of cancellation is more likely to result in cases where no ready substitutes exist. This is similar to the case of the lettuce root aphid where, due to the lack of an alternative to parathion, yields to a particular group of growers were predicted to decline by 25 percent. This type of effect is similar in nature to that which may arise in certain areas from the passage of a blanket pesticide restriction program.

users ($132,885 per year); yet, the per-acre figures show that as individuals the Umatilla Valley growers are hit considerable harder by cancellation (up to $50 per acre in Umatilla Valley verses $4.00 per acre in California). If grower profits were $150 per acre (considered high by many), the cancellation would cut profits by one-third. This may force these growers into bankruptcy.

V. Conclusions

This chapter demonstrates the types of information which can be created by studying the effects of environmental regulation on agricultural. There are several implications which this type of analysis addresses. The first is a recognition of the fact that the burden of a pesticide's cancellation is spread unevenly. It is important to specify target groups which may be affected by the proposed regulation and quantify its effect on them.

The example used in this chapter demonstrates that the overall effects of a cancellation of parathion on these crops is rather low while the effects in certain areas can be very substantial. This information may be used by policymakers to grant exemptions, or make other allowances, for growers in areas particularly hard hit. Exemptions can only be effective when introduced with appropriate monitoring mechanisms which prevent abuses.

The effects of a pesticide cancellation were shown to raise market prices for the product. While users of the pesticide generally lose due to the increased costs and/or reduced yields, some users may actually gain because of the increase in output price. Nonusers of the pesticide gain in the form of increased revenues while domestic and foreign consumers lose. Export revenues from the crop are shown to increase.

The analysis in this chapter is of short-run impacts. In the past, agriculture has demonstrated the ability to adjust to these types of changes over time. In the long run research and development may solve many of the greater short-term effects

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increased pesticide applications and the cost of postharvest treatments in complying with quarantine regulations in order to ship produce out of state. In addition, consideration is given to the impacts that increased costs and/or decreased yields might have through market adjustments.

I. Background and Assumptions

The basic assumption of the study is that, if eradication efforts fail for one reason or another, the Medfly will expand from its current limited area of infestation in Southern California into commercial agricultural areas in the state. Furthermore, once established, control of the Medfly will involve substantial costs on the part of those affected crops. This chapter estimates those costs as well as the cost of complying with the quarantine regulations likely to be imposed on California by other countries, states, and USDA-APHIS.

This chapter also assumes that expenses which are incurred in the agricultural sector in producing and marketing fruits and vegetables will ultimately be borne by the consumer. The effects of increased costs may not, and usually do not, appear immediately in the marketplace. However, adjustments in supply and demand do occur over a period of time so that the impacts of increased costs will eventually occur. While an exhaustive analysis of market impact is not attempted in this study, a limited analysis is conducted regarding how increased costs and decreased yields might impact producer revenue.

Finally, this study does not attempt to distinguish whether the establishment of Medfly will have different outcomes in different parts of the state. It assumes that, once established, Medfly will become a significant problem for those crops identified.

An important consideration in estimating costs is the identification of those crops which serve as a Medfly host. In 1981, a total of 23 agricultural commodities or species were identified as hosting Medfly, and 20 were analyzed. In 1990, the CDFA

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ECONOMIC ANALYSIS OF THE ESTABLISHMENT OF MEDFLY IN CALIFORNIA

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Beginning in 1989 and continuing through the first part of 1990, infestations of the Mediterranean Fruit Fly, *Ceratitis capitata* (Wied.) were discovered in Southern California. With the discoveries, the California Department of Food and Agriculture (CDFA) and the U. S. Department of Agriculture-Animal, Plant, Health Inspection Service (USDA-APHIS) launched a series of programs designed to eradicate the pest. Part of the programs involved aerial applications of malathion-treated lure (bait) to decrease the numbers of Medfly so that a sterile male program could eliminate the rest of the infestation. The aerial application of malathion-treated bait brought out public concern over the safety of the program. This concern has threatened the termination of aerial applications which, in turn, could allow establishment of the Medfly as a permanent pest in California—spreading from pockets in Southern California to other parts of the state. The threat of the Medfly outbreak spreading to other areas has resulted in concern over the economic impact of the pest.

The purpose of this chapter is to provide a current estimate of the economic effects of the establishment of the Medfly in commercial agricultural areas of California. A 1981 study (Galt and Anderson, 1981) laid a solid foundation for the estimation of the economic impact of the Medfly on California agriculture. This study was recently updated (see Siebert and Pradhan, 1990) and provides background for this chapter[1] which estimates the costs of controlling Medfly in the field through

[1] In addition to these studies, see Carter (1990).

TABLE 1

Acres, Value, California Share of U. S. Production, and Percent of Crops Exported, 1988

	1988 acreage	1989 value	1988 share of U. S. production	Percentage of crops exported
	thousand acres	thousand dollars	percent	percent
Apples, all	22.20	96,200	6.50	-
Apricots	21.50	35,948	98.30	12.2
Avocados	74.70	200,490	85.80	10.4
Bell peppers	18.65	77,155	100.00	3.9
Cherries, sweet	10.30	24,418	13.40	51.2
Dates	5.00	19,203	100.00	22.5
Figs	17.70	16,320	100.00	7.3
Grapes, raisin	271.00	634,110	84.10	4.3
Grapes, wine	297.00	646,090	100.00	25.9
Grapes, table	86.20	264,150	96.30	21.1
Grapefruits	20.60	52,795	9.80	36.7
Kiwis	6.90	26,565	100.00	49.7
Lemons, fresh	48.90	184.576	83.90	36.2
Lemons, processed	a	4,956	76.40	-
Limes	1.00	2,566	10.60	-
Mandarins (tang.)	8.20	28,862	32.00	16.6
Oranges	172.00	408,289	24.80	20.9
Olives	31.50	65,175	100.00	2.6
Nectarines	23.60	79,290	100.00	b
Peaches, fresh	26.10	63,504	29.60	11.0
Peaches, processed	27.60	114,662	96.30	3.4
Pears, fresh	5.90	25,406	19.00	9.7
Pears, processed	17.10	60,109	53.00	
Persimmons	1.20	6,961	100.00	
Plums, fresh	40.00	94,796	82.90	21.0
Prunes (fresh wt.)	75.80	159,100	100.00	29.6
Tomatoes, fresh (pink & red ripe)	37.50	247,339	28.50	12.4
Tomatoes, processed	226.10	569,060	90.50	2.2
TOTAL	1,594.25	4,208,095		

[a]Included in total lemon acreage.

[b]Included with peaches.

has identified a list of 35 commodities that could serve as possible hosts to the Medfly. This list includes 19 of the commodities from 1981 (loquat, prickly pear, quince, and strawberries are not on the list). In addition, USDA-APHIS has published a list of regulated articles subject to quarantine from Medfly-infested areas in California effective February 16, 1990.[2]

Defining the true biological (i.e., those that allow survival and reproduction) hosts for Medfly is very important in analyzing the potential impact. If the suggested 1990 list of hosts is considered, the 1989 value of production is $6.446 billion and the 1988 value of exports is $1.738 billion.

In considering which commodities could serve as host to the Medfly, it is important to distinguish the differences in impacts. Discussions with entomologists suggest that soft fruits such as peaches, nectarines, and plums would be highly susceptible to damage from the Medfly as well as postharvest treatments; hence, a higher economic impact is more probable than walnuts or almonds (which also have been identified as possible hosts). After considerable discussion with entomologists, the crops identified in Table 1 are the likely Medfly hosts considered in this chapter. It should be pointed out that, in addition to those agricultural crops not likely to be significantly affected, there are other nonagricultural hosts (i.e., ornamentals and wild hosts) that are not considered.

From Table 1, it can be seen that a total of 28 crops are listed with a total acreage of nearly 1.6 million acres. It should be noted that lemons, peaches, and pears have been divided into fresh and processed components. The significance of this division is that, while all of the crops listed will receive a field treatment of a pesticide to eradicate or control Medfly, quarantine treatments for Medfly will take place only for the fresh component of the crop.

[2]See *Code of Federal Regulations* (1990).

loss even with the use of insecticides due to nonuniformity of treatment, organic growers, and abandonment of crops, this chapter assumes that significant losses due to damage from the Medfly would not occur with a regular field treatment schedule. The major costs to growers would be the cost of insecticides and costs of application. This assumption is based on discussions with a number of entomologists.

One area that will be impacted significantly with the possible establishment of Medfly will be organic growers, those who are practicing the emerging concept of sustainable agriculture, and producers of home-grown produce. Given the destructive capability of the Medfly, it is highly probable that crop losses would be too great to continue the practice of organic farming or sustainable agriculture in those affected crops. In addition, growers of home-grown produce will likely find that crop losses would be considerable and either abandon the crop or use increased amounts of pesticides. In the case of growers using organic and sustainable agricultural methods, it is assumed in this study that they will turn to controlling Medfly through the use of pesticides, and their increased costs will be reflected in the total costs estimated in this study. There is no reliable estimate of the value of home-grown produce; hence, this study makes no attempt to evaluate the losses and increased costs that might occur. However, it is likely that the total costs associated with an establishment of Medfly in California will increase due to the home-grown produce factor.

Costs of controlling the Medfly in the field are dependent on two main factors. The first is the number of days that a crop would be susceptible to Medfly and, consequently, the number of applications needed to control it. The second factor is the cost of the material used to control Medfly and the cost of application.

In estimating the days susceptible to Medfly and number of applications, low and high ranges are constructed. The reason for the range is that it is difficult to precisely estimate the number of days a particular crop may be susceptible to Medfly and the number of applications needed. Based on the current emergency regulation

The 1989 farm value of the crops in this study amounted to slightly over $4.2 billion. The relative importance of the crops to total U. S. production varies. Significantly, California grows 100 percent of the bell peppers, dates, figs, kiwis, raisin grapes, nectarines, olives, persimmons, and prunes in the United States. Other significant crops as a percent of U. S. production are apricots, avocados, wine grapes, table grapes, lemons, processed peaches, plums, and processed tomatoes. It can be argued that decreased production due to Medfly damage in these crops will be difficult to replace from U. S. sources.

Many of the crops in this chapter are exported. As observed from Table 1, exports play a significant role in many of the crops listed. The total value of exports at the farm level amounts to $496,398,000 or 11.8 percent of total farm value. Although California is a significant factor in the production of many crops in the United States that could be impacted by the Medfly, the state also has a significant share of U. S. exports.

Overall, the crops that would be possible hosts to the Medfly, if it were to become established in California, have a significant impact both in terms of the value of farm production and export markets.

II. Production Costs to Control Medfly

This section provides estimates of costs for controlling Medfly in the field. The 1981 study estimated the cost for control as well as losses due to Medfly damage. This latter cost was assumed to be 7.5 percent of the crop for all commodities. If insecticides are not used, then crop losses would definitely occur based on past Medfly studies. However, no firm estimates of losses are known for each specific commodity, with or without spraying.

For purposes of this study, it is assumed that producers of affected crops would use insecticides to control Medfly. While there is a likely possibility of a crop

TABLE 3

Estimated Pesticide Application Costs as a Percentage of 1989 California Farm Production Value

	Control costs as percentage of 1989 California value	
	Low	High
Apples, all	2.08	5.88
Apricots	5.38	11.66
Avocados	15.09	43.59
Bell peppers	1.81	2.42
Cherries, sweet	3.80	8.23
Dates	2.34	6.64
Figs	9.76	42.30
Grapes, raisin	3.85	16.67
Grapes, wine	4.14	17.93
Grapes, table	2.94	12.73
Grapefruits	36.87	52.68
Kiwis	2.34	5.06
Lemons	39.34	61.40
Limes	5.26	22.80
Mandarins (tang.)	7.67	29.41
Oranges	43.60	56.87
Nectarines, fresh	3.26	7.06
Olives	5.36	23.24
Peaches, fresh	3.70	8.01
Peaches, processed	2.17	4.69
Pears, fresh	2.09	4.53
Pears, processed	2.56	5.55
Persimmons	1.55	4.40
Plums, fresh	3.80	8.23
Prunes (fresh wt.)	4.29	9.29
Tomatoes, fresh (pink & red)	1.14	2.46
Tomatoes, processed	2.98	3.97

TABLE 2

Estimated Costs of Controlling Medfly Through Applications of Malathion-Treated Bait

	Range of control costs		Cost per pound of produce	
	Low	High	Low	High
	thousand dollars		cents	
Apples, all	1998	5,661	.31	.87
Apricots	1,935	4,193	.84	1.82
Avocados	30,254	87,399	9.28	26.81
Bell peppers	1,399	1,865	.35	.47
Cherries, sweet	927	2,009	1.78	3.86
Dates	450	1,275	1.01	2.87
Figs	1,593	6,903	1.66	7.19
Grapes, raisin	24,390	105,690	.64	2.76
Grapes, wine	26,730	115,830	.49	2.13
Grapes, table	7,758	33,618	.54	2.34
Grapefruits	19,467	27,810	3.48	4.97
Kiwis	621	1,346	.86	1.85
Lemons	72,617	113,326	5.90	9.20
Limes	135	585	1.16	5.03
Mandarins (tang.)	2,214	8,487	1.45	5.55
Oranges	178,020	232,200	4.04	5.27
Olives, fresh	4,253	18,428	1.73	7.49
Nectarines, fresh	2,124	4,602	.53	1.15
Peaches, fresh	2,349	5,090	.73	1.57
Peaches, processed	2,484	5,382	.21	.45
Pears, fresh	531	1,151	.33	.71
Pears, processed	1,539	3,335	.33	.71
Persimmons	108	306	.94	2.66
Plums, fresh	3,600	7,800	.85	1.83
Prunes (fresh wt.)	6,822	14,781	.48	1.03
Tomatoes, fresh	2,813	6,094	.27	.59
Tomatoes, processed	16,958	22,610	.10	.13
TOTAL	414,086	837,772		

Under the first option, the major impact would result in reduced yields and poorer quality. In the 1981 study, it was assumed that an economic loss of 2.5 percent would occur from secondary pest outbreaks. If this figure is applied to the 1989 farm value of the crops considered in this study, a loss of $105.2 million would result. The second option would involve the application of a pesticide to control the pest. This application may be in addition to the malathion used to control the Medfly but would likely be combined. In this case the additional cost may result from any increase in the cost of materials used. It is likely that a more toxic material than malathion would be used, but this will depend on the pest which needs to be controlled. An estimate of the additional cost that will result from a decreased use of IPM will depend on the crop, pests involved, and the control strategies selected.

IV. Postharvest Quarantine Treatment

If Medfly is established in California, the state will likely be placed under quarantine for shipments of affected commodities leaving the state for both domestic shipments to other states and exports, particularly to the rapidly growing markets of the Pacific Rim. In order to ship agricultural products under the quarantine, they would have to be treated to insure that they are not contaminated by Medfly. This section estimates the costs of complying with quarantine requirements for produce shipped out of California.

Two alternatives now exist for most commodities: methyl bromide fumigation and cold treatments. It should be noted that, while methyl bromide is currently approved for use, it may not remain a viable alternative in the future due to questions being raised about its impact on the environment and food health and safety (ethylene dibromide use was canceled). In addition, a vapor heat treatment exists for some commodities which cannot be treated with methyl bromide or cold treatments.[5] While

[5]Details of quarantine treatments can be found in USDA-APHIS (1989).

in the form of higher prices. This question will be discussed in greater detail in the market impact section.

III. Impact on Integrated Pest Management

During the past decade, California agriculture has embarked on an intensive program of integrated pest management (IPM). Its goal is to reduce significantly the amount of pesticides used in production while maintaining yields and net value to the grower. The program is based on research conducted by the University of California and others on which pest and disease management strategies are based. In addition, the program has been greatly assisted by the growth of a professional corps of pest management advisors who are educated and licensed to provide advice to farmers and others who use pesticides.

This program has resulted in a significant reduction in the amounts of pesticides used in the crops selected for the program. Through IPM research and applications, the control of pests and diseases with nonpesticide methods has increased.

If the increased use of malathion or some other pesticide is applied to the crops listed in this study, it is likely that the IPM programs will be less successful, particularly those using beneficial organisms. Data are not available at this point to evaluate the impact of increased applications of malathion on IPM programs. However, it is likely that pests other than Medfly which are now controlled through IPM can reemerge to once again threaten crops (secondary outbreaks). The options open to a farmer under a secondary outbreak would be (1) allow the pest to survive without additional applications of pesticides to control it and accept the economic damage of crop from reduced yields or (2) apply pesticide applications to control the additional damage from the pest which will result in increased costs.

TABLE 4

Estimated Shipments in Fresh Fruits and Vegetables from California[a]

	California production	Utilized fresh	Production processed	Fresh shipment from California
	tons			
Apples	315,000	152,500	162,500	68,283
Apricots	95,000	20,600	74,400	19,043
Avocados	178,000	178,000	0	155,066
Bell peppers	199,460	119,676	79,784	107,708
Cherries, sweet	26,000	19,500	6,500	12,280
Dates	21,000	21,000	0	18,735
Figs	46,500	1,500	45,000	1,358
Grapefruits	291,850	203,500	88,350	108,648
Grapes	5,240,000	766,000	4,474,000	661,238
Kiwis	31,000	29,100	0	27,319
Lemons	646,000	383,800	262,200	347,983
Mandarins (tang.)	78,375	57,150	21,225	40,020
Oranges	2,205,000	1,545,000	660,000	1,333,494
Nectarines	200,000	199,000	1,000	177,340
Peaches	769,000	160,000	574,000	87,516
Pears	303,000	75,000	228,000	31,113
Plums	216,000	216,000	0	191,084
Tomatoes, fresh	445,300	445,300	0	193,305

[a]California fresh apple shipments are estimated by subtracting fresh arrivals in California from California consumption of fresh apples and then subtracting this result from California production utilized for fresh market.

Sources:

California Fruit and Nut Statistics (1979-1988).

California Vegetable Crops, Acreage, Production, & Value (1979-1988).

Economic Research Service, USDA (1989a, b).

these treatments are effective, research indicates that product losses would occur due to shortened shelf life, deterioration of quality, and other physical damage to the fruit brought on by the treatments.

For purposes of this study, it is assumed that all fresh produce that is shipped out of California will be subject to quarantine treatment. Upon the establishment of Medfly on a statewide basis, quarantine treatments are likely to be required for shipment out of state irrespective of the field treatment involved.

Quarantine treatment ideally should take place at the packing facility to minimize the transportation and handling of the fruit. However, the time and location of treatment will vary depending on the characteristics of the fruit, treatment to be used, and location of the treatment facility. This chapter is not concerned with the exact details of how the treatment will take place, only that it will and at a cost.

While the use of methyl bromide is approved, cold treatment is preferred because of toxic effects and subsequent fruit damage. Citrus fruits are in this category. In addition, cold treatment can take place while the fruit is being shipped in containers. USDA-APHIS must certify the container, and the importing country must allow this method to be used. Japan has been especially difficult in allowing cold treatment to be used in transit and has generally insisted that the treatment take place before the product is shipped.

In order to determine the costs of complying with the quarantine of California products, the amounts of product affected and the per unit costs of treating them must be estimated. Table 4 presents estimates of affected products that are shipped out of California.

This table was constructed to determine California consumption using per capita consumption data developed by the USDA. After subtracting the amount of product going to the processing production, the difference was determined to be the amount of fresh product shipped from California and subject to quarantine restrictions.

TABLE 5

Estimated Costs of Quarantine Treatment for Medfly

	Treatment costs	Treatment damage	Treatment loss	Total treatment cost
	dollars	percent	dollars	dollars
Apples, all	1,365,660	2.00	404,235	1,769,895
Apricots	380,860	2.50	148,817	529,677
Avocados	3,101,320	2.00	3,814,624	6,915,944
Bell peppers	2,154,160	2.00	833,271	2,987,431
Cherries, sweet	245,600	.00	0	245,600
Dates	374,700	2.00	324,116	698,816
Figs	27,160	2.00	9,234	36,394
Grapes	13,224,760	2.00	4,872,134	18,096,894
Grapefruits	5,432,400	2.00	410,452	5,842,852
Kiwis	1,365,950	2.00	399,851	1,765,801
Lemons, fresh	17,399,150	2.00	3,282,029	20,681,179
Mandarins (tang.)	2,001,000	2.00	301,976	2,302,976
Oranges	66,674,700	2.00	4,938,330	71,613,030
Nectarines	3,546,800	5.00	3,515,322	7,062,122
Peaches	1,750,320	2.50	857,657	2,607,977
Pears	622,260	2.00	194,694	816,954
Plums, fresh	3,821,680	2.50	2,126,056	5,947,736
Tomatoes, fresh	3,866,100	2.00	1,844,594	5,710,694
TOTAL	127,354,580		28,277,392	155,631,972

No distinction is made between a product shipped from California for export and that for domestic consumption in other states.

The cost for postharvest quarantine treatment varies according to the treatment used. Not all commodities can be treated with methyl bromide. Commodities that cannot will have to use the cold treatment or vapor heat treatment. In order to determine what the costs of these various treatments are, various industry personnel were surveyed. Based upon the information received, fumigation treatment costs are estimated to be at the rate of 1 cent per pound of product treated while cold treatment costs are at the rate of 2.5 cents per pound of product treated. Products are being treated using the vapor heat treatment in Hawaii; but, as in the case of fumigation in California, where a number of commodities are already being treated, costs were not readily available. Hence, a rate of 1 cent per pound was assumed for those products treated with the vapor heat treatment. It is likely to be higher given that it is a relatively new technology, and there are still many aspects to be learned regarding its application.

The results of applying these rates to the various commodities involved are found in Table 5. In this table, all of the crops were assumed to be treated with methyl bromide according to the USDA-APHIS Quarantine Treatment Manual except for oranges, mandarin oranges, lemons, grapefruits, and kiwis which were assumed to be treated via the cold treatment method. The reason for this assumption came about in discussions with industry personnel who stated that methyl bromide treatment was unsuitable for these crops and would cause too much damage. Bell peppers were assumed to use the approved vapor heat treatment which is the only option for them.

In addition to the costs of quarantine treatment, certain losses in damage to the fruit can be expected. Since 1981, a number of research studies have been conducted, particularly for the effect that methyl bromide has on various commodities. These studies were conducted by the USDA Agricultural Research Service and the

A second scenario involves the impacts that would take place if selective embargoes were placed on out-of-state shipments from California. An example of this scenario is if Japan or a state such as Florida refuses California produce under any condition. An analysis under this scenario would then have to take into consideration the revenues given up under the embargo as well as the gains in revenues by redistributing the volume in other markets.

The assessment of market impact under the scenarios described above involves the effects that take place when changes in prices and quantity occur in a market. In order to appropriately analyze the changes that might take place, price elasticity of demand or price flexibility measures must be available or calculated. The condition of the market as measured by these instruments is crucial to estimating potential impacts. For example, an inelastic demand for a commodity would result in less total revenue returned to a producer if additional quantities are sold. Conversely, total revenue would increase if less quantities are sold. Under a condition where the market has an elastic demand, the reverse impact in total revenue would take place.

A search of published works was conducted for these measures. Appropriate price flexibility measurements were found for apples, apricots, cherries, grapes, lemons, oranges, nectarines, peaches, pears, and plums (see Nuckton, 1978). The price flexibilities for these crops are for prices at the farm level and were calculated from annual prices for the period 1947-1970. While measurements based on a more current price series would have been preferable, these price flexibilities were judged to be adequate for some limited analysis in this report. No elasticities or flexibilities were found for the f.o.b. or retail level that were judged suitable. A review of these price flexibilities suggests that most of the crops have the characteristic of an elastic demand at the farm level with the exception of lemons and plums.

As a result of previous estimates of impact of the Medfly in this study, two estimates of market impacts can be made. One is derived from Table 5 in which

University of California. In Table 5 a loss factor of 2 percent was assumed if research reports did not indicate otherwise. This table shows that quarantine treatment costs are estimated to be $127.3 million. Another $28.3 million is estimated due to damage from treatment for a total estimated cost of $155.6 million.

In addition to the costs of quarantine, additional costs are required in constructing and upgrading facilities and increased transportation costs. In particular, additional treatment facilities for both cold storage and fumigation will likely have to be constructed. The cost of these facilities is estimated to be over $100 million.[6]

Packing and shipping facilities would also have to be upgraded in order to provide work areas secure from Medfly intrusion. A construction cost of $10.713 million is estimated.[7]

It is likely that increased costs of transportation would occur in order to treat fruit under quarantine. Since it is apparent that most of the fumigation with methyl bromide will be done on site at the packing and shipping facility, especially if tarps are used, it is presumed that only fruit needing cold treatment will require additional transportation. This annual cost is estimated to be $8.1 million.[8]

V. Market Impact

At least two scenarios emerge with respect to market impacts. One scenario involves a thesis that current shipments of produce from California would continue as long as quarantine treatments are made and certified. This scenario reflects the assumptions contained in this chapter and involves an analysis of impact of increased prices or decreased volumes in the market.

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[6]For details, see the Medfly update by Siebert and Pradhan (1990).

[7]This estimate is based on applying material cost and labor indexes found in U. S. Department of Commerce (1990). For details, see Siebert and Pradhan (1990).

[8]For details, see Siebert and Pradhan (1990).

TABLE 6

Calculation of Market Losses Due to Medfly Using Average Price Increases

	1989 Value	Price flexibility	Price change	Quantity change	Estimated value
	thousand dollars		percent	percent	thousand dollars
Apples	96,200	-.363	.04	-.110	89,023
Apricots	35,948	-.465	.09	-.193	31,599
Cherries	24,418	-.467	.06	-.128	22,558
Grapes	264,150	-.981	.08	-.081	262,017
Lemons	184,576	-1.690	.50	-.295	194,952
Oranges	408,289	-.886	.50	-.564	266,816
Nectarines	79,290	-.629	.04	-.063	77,218
Peaches	63,504	-.364	.06	-.164	56,218
Pears	25,406	-.609	.07	-.114	24,060
Plums	94,796	-1.133	.06	-.052	95,162
TOTAL	1,329,372				1,119,624

various losses from quarantine treatment of the Medfly were estimated. If these losses are applied to the price flexibilities for the crops identified, a slight loss in market revenue of $4 million would occur. If yield losses occur that are higher than the ones identified, the loss in revenue to the farm sector could be higher. This estimate, of course, assumes that current patterns of shipments would continue to occur with appropriate quarantine treatments.

The second estimate is based on data from Table 3 which display the amount of pest control costs as a percent of the farm value of the crops considered in this study. If it is assumed that prices increase on an average between the high and low figures given, then quantity demanded will decrease appropriately. For the 10 crops identified, this action will result in a revenue decrease of $209 million to the farm sector. Calculations for the high and low ranges of price increase results in a range of $265 million to $165 million in lost revenues. The price flexibilities and calculations that arrive at these figures are found in Table 6.

Another question that arises with respect to market impact is: What happens if export markets are eliminated or decreased due to embargoes? Much of California agricultural exports go to the Pacific Rim countries. Nearly $500 million is exported to Japan and other Asian countries in the Pacific Rim. Lemons, oranges, and grapefruit account for nearly $260 million of this total. Cherries, table grapes, avocados, kiwis, peaches, and plums account for a combined total of over $100 million. Especially critical in exports to the Pacific Rim is Japan which is a premium market that emphasizes quality and has the available income to purchase California agricultural products that meet its specifications.

The Japanese market is one in which hard fought gains have been made through negotiations. It has been reported by trade experts that, if Japan goes, so will the other Asian countries. If these export markets are lost or reduced, the impact on the California farm economy will depend on a number of factors, primarily those which

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relate to alternative markets. The gains in those markets will have to be compared to the losses in the markets which are lost. In order to appropriately estimate the impact of a Japanese embargo (and others like it) on California produce, elasticities of demand are needed for the markets that will receive the additional quantities that occur as a result of the embargo. At the current time, adequate data and economic measures do not exist in order to carry out a reliable analysis. However, in general, it can be stated that a Japanese embargo will be costly to those industries affected by it. How costly will depend on how much additional revenues can be generated by moving the embargoed quantities into other markets.

The final note to make about market impact is the timing of the effects. It will take a number of years for market adjustments to take place before a new equilibrium is reached. For example, in the first year of Medfly establishment, the costs that have been identified in this report will likely fall mostly on the producer and packer. If these costs cannot be absorbed by the producer/packer, price increases will be attempted in subsequent years. Less efficient producers/packers will be forced out of the market if they are not able to compete with higher costs, and subsequent decreases in quantities due to this elimination will result in higher prices. With higher prices will come an expansion of productive capacity (either in California or some other competing area) until at some point the market reaches a new equilibrium.

In summary, the limited market impact analysis carried out in this section suggests that initially it would be difficult to recapture losses incurred by producers and packer/shippers through the marketplace. Because of the nature of demand for the products considered, losses due to decreases in quantities packed or increased costs due to pesticide applications and quarantine control will actually result in less revenue (not more) for the producers during the first phase of adjustments in the market.

9

ENVIRONMENTAL REGULATIONS AND THE COTTON INDUSTRY*

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I. Introduction

Pest management practices in California's food and fiber production system are in transition. Dominated by synthetic organic pesticides in the two decades immediately following World War II, pest control programs recommended by University of California researchers in recent years have incorporated a variety of strategies which have resulted in more ecologically balanced "integrated" approaches to managing pests in many of California's major crops. Despite reductions in pesticide usage which have been realized through integrated systems, the public now perceives that pesticides constitute an involuntary and unacceptable threat to food safety, the environment, and the health of farm workers. This concern has led to a number of legislative and public initiatives restricting pesticide use. Further restrictions on pesticide availability have resulted from voluntary suspensions by manufacturers and by the development of pesticide resistance in pest populations. A new development is the strong possibility that bankers and creditors may restrict credit to firms that are using or have used certain classes of toxic chemicals. At the same time, bankers and

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the target pest, alternative pesticides, alternative nonchemical controls, constraints to the rapid adoption of some of these alternatives, and the research agenda to develop effective alternatives. A number of conventional pesticides will remain available because they will be supported by their registrants on specific crops, and will meet health and environmental requirements for continued use. Several management practices that are not now used as extensively as in the past may again see greater use. Examples include crop-free periods, extensive rotations, and various sanitation practices such as removal of crop residues following harvest. Development and release of new pest-resistant cultivars will continue to be an important alternative to pesticide use.

Many factors will determine whether these and other available and emerging nonchemical alternatives will be practical for growers, i.e., compatibility with current production practices, ability to yield products acceptable to the marketplace, and capability to produce a profitable return. In these terms, the practicality of a specific alternative may be debatable. Some alternatives which appear promising in some locations have not been adequately developed or tested. We simply do not know their impacts on yields, crop quality, costs, labor-management requirements, equipment requirements, and profitability under the diverse growing conditions found in California.

II. The Complexity of Estimating Economic Impacts

The impending pesticide regulations could have far-reaching economic impacts affecting consumer prices, grower incomes, California's share of the market for specific commodities, and the overall economic growth of the state's economy. Some of the economic impacts would likely be negative, while others would be positive. While an understanding of the impacts are limited at this time, it may be useful to describe the general direction and scope of changes that might occur.

creditors may also be averse to the risk associated with untested alternative methods and may restrict credit to firms who adopt relatively conservative approaches to previously untested alternatives to pest control.

All of these and other factors are propelling farmers and the University of California to accelerate efforts to find productive and profitable alternative approaches for pest control in crop and animal production. Understandably, many growers fear that alternatives will be either unavailable, more costly, or less effective than conventional pesticides. They believe that many government and industry policies will make the transition to new alternatives difficult, if not impractical, or even financially disastrous to many growers. Notable examples include restrictive cosmetic standards for fresh fruits and vegetables and federal price support programs which financially penalize farmers for adopting crop rotations and other practices that would greatly reduce the need for herbicides and other pesticides. Most of these policies were enacted when pesticide use was not subject to such intense public concern.

What chemical and nonchemical substitutes will be available to replace the pesticides facing restriction under current and proposed regulations? A report in the July-August, 1990, issue of *California Agriculture* contains a preliminary summary of a study on alternatives to pesticides which is being done by pest management specialists within the University of California's Division of Agriculture and Natural Resources (DANR). The study has identified those pesticides that are potential candidates for removal from use as a result of two existing laws and an initiative measure slated for the November, 1990, ballot, the California Environmental Protection Act of 1990 (EPA 1990). These laws are the California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65) and the Federal Insecticide, Fungicide, and Rodenticide Act as amended in 1988 (FIFRA 1988). The study includes a statewide survey of Extension farm advisors and specialists who contributed to a large data base. Data for each crop and pesticide combination include soon the pesticides would be phased out. Some compounds could be withdrawn immediately by their registrants under FIFRA or more gradually as chemicals are phased out over 5 to 13 years under the proposed EPA 1990.

As a very simplified point of departure for the discussion, Figure 1 depicts hypothetical supply (S) and demand (D) curves for a farm commodity, where the theoretical equilibrium price and quantity is given by P_E and Q_E, respectively. A widely quoted analysis of the impact of the removal of pesticides from use has assumed that all the targeted pesticides would be banned immediately (Knutson et al., 1990; GRC Economics, 1990). While this is a very unrealistic assumption, if this was to occur, the effect would be a supply curve that looks like t_0. That is, prices would increase dramatically and the quantity of the commodity marketed would decrease dramatically. On the other hand, if the targeted pesticides were those subject to the 5-13 year phase-in contingency, a different scenario is demonstrated in Figure 1. Theoretically, with high prices and a relative shortage of cotton, producers and scientists will be induced to come up with new alternatives to replace the phased out pesticides. This is the well-known economic concept of induced innovation (Ruttan, 1982). As time goes by, ($t_0 \rightarrow t_1 \ldots t_{12}$) sufficient innovations are discovered that allow supply to be expanded, thus gradually reducing the price toward the original equilibrium price and quantity produced.

III. Some Theoretical Impacts on California's Cotton Industry

While this is a relatively straightforward theoretical result, the realities of the cotton industry are much more complex than this, and many key parameters are unknown. For example, the 1990 Farm Bill may contain language that will enable cotton growers to adopt crop rotations with little or no loss of price support payments or acreage base. The rate at which practical alternatives to the targeted pesticides will become available is also unknown. Likewise, the profitability of other crops that

The economic impacts on farm production, costs, and profits will occur at several levels. The impact that will be felt first may be a change in the costs and effectiveness of pest control. The outcome will vary from one location to another, depending on climate, soil conditions, populations of natural enemies, and other factors that vary from field to field and from one area of the state to another. Next, the impact will be felt at the level of the market for farm commodities, as growers change their methods of pest control and adjust their mix of crops and livestock enterprises grown in response to expected changes in costs, yields, prices, and risks. If no practical alternatives to the withdrawn pesticides are available, crop yields and quality may decline due to weed pressure, defoliation by insects and mites, root impairment by nematodes and disease, or other pest damage. Costs of pest control may increase if available pesticides or cultural practices turn out to be more expensive than the withdrawn pesticides. California's share of some commodity markets may decline if more severe pesticide regulations are adopted here than in competing states and nations. And since different commodities and locations will be affected in different degrees, significant structural changes are likely to take place in California agriculture as a result of more restrictive pesticide regulations. The speed at which growers, researchers, and industry are able to come up with practical alternatives will determine the future shape and direction of California agriculture.

Analysis of the University of California data base described above will shed considerable light on the subject but, because of the many unknowns, will not provide a complete set of answers. Since there are no historical precedents for situations of this magnitude, many important outcomes are difficult to predict. The best we can do at present is speculate on the likely outcomes based on past experience, logic, and economic theory.

In considering some of the theoretical impacts of the removal of certain pesticides from use by the cotton industry, one of the important considerations is how might be produced on cotton farms will undoubtedly change as a new array of commodity prices and alternative production methods emerge. Given all these and many other imponderables in the system, it becomes clear that it is a difficult to predict reliably what is likely to occur while the process of innovation and adjustment to the new regulations is occurring. One possibility is that, while California's prices are high, other states and nations that will not experience the same phase out of pesticides would compete more vigorously with California cotton on the basis of lower prices, thereby capturing a larger share of the market and, thus, undermining the industry's economic viability. A recent study by Lichtenberg, Zilberman, and Ellis (1988) shows that a 1 percent increase in the cost of producing cotton in California would reduce cotton production in California by 0.36 percent or 14,000 bales. Simultaneously, production would increase in the Southeast by 0.38 percent (or 2,000 bales), in the Delta by 0.21 percent (or 6,000 bales), and in the Plains states by 0.05 percent (or 2,000 bales). This would result in a 12 percent increase in price (or 7 cents per pound). Additionally, total export demand would fall by 0.01 percent (or 600 bales) and total domestic demand would decrease by 0.05 percent (or 3,000 bales).

Decreases in yield and/or quality may also occur as a result of a phasing out of pesticides. According to Lichtenberg, Zilberman, and Ellis, a 1 percent decrease in cotton yields in California would reduce cotton production in California by 0.81 percent (or 32,000 bales). While other regions of the United States would increase production in response to California's decrease, resulting in a net U. S. decrease in production of 0.07 percent (or 8,000 bales), prices would increase 27 percent or 16 cents per pound.

The impacts of these changes in production, demand, and prices are relatively complex. According to Lichtenberg, Zilberman, and Ellis, while there would be a relative change in the distribution of revenues away from California, export revenues would, in fact, increase. More importantly perhaps, because of the relative inelastic

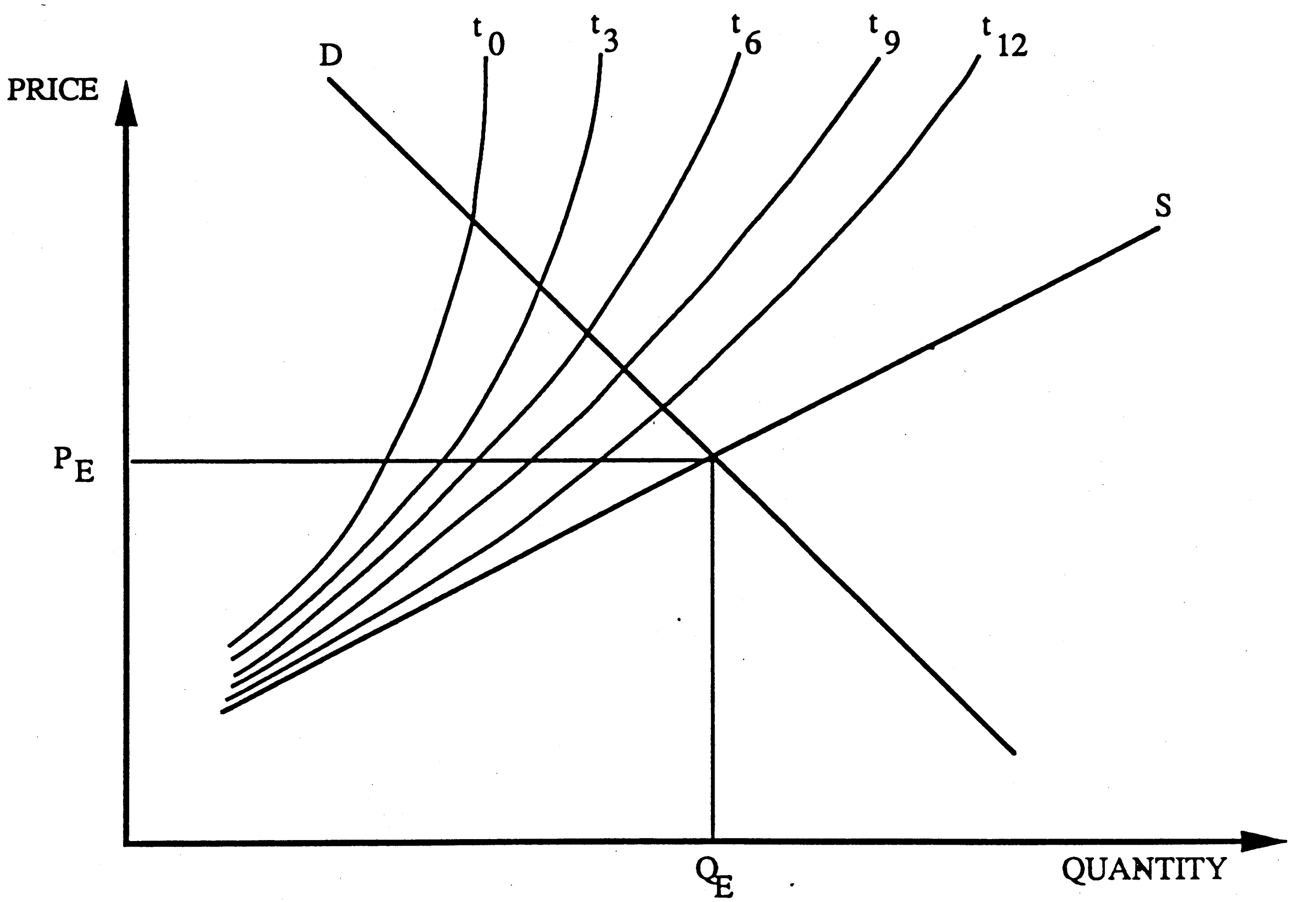

Figure 1

nonfarm sector of the state's economy. More importantly, however, is that, while consumers may spend an *average* of 12 percent of their total incomes on food, some low-income people may spend up to 50 percent of their income on food. For these people, a significant increase in food prices may be almost intolerable. These effects, while impossible to measure or anticipate accurately, must, nonetheless, be taken into account in the discussions of the total costs and benefits of the removal of some pesticides.

The bottom line of this theoretical examination of the potential impacts of the use of pest management alternatives on the cotton industry is that it is vital to accelerate the development and adoption of as many practical new innovations as possible. Examination of the University of California data base described above will provide valuable insights by identifying some of the potential "best" alternatives to the banned pesticides and by also identifying where large gaps are likely to occur (i.e., anticipated large increases in cost of production). Research and extension resources will be focused to try to come up with economically viable and environmentally safe alternatives.

In summary, the road ahead will not be easy. Development of alternatives may be expensive and may require an accelerated research and development program. To succeed, there must be a cooperative effort among producers, researchers, and extension personnel. The challenge of a healthier environment, cleaner water resources, and increased food safety and nutrition is one that will impact all of agriculture, the entire state of the nation. We all need to increase our cooperative efforts to communicate and implement new innovative techniques. No one will be exempt. By pulling together, we can meet this challenge and enter the new millennium stronger than ever before.

demand for cotton, prices will increase more than the proportionate decrease in quantity demanded, resulting in higher gross incomes to cotton producers.

Of course, if market prices of cotton rise relatively more than the prices of competing materials (notably synthetics and wool), consumers and manufacturers could reduce their utilization of cotton. But this could also be offset by shifts in demand due to increases in consumer income. These effects could cause substantial structural changes in the California cotton industry. On the other hand, history has shown that California cotton producers are very resilient, adapting to crises with many creative and practical innovations. To the extent that they are able to succeed, California cotton growers will continue to compete on U. S. and international markets.

IV. Off-Farm Impacts

Some of the factors that are difficult to quantify but must be taken into account in any economic analysis are those associated with the costs and benefits of the proposed pesticide regulations. For example, farm worker safety may be enhanced. However, if California agriculture declines as a result of the disproportionately more severe pesticide regulations faced by the state's growers, the number of farm jobs may also decline. Offsetting this factor is the possibility that some of the alternative pest control strategies may require additional cultivation to control weeds and, for example, more intensive scouting to control insects.

Other potential benefits include reduced pesticide contamination of the environment and cleaner water resources. Both of these factors would have a positive economic impact.

On the negative side, if food prices increase as a result of these environmental regulations (and this outcome is by no means clear), then consumers may have to spend more of their incomes on food, thereby reducing purchasing power and demand for nonfood items. This factor would tend to reduce employment and incomes in the

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PESTICIDE REGULATION: PROBLEMS IN TRADING OFF ECONOMIC BENEFITS AGAINST HEALTH RISKS

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By federal law, chemical pesticides are supposed to be regulated so that their economic benefits outweigh any adverse effects on human health or the environment. In practice, weighing the positive and negative effects of almost any pesticide proves to be a complex and uncertain matter. In order to examine some of the issues involved in weighing society's trade-offs from pesticides, a study was undertaken of cotton pest problems in the Imperial Valley. The goal was to develop policy recommendations for pesticide regulation which successfully take into account both the economic contribution of pesticides to the region's cotton production and the adverse effects caused by introducing pesticides into the environment. A number of interesting issues came to light in the course of the study which have obvious application to other crop-producing regions as well. These issues include the economics of secondary pests and of genetic resistance and the overall problem of finding a framework for comparing economic benefits with health risks.

I. Secondary Pests

A large number of important pests in the United States and worldwide are considered to be "induced secondary" pests, meaning that they were not major problems originally but have become so as a result of particular growing practices. In

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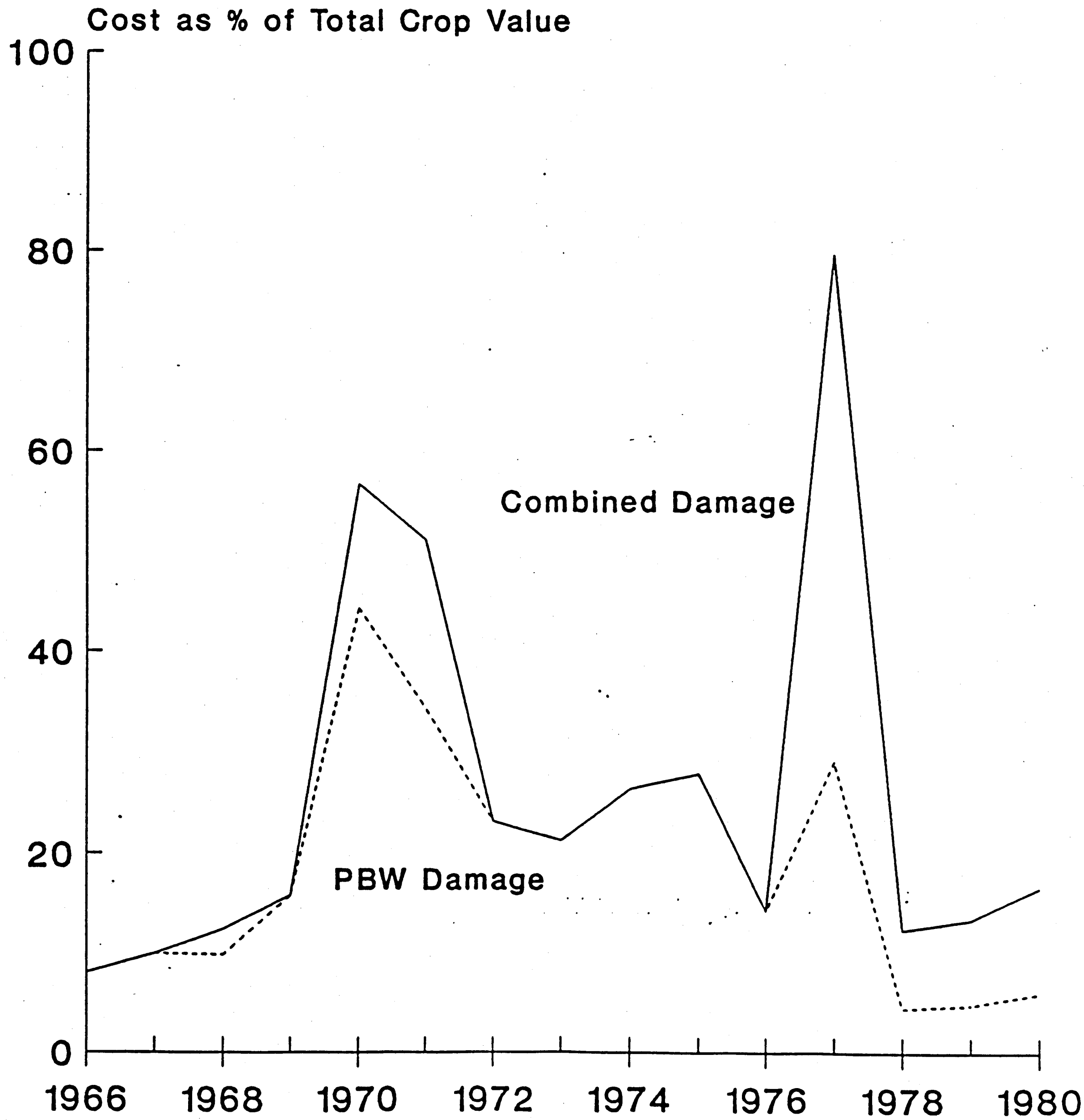
History of Pink Bollworm and Secondary Pest Damage in Imperial Valley



Source: Burrows et al. (1982)

Figure 1

particular, the use of agricultural inputs, such as pesticide or even water, may cause the elevation of previously rather innocuous species into major agricultural threats.

In the Imperial Valley, numerous pest problems have afflicted cotton production, but the outstanding pest problem since the late 1960s has been pink bollworm. If not successfully treated, pink bollworm can cause from 50 percent to 80 percent of yield reductions. Several generations of chemical pesticides, including carbamates, organophosphates, and synthetic pyrethroids, were used against pink bollworm with varying degrees of success.

Unfortunately, chemical controls targeted at pink bollworm also destroyed various natural predators which, in turn, permitted serious secondary pest infestations to develop. The extent of the damage caused by pink bollworm and associated secondary pests (primarily tobacco budworm) over a 15-year period is shown in Figure 1. By itself, pink bollworm caused annual losses throughout the region—from 4 percent to 44 percent of total crop value. When the damage caused by secondary pests is also included, total damage was from 8 percent to 80 percent of total crop value.

II. Impact of Secondary Pests on Pesticide Regulation

Pesticide regulators need to determine in dollar terms a pesticide's contribution to the agricultural economy of crop-producing regions where it is used. Ideally, one would like to know by how much the region's net revenue from farming would be reduced if the chemical were to be banned or if its use were to be restricted by government regulation. These calculations are especially tricky to make for the many chemicals which are used primarily to combat secondary pests. In some cases, the best solution to a secondary pest problem may be not a frontal attack with chemical pesticide but, rather, a change in the way the *primary* pest is managed because the

TABLE 1

Difference in Profit Per Acre for Early and Long-Season Cotton

Item		Early season		Long season
		dollars		
Crop value per acre (lint)		$968.51		$1,101.12
Costs per acre				
Insect control	$43.05		$127.68	
Bale tax	1.67		1.91	
Aflatoxin	8.91		10.12	
Harvest	143.24		162.86	
Loan charges	3.35		9.14	
Marginal irrigation cost	- -		18.23	
Margarinal fertilizer cost	- -		21.10	
Marginal defoliation cost	- -		4.27	
Partial variable costs per acre		$200.22		$355.31
Partial profits per acre		$768.29		$745.81
Profit difference (in favor of early termination) = $22.48				

Source: Burrows et. al (1984).

secondary pest problem, by definition, results from a disruption of the local ecosystem, usually as a consequence of pesticide use.

In the Imperial Valley, just such a situation appears to have been the case. An alternative means of pink bollworm control exists, namely, the adoption of a shortened growing season. This cultural practice prevents pink bollworm from overwintering and greatly reduces the number of emergent larvae the following spring. Several studies conducted during the mid-1980s concluded that, although it results in a total yield reduction, the shortened growing season is more profitable because of major cost savings for pest control measures which are no longer required (Table 1). Early season termination of the growing season causes crop value per acre to decrease from $1,101.12 to $968.51. At the same time, however, the cost of insect control decreases from $127.68 to $43.05, and there are additional cost reductions for activities which no longer must be conducted in the field during the later part of the growing season. The net result is that, even though total cotton yield is smaller, net income per acre increases by $22.48.

In spite of such evidence, long season cotton production continued in Imperial Valley for a number of years. In this context, imagine a state or federal pesticide regulator attempting to determine the true economic value of a pesticide which is used exclusively to control secondary pests. Conventional wisdom would simply look at how much crop would be saved from secondary pests when the pesticide is used. The value of the pesticide would simply be calculated as the market value of the yield thus preserved, minus the cost of the chemical. Given the above analysis, however, it can be argued more convincingly that the true value of the pesticide in controlling secondary pests is *zero*, i.e., if the primary pest (pink bollworm) is controlled in the most profitable way, through adoption of the shortened growing season, then large quantities of pesticides are not needed against pink bollworm. This, in turn, means that natural enemies are not destroyed, and induced secondary pest problems do not chemical toxin, nor are they any longer controlled by the pesticide, because they have developed genetically resistant strains. The result can be devastating economic losses, *even though the primary pest is still being successfully controlled.*

IV. Resistance and Regulation

For the pesticide regulator who is required to calculate economic benefits for each chemical pesticide, resistance creates a sort of moving target. We may be able to estimate the dollar value of the pesticide this year, but what will be its value in three to five years when resistance may have appeared in one or more species and reduced its efficacy? It is even possible that in some cases a region's agriculture might be better off *not* introducing an effective pesticide because in the long run it will result in a disrupted agricultural ecosystem with rampant resistance problems and no natural enemies. Should the regulator calculate economic benefits on a short-term basis or attempt to predict the longer-term pattern?

In the Imperial Valley, cotton was one of the economic benefits claimed for pesticide chlordimeform (Galecron, Fundal) during the mid-1980s because it would slow the development of secondary pest resistance to the synthetic pyrethroids, which were being relied on to control simultaneously both pink bollworm (the primary pest) and tobacco budworm (a key secondary pest). If true, this resistance-retarding effect would give chlordimeform substantial economic value. Unfortunately, there is no known way to predict such effects accurately. We can, however, examine the economic value of resistance retardation under hypothetical conditions. Figure 2 shows the falling efficacy of the pyrethroid if resistance were to increase by 25 percent per year. The toxicity of the pyrethroid to tobacco budworm falls from 85 percent mortality initially to about 25 percent in year 5 and only 10 percent in year 10. If we hypothesize that chlordimeform could slow the development of resistance by one-half (12.5 percent per year), the percentage of pests killed would be much higher—about arise. Therefore, the economically efficient solution to the overall pest problem does not require the use of pesticides targeted at secondary pests—they are simply not needed.

III. Pest Resistance

Resistance to pesticides is one of the critical pest control problems facing agricultural producers. A chemical which initially provides satisfactory control of a pest often loses its efficacy, sometimes only within a few years of commercial distribution. The combined effects of pest resistance and regulatory restrictions may cause growers to lose a substantial portion of their pest control "arsenal," leaving them with fewer tools available for responding to routine pest control problems or severe infestations.

Interestingly, it is often secondary pests rather than primary pests which may more easily adapt to chemical pesticides and become resistant. In cotton, two Heliothis species—tobacco budworm and cotton bollworm—have displayed this tendency in diverse geographical regions. The widely acknowledged Integrated Pest Management (IPM) program for Texas high plains cotton—which has successfully eliminated most pesticide use in that region—got its impetus from repeated failures to control secondary pests by chemical means.

A common scenario for pest control programs involving broad-spectrum chemical pesticides—a scenario which has appeared in numerous crops and regions—is the following: a chemical pesticide is successfully introduced to control a target pest (the "primary" pest), and for a period of time this control is also successful against a range of other pests ("secondary" pests) as well. Crop damage is reduced, and the region enjoys increased profits. After a few years, however, one or more of the secondary pests become resistant to pesticides. These pests are no longer controlled by natural enemies, which have been destroyed by the broad-spectrum

50 percent in year 5 and 30 percent in year 10. The useful life of the pyrethroid material would be extended by several years.

The resulting savings to growers was calculated using a plant-and-pest simulation model which captures the effects of annual variations in weather patterns. Figure 3 shows total pest damage—both with and without the use of chlordimeform to slow resistance. Over the first five-year period, the net value of the resistance-retarding chemical (discounted at 5 percent per year) has been calculated to be $181 per acre. This is a substantial sum, which would be important in calculating economic benefits for the chemical. However, the alleged effect on resistance has never been scientifically verified.

V. Weighing Profits Against Cancer Risks

In spite of many complexities like those already mentioned, regulatory agencies are required to evaluate economic benefits from pesticides. In addition, they must evaluate risks to public health and the environment and attempt to write regulations which insure that each pesticide does more good than harm.

How should economic benefits and toxic hazards, e.g., human cancer risks—be weighed and compared? In many situations it is customary to restrict health risks from a toxic material to be less than a specified standard, such as one excess cancer per million people exposed. According to such a standard, a pesticide which causes excess cancer risk to consumers, farmers, or farm workers of more than one chance in a million would be restricted, by various methods up to and including a ban, until the risk is brought down to the designated safety standard.

But how is the risk estimate itself determined? For carcinogenic materials, it is usually derived from studies of laboratory animals fed relatively high doses of the chemical. To determine human risk, assumptions must be made about how to extrapolate from small animals to humans and from the effects of large doses to the

Increasing Resistance Over Time If Chlordimeform Retards Resistance by 1/2, And Basic Rate of Increase is 25%

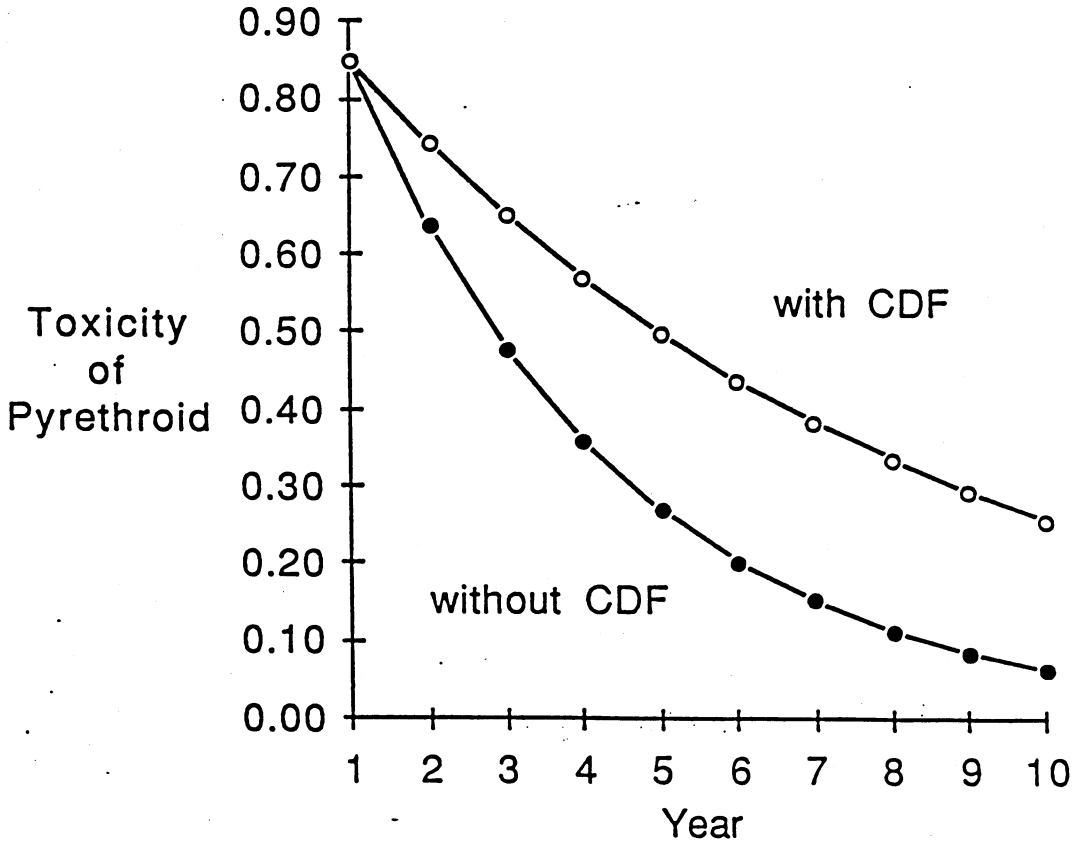


Figure 2

effects of much smaller doses of pesticide normally encountered in everyday life. To avoid underestimating human risk, the assumptions which are made intentionally err on the side of caution. As a result, official risk estimates may in many instances overestimate human risk. In some cases it becomes quite improbable that any individual would actually face a risk as high as the official estimate.

It has been suggested that health risk estimates could be made more accurate, without sacrificing caution, by formally acknowledging that the risk estimate does not, in fact, represent our "best guess" of the level of risk but instead a *conservative estimate* or upper confidence level. If the estimate is an upper 99 percent confidence level, for example, the implication is that we can be 99 percent certain that the true level of risk for any individual is less than the estimated value.

It should be emphasized that this is not how risk estimates are currently handled and reported. How would pesticide regulation be different if they were? Primarily, such a policy would result in more consistent regulatory decisions since decisions about different chemical pesticides, for example, could be based on risk estimates which are "equally conservative." This is currently not the case.

The point can best be made with an example. Chlordimeform is a relatively powerful carcinogen which has been withdrawn from registration by its manufacturers because there is strong evidence that it imposes undue cancer risks on those who work with it. Table 2 shows the risk factor estimates of the U. S. Environmental Protection Agency (EPA) used to measure cancer risk for chlordimeform. Animal potency is a measure of the chemical's power to cause cancer in laboratory animals which were fed high doses. Dermal absorption is the fraction of material on the skin which is assumed to be absorbed—about one-third. Years of employment involving the handling of this particular chemical is estimated at 35. Finally, annual exposure in milligrams per kilogram of body weight is estimated for three occupational categories—mixers/loaders, pilots, and flaggers.

Yield Losses Due to Insect Damage,
For Two Rates of Increase in Resistance

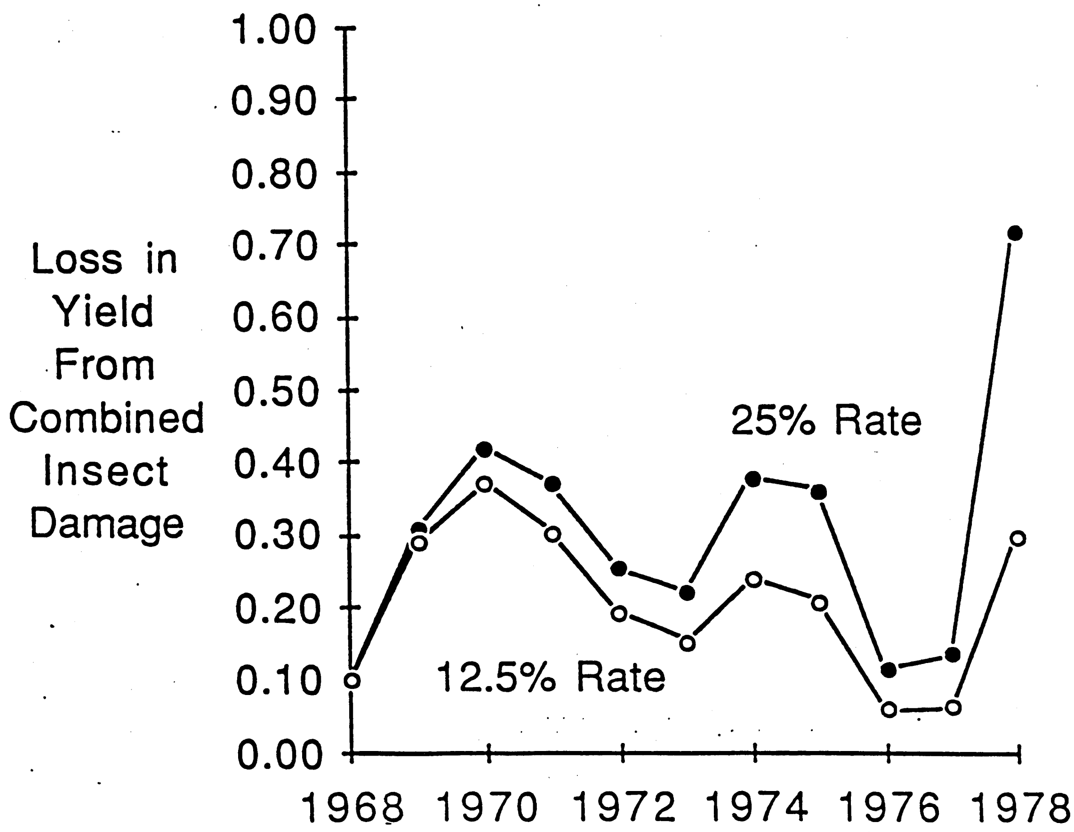


Figure 3

To arrive at its overall risk estimates, EPA typically multiplies a series of risk factor estimates such as these together. For example, for mixers/loaders (the occupational group with the highest probability of cancer), the risk factor calculation is 1.0 x .3 x 35.0 x 10.3, divided by a 70-year life span in days (70 x 365). The resulting values are shown at the bottom of Table 2. For chlordimeform, all risk estimates are on the order of one chance in a thousand (10^{-3}) or one chance in 10 thousand (10^{-4}) of contracting cancer as a result of exposure to chlordimeform. These values are much larger than the one chance in a million standard which is often used as a general guideline.

Keeping in mind, however, that all of the estimated values for the risk factors were chosen to be conservative, i.e., to err on the side of caution, it is possible to examine the effects of this conservatism on the final risk estimate. If it is assumed that each of EPA's risk factor estimates represents a 98 percent confidence level, it can be shown that the overall risk estimates at the bottom of Table 2 actually represent a 99.9 percent confidence level. Given this assumption, the data imply that we can be 99.9 percent certain that the true risks for each occupational group are less than those shown. This extremely conservative result stems directly from multiplying together the already conservative risk factor estimates.

It is not difficult to correct mathematically for the above effect. This has been done using a lognormal probability distribution. Results for the mixers/loaders occupational group are shown in Figure 4. The conventional estimate of risk is shown in Table 2—about 10^{-3} or one chance in a thousand. As the application rate of the pesticide falls, moving from right to left, risk declines. The probabilistic estimate is an upper 98 percent confidence interval for overall risk. Instead of one chance in one thousand, overall risk is estimated to be about one chance in 10 thousand or less, again falling as the pesticide application rate falls.

TABLE 2

EPA Risk Factor Estimates for Chlordimeform

Factor	
Animal potency	1.0
Dermal absorption	0.3
Years employed	35.0
Exposure (milligrams per kilogram per year)	
Mixers/loaders	10.3
Pilots	0.2
Flaggers	0.6
Lifetime cancer risk	
Mixers/loaders	4×10^{3}
Pilots	8×10^{5}
Flaggers	2×10^{4}

In both cases, risk estimates are conservative in the sense that a substantial margin of error has been built in to be sure that human health is adequately protected. The difference is that the 98 percent level of certainty is assigned to the overall risk estimate rather than to each of the risk factors individually. Since the number of risk factors used in various analyses is not always the same, this technique provides greater consistency from one analysis to another. If 98 percent is not considered a sufficient degree of certainty, it is a simple matter to generate estimates for 99 percent certainty or an even higher confidence level.

VI. Summary

Pest control issues for cotton in Imperial Valley have been used to illustrate some of the problems associated with regulation of pesticides. A rational pesticide policy, as well as federal law, requires that trade-offs between economic benefits and toxic hazards be systematically evaluated and weighed. Economic benefits can be extremely difficult to evaluate because of numerous biological complexities, including secondary pest infestations and pest resistance to pesticides. Environmental and health effects, particularly chronic health effects such as cancer, mutation, and birth defects, are also inherently difficult to evaluate because, short of a public health disaster, human data are practically nonexistent.

Several techniques have been described which can assist in rationalizing pesticide regulation. On the production side these include simulations which take into account biological complexities such as secondary pests and long-term calculations of economic benefits which account for the development of resistance leading to a relatively short life span for many pesticides. On the health side, it is necessary to deal objectively with the great uncertainty which surrounds estimates of chronic health risk. In spite of the difficulties, it is in society's best interests to undertake the weighing of costs and benefits in as scientific and objective a manner as possible in

Probabilistic and Conventional Health Risk Estimates

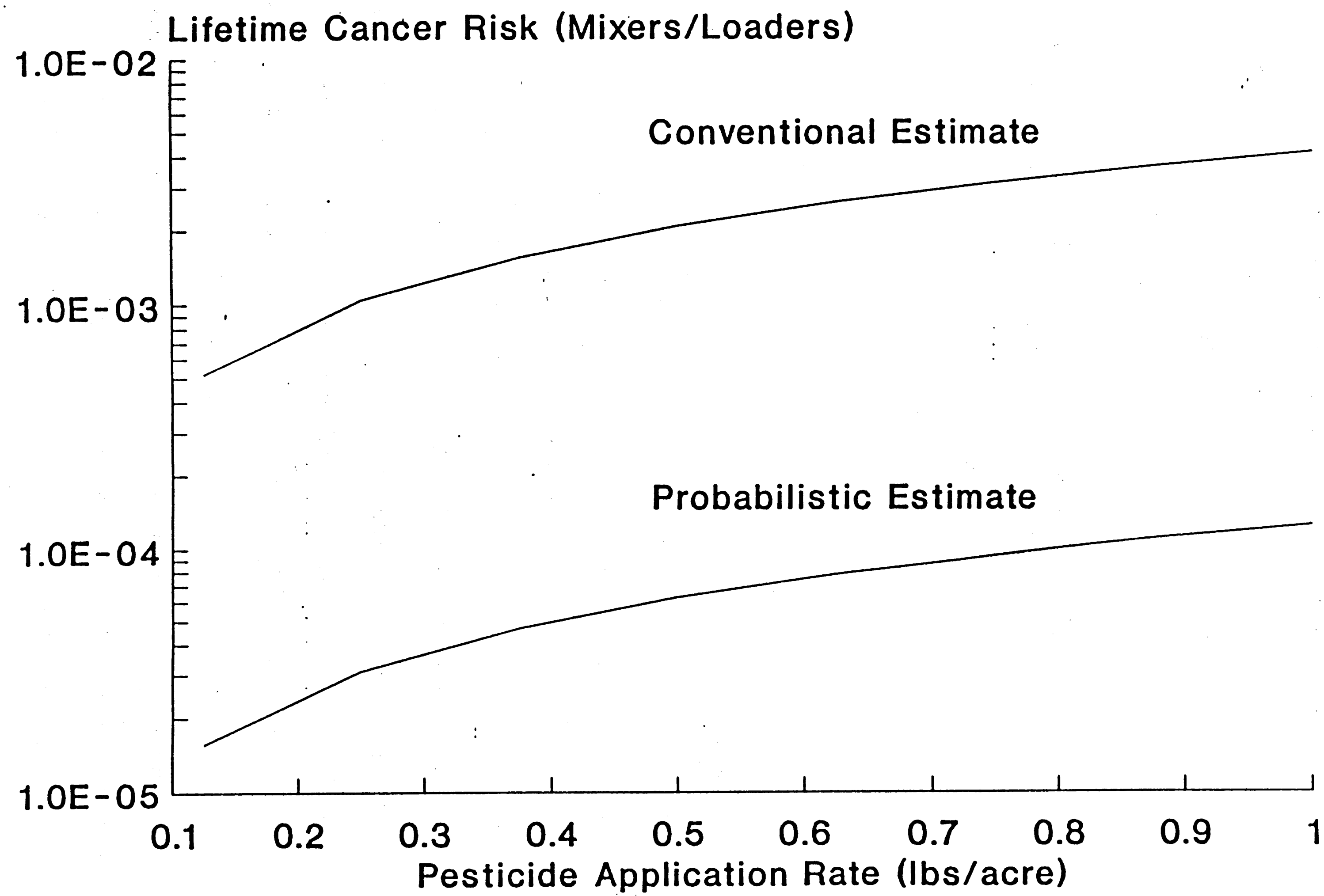


Figure 4

11

PESTICIDES, REENTRY REGULATION, AND FARM WORKER SAFETY

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Pesticides have become increasingly controversial in California and, indeed, throughout the nation. They have long been linked to ecological damage, including destruction of avian populations such as pelicans, bald eagles, and many other species. Over the past few years, U. S. Environmental Protection Agency (EPA) proposals for pesticide-use restrictions to protect endangered species have been the subject of fierce debate. During the late 1980s, the focus of public attention shifted to the risks to human health and safety associated with pesticides. Concern over pesticides in groundwater has prompted intense scrutiny of groundwater quality. The EPA and the U. S. Geological Survey have sampled a broad variety of wells at the national level, while the California State Department of Health Services continues to monitor drinking water wells at the state level. Concern over pesticide residues on foods erupted into public consciousness with the scare over Alar in apples and has remained intense. Recent surveys undertaken by the Food Marketing Institute indicate that food safety, especially pesticide residues, continues to be a major concern of consumers. Environmental groups in California have pushed for increasingly strict regulation of pesticides. The "Big Green" initiative currently on the order to avoid having regulatory outcomes be determined by the relative strengths of special interest groups.

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While food-borne residues appear to have the tightest hold on the public imagination at present, field worker and applicator safety issues are arguably the most pressing health and safety problems associated with pesticide use. This issue has also been the subject of intense discussion recently, as the EPA worked to issue new regulations on farm worker safety. The United Farm Workers of America has made pesticide exposure the centerpiece of their organizing campaigns in recent years.

One of the most commonly used methods for protecting field workers from exposure to toxic pesticides is to restrict entry into treated fields until enough of the residues degrade into nontoxic by-products. During the growing season, workers may be forbidden to work in treated fields for a period of time known as a reentry interval. Other regulations forbid harvest for a specific period of time after application of a pesticide; this time period, known as a preharvest interval, is set to protect harvest workers and also to allow food-borne residues to decay to an acceptably low level.

While the pesticides currently used are generally short-lived, the time required for residues to disappear completely is sufficiently long that reentry intervals based on zero-detectable residues would render farming impossible. Even relatively short reentry intervals may create significant problems for scheduling farming operations. Since absolute safety cannot reasonably be attained, policymakers confront a choice as to what level of safety to target. Answering this question requires evaluating trade-offs between the risk of poisoning borne by workers and revenue losses suffered by growers caused by restrictions placed on harvesting. We analyzed these trade-offs at the farm level, focusing on setting an appropriate preharvest interval, after the use of an acutely toxic insecticide. We began with the pesticide-use decisions faced by a grower. We then examined the effects of alternative preharvest intervals on the grower's profits and on the expected number of poisoning incidents. Finally, we consider the trade-off between a grower's losses and the medical costs of poisoning cases and evaluate current policy in light of our findings.

I. Reentry Regulation and Pesticide Use

We analyzed the effects of setting a preharvest interval on patterns of pesticide use using a stylized model of crop growth for a fruit or vegetable crop since these crops are affected the most heavily by reentry regulation. There is typically an optimal time to harvest such crops. If the crop is harvested too early, yield or quality may be less than the maximum. If the harvest is delayed, revenue may be lower for a variety of reasons. There may be losses due to fruit drop. The crop may get overripe and, thus, suffer more spoilage or earn a lower price. The price of the crop may fall as the season progresses because of increases in supply as harvesting is initiated in more and more growing regions. Thus, whenever possible, the grower will harvest at the optimal time because profit will be at a maximum.

Suppose that a late-season insect infestation occurs. Assume that, if the grower treats the infestation when it occurs, the crop will not be damaged. If the pesticide used has a preharvest interval that is sufficiently long, treating the pest infestation when it occurs, i.e., reactively, may force the grower to delay the harvest beyond the optimal time. On the other hand, if the farmer treats the crop in anticipation, the pesticide will have decayed somewhat by the time the pest arrives. It will be less effective, and the crop will suffer some damage. In other words, a preharvest interval will force the grower to deal with a trade-off between losing money from delaying the harvest or from additional damage to the crop. If the value of the additional damage incurred by treating the crop a day earlier exceeds the revenue lost from delaying the harvest by a day, the grower should follow a reactive pesticide-use strategy. If the revenue lost from delaying the harvest by a day exceeds the value of the additional damage incurred by treating the crop a day earlier, the grower should follow an anticipatory pesticide-use strategy.

Anticipatory treatment with pesticides, sometimes termed prophylactic pesticide use, has been widely criticized, and many of the efforts involved in promoting integrated pest management (IPM) have been devoted to fostering reactive pesticide-use patterns. It has been hypothesized that prophylactic strategies are due to aversion to risk or inadequate training. Our analysis indicates that reentry regulation or, for that matter, anything that interferes with scheduling operations may also motivate prophylactic pesticide use.

II. Codling Moth Infestations in Apples

Empirically, we looked at the use of organophosphate insecticides to protect apple crops from infestations of codling moth larvae from moth flights shortly prior to harvest. The yield and quality of the apples were assumed to increase up until the maturity date, which is the earliest date at which the crops may be harvested. After the maturity date, yield and quality will remain constant for a considerable length of time, but the price the farmer receives will decline as time passes because the aggregate supply of apples will increase as producers in other regions harvest and market their crops. The price will continue to decline until it equals the price for processing uses. An analysis of the intraseasonal trends in farm-level apple prices in three major producing states (Washington, Michigan, and California) indicated that the price of apples for fresh consumption declines exponentially at a rate of 0.24-percent per day as the season progresses.

A late-season flight of codling moths produces an infestation of larvae in the fruit, i.e., wormy apples. If the apples are treated with an organophosphate insecticide, the moths will be killed before they lay eggs and damage will be avoided.

If the crop is left untreated, about 10 percent of the crop typically becomes infested and is, therefore, unsalable. These insecticides decay exponentially over time. Residue data from citrus and apples suggest that ethyl parathion, the insecticide considered in this study, decays at a rate of 80 percent per day. Treating the crop an additional day before the arrival of the pest thus increases survivorship and damage exponentially up to a maximum of 10 percent of the crop.

With these parameters, the additional damage incurred by treating the crop a day earlier far exceeds the revenue lost from delaying the harvest by a day; thus, the grower should follow a reactive pesticide-use strategy.

III. Residue Poisoning From Parathion Exposure Among Apple Harvesters

The risk of clinical illness in workers as a result of exposure to residues of parathion applied to apples at various locations was modeled as a process with several stages. First, the pesticide is applied. Second, a decay process takes place in which some of the parathion is converted to the oxygen analog, paraoxon. Residue levels may be reduced by rainfall as well. Exposure takes place days or weeks after application when crews enter the field to harvest the crop. Clinical illness is usually due to a dermally absorbed dose of paraoxon because, after three days, the parathion residues have practically disappeared.

The decay of parathion, its conversion to paraoxon, and the decay of paraoxon were assumed to follow exponential processes as suggested by data from citrus and apple orchards. The dermal dose was assumed to be proportional to the residue levels on the leaves and the time spent working in the field. The fractional inhibition of red blood cell cholinesterase was modeled as a function of dermal dose using a cumulative exponential distribution. The probability of clinical illness was modeled using a function of cholinesterase inhibition using a logistic distribution. The parameters of the decay model were estimated utilizing data obtained from citrus crops, but limited data on apples suggest a similar pattern. The reduction in residue levels from rainfall was assumed to be proportional to an exponential function of cumulative precipitation. The constant of proportionality relating dermal dose to residue levels and the parameters of the cholinesterase inhibition function were taken from experiments conducted by the School of Public Health of the University of California at Berkeley. An eight-hour workday was taken as the time of exposure. Two types of clinical illness were considered—mild cases and severe ones. The parameters of both models were derived from clinical experiences of farm worker poisoning incidents in California.

IV. Trade-Offs Between Grower Revenue and Worker Poisonings

We used the models presented in the two preceding sections to evaluate the impact of reentry regulations on apple growers' revenues and apple harvesters' safety in three major apple-producing states: Washington, Michigan, and California. We assumed that a flight of codling moths arrived four days before the optimal harvest date, that parathion was applied at a rate of 2.0 pounds of active ingredient per acre, and that, as is typical, the crop produced on a 50-acre block would be harvested in one day by a crew of 500 (10 workers per acre). Losses in growers' revenues were compared to the risk of severe and mild poisoning to each individual worker. Rainfall levels of 0, 0.5, and 1.5 inches during the reentry period were used to take into account the differences in weather conditions encountered in the different regions under investigation: California receives virtually no rainfall during the harvest period, Washington receives an average of 0.5 inches, and Michigan receives an average of 1.5 inches under normal conditions. Orchards in all three states were assumed to have yields of 10 tons per acre. The price of apples in California was taken as $300 per ton, corresponding to a maximum revenue of $150,000 for a 50-acre block. Regression analysis suggested that price levels in Michigan and Washington were about 17 percent and 32 percent above that of California. Since Michigan harvests about four weeks after California and two weeks after Washington, the maximum price in these states should be 9.8 percent and 28.2 percent higher than California, respectively, giving estimates of about $165,000 per 50-acre block in Michigan and $192,000 per 50-acre block in Washington.

Table 1 shows the expected numbers of severe and mild parathion poisoning cases plus the fraction of revenue lost due to harvest delays. The risk of poisoning is quite serious. With a preharvest interval of four days or less, there will be an average of 2.5 severe cases and 43 mild cases under California conditions, 1.6 severe and 29 mild cases under Washington conditions, and 0.8 severe and 15 mild cases under Michigan conditions. (At any given time, there will be almost 19 times as many mild as severe cases.) Each additional day entry is prohibited reduces the number of mild and severe cases by about 13 percent. Each additional inch of rainfall reduces the total number of expected cases by about 75 percent. Even so, the risk of poisoning remains rather high for a lengthy period of time: If reentry is prohibited for as much as two weeks, there will still be an average of one severe poisoning incident for roughly every two 50-acre blocks harvested in California, one severe incident for every three 50-acre blocks harvested in Washington, and one severe incident for every four 50-acre blocks harvested in Michigan.

At the same time, the losses imposed by reentry regulation can be considerable. Each additional day's delay in harvesting reduces total revenue by about 0.24 percent, corresponding to $360 per 50-acre block in California, $460 per 50-acre block in Washington, and $395 per 50-acre block in Michigan. Total harvesting labor costs, by contrast, amount to about $425 per 50-acre block in Washington. A preharvest interval of two weeks would result in a revenue loss on the order of 2.5 percent; since profit margins in apple production range from 3 to 10-percent, such a loss would represent a sizable fraction of net income.

TABLE 1

Health Risks and Revenue Losses Under Alternative Reentry Intervals

Reentry intervals (days)	Expected number of severe poisonings			Expected number of mild poisonings			Fraction of revenue lost
	California	Washington	Michigan	California	Washington	Michigan	
0-4	2.46050	1.63800	0.81650	42.6950	29.2650	15.0000	0
5	1.95600	1.33250	0.69100	34.5800	24.0600	12.7600	0.002397
6	1.57650	1.09650	0.59100	28.2250	19.9600	10.9500	0.004788
7	1.28550	0.91250	0.51050	23.2450	16.7150	9.4850	0.007174
8	1.06000	0.76750	0.44520	19.3150	14.1300	8.2900	0.009554
9	0.88350	0.65250	0.39155	16.2050	12.0600	7.3050	0.011928
10	0.74500	0.56000	0.34725	13.7200	10.3850	6.4900	0.014296
11	0.63400	0.48540	0.31045	11.7300	9.0250	5.8100	0.016659
12	0.54550	0.42450	0.27965	10.1200	7.9100	5.2350	0.019016
13	0.47340	0.37450	0.25370	8.8050	6.9900	4.7555	0.021368
14	0.41470	0.33315	0.23165	7.7300	6.2250	4.3460	0.023714
15	0.36960	0.29865	0.21290	6.8400	5.5900	3.9965	0.026054
16	0.32645	0.26970	0.19680	6.1050	5.0550	3.6965	0.028389
17	0.29305	0.24530	0.18295	5.4850	4.5995	3.4380	0.030718
18	0.26500	0.22450	0.17095	4.9515	4.2130	3.2135	0.033041
19	0.24125	0.20680	0.16000	4.5245	3.8825	3.0185	0.035359
20	0.22110	0.19155	0.15135	4.1495	3.5985	2.8480	0.037672
21	0.20385	0.17840	0.14335	3.8280	3.3530	2.6980	0.039978
22	0.18900	0.16700	0.13635	3.5515	3.1400	2.5660	0.042280
23	0.17620	0.15705	0.13010	3.3120	2.9540	2.4495	0.044575
24	0.16510	0.14835	0.12460	3.1040	2.7915	2.3465	0.046866
25	0.15540	0.14070	0.11970	2.9230	2.6485	2.2545	0.049150
26	0.14690	0.13400	0.11535	2.7640	2.5225	2.1725	0.051430
27	0.13945	0.12805	0.11145	2.6245	2.4110	2.0995	0.053704
28	0.12835	0.12275	0.10795	2.5010	2.3120	2.0340	0.055972

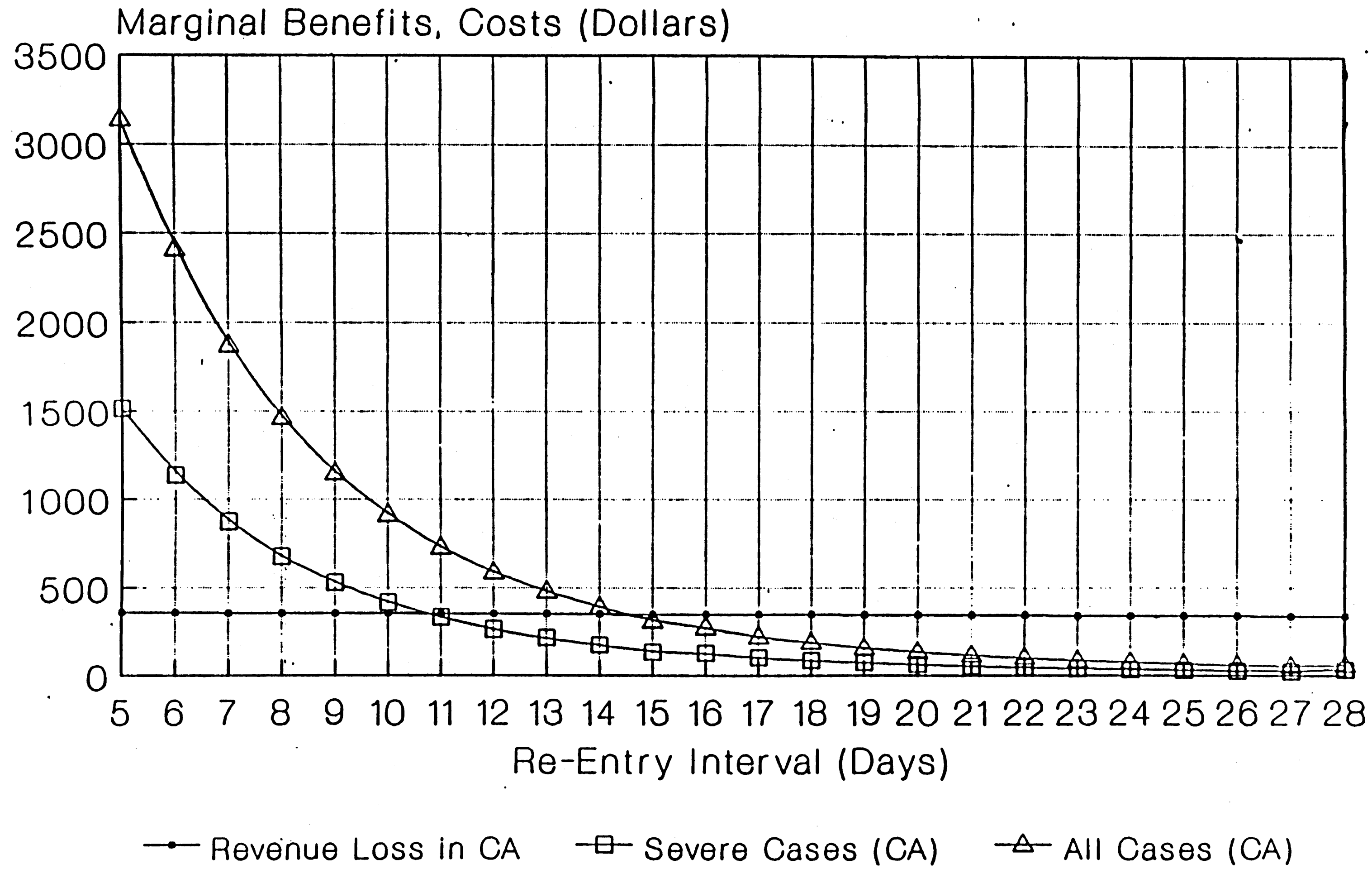
V. Setting an Appropriate Preharvest Interval

According to economic theory, the optimal preharvest interval is found by equating the marginal cost of additional harvest delays in terms of revenue lost with the marginal benefits associated with reductions in the number of poisoning incidents. For illustrative purposes, we calculated these optimal preharvest intervals under the conservative assumptions that benefits were restricted to average avoided costs, that is, to the average costs of hospitalization plus average lost wages. We ignored other costs such as long-term losses due to chronic neurotoxic effects, the value of pain and suffering, and the costs imposed on consumers by the presence of residues remaining at the time of ingestion.

A severe parathion poisoning case typically requires three days of hospitalization, with the first day spent in intensive care, followed by two weeks of recovery, i.e., lost work time. Assuming average costs of $1,200 per day for intensive care and $500 per day for a standard hospital bed implies total hospitalization costs of $2,200. Assuming an average wage of $10 per hour for an eight-hour day implies total lost wages of $800, for a total cost of $3,000 per severe case. A typical mild case requires no hospitalization, a medical care cost of about $40 per case, and two days of lost work time for a total cost of $200 per case.

Figure 1 shows the marginal costs and benefits from severe cases and all poisoning cases associated with different preharvest intervals in California. According to the conservative criteria used here, the optimal preharvest interval for California is 15 days. Current EPA regulations require 14 days regardless of rainfall conditions for applications of parathion on apples such as the one considered here. Interestingly, the current pre-harvest interval is quite close to the optimal one calculated here for California.

Figure 1
Optimal Re-Entry Interval in California



Rainfall, and thus residue levels, are greater in Washington and Michigan; and the optimal preharvest intervals are correspondingly shorter—12 days in Washington and 9 days in Michigan. Thus, as long as local rainfall can be monitored effectively, the same levels of safety implicit in the 14-day preharvest interval can be achieved at lower cost by making the preharvest interval dependent on rainfall. For example, lowering the preharvest interval from 14 to 9 days when there have been 2 inches of rain would cut the losses suffered by Michigan apple growers by $1,944 per 50-acre block, (almost 50 percent), while lowering it from 14 days to 12 days, when there have been 0.5 inches of rain would cut the losses suffered by Washington growers by $904 per 50-acre block (almost 20 percent).

VI. Conclusion

Pesticide regulation is becoming increasingly complex. Demands for protecting public health and the environment are growing, and greater protection can be achieved only at heightened cost. Society is thus confronted with increasingly difficult choices about pesticides. Our work shows that careful analysis integrating economics, agronomy, and the environmental and biomedical sciences can assist this decision process considerably. Modeling farm-level pesticide-use decisions helped further understanding of how growers operate. Integrating agronomic and environmental health models into an economic context illustrated the magnitudes of the trade-offs involved in setting policy. The empirical example in this chapter demonstrated the inefficiency of uniform regulation, and there are substantial gains from varying regulations in correspondence to variations in environmental and economic conditions. In particular, it seems justified to have stricter reentry regulations in California than in other states. The results here also indicate that existing reentry regulations are appropriate when the health costs consist only of medical costs and lost labor. The existing regulation may be viewed as lenient if one assigns high costs to pain and suffering.

The results of this chapter are preliminary and mostly demonstrative. Clearly, further research integrating farm-level pesticide-use decisions, industry-level market operations, and the environmental and human health effects of pesticide exposures can help make more informed and efficient decisions about pesticide use.

12

EFFICIENT REGULATION OF HUMAN HEALTH AND SAFETY UNDER UNCERTAINTY: CALIFORNIA WATER QUALITY CASE STUDIES

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Potential risks to human health and safety arising as a by-product of production processes have become a major source of concern for public policy. Controversy continues to rage over the extent of and appropriate remedies for risks associated with water contamination, air pollution, pesticide use, and food safety.

These risks are often quite subtle and, therefore, difficult to detect or verify reliably, and quantitative estimates of risk are typically subject to considerable uncertainty. The bulk of environmental and food safety legislation calls for safeguarding public health with an adequate margin of safety in recognition of these uncertainties. Efforts to mitigate these risks typically entail substantial economic costs in terms of reduced productivity, losses in output, and increased prices. More recent legislation (Food Drug and Cosmetic Act; Federal Insecticide, Fungicide, and Rodenticide Act; Toxic Substances Control Act; and Safe Drinking Water Act) recognizes the need to balance these costs against risk reductions achieved. In sum, it is imperative to base policy determination on thorough evaluations of the trade-offs between enhanced safety and reductions in economic well-being that take uncertainty into account.

Research in quantitative risk assessment, production management, and economic welfare analysis has provided an arsenal of tools for conducting such trade-off evaluations. This chapter presents a decision methodology that integrates these components and discusses lessons from two applications of the methodology to water quality problems in California.

I. Efficient Risk Management Under Uncertainty

One of the key difficulties facing policymakers is the high degree of uncertainty about quantitative estimates of risk. It is difficult to determine reliably the degree to which exposure to, say, pesticide residues causes a heightened risk of contracting cancer. Contamination and exposure processes are subject to considerable randomness due to weather and other factors and, moreover, vary substantially across locations and individuals. Dose-response parameter estimates derived from animal studies are shrouded with uncertainty because of difficulties in interspecies comparison and because of the high doses typically used. Even when epidemiological estimates are available, the statistical uncertainties are substantial.

The methodology presented here explicitly incorporates uncertainty considerations into the decision-making process. It views the government as having two objectives: maximizing net market benefits and minimizing risk. Net market benefits refer to the real incomes of producers and consumers derived from production and consumption of items affected by regulation, less government expenditures. To account for uncertainty about risk estimates, the risk objective is defined as an upper bound that is not exceeded with a certain degree of confidence, for example, the level below which risk is estimated to fall, say, 95 percent of the time. This corresponds to the use of confidence intervals from classical statistics to adjust for uncertainty and addresses the need for allowing a margin of safety raised in the legislation.

The trade-offs between these two objectives can be estimated by solving a constrained optimization problem of maximizing net market benefits subject to the constraint on the risk objective (Lichtenberg and Zilberman, 1988). Solving the problem while varying the constraint repeatedly yields a set of trade-offs between market welfare and risk and an associated set of policies.

Formally, let X be a vector indicating the extent of use of the policies to be considered. For example, X_1 may be the level of a tax on emissions of toxic elements into a body of water and X_2 may indicate the severity of restrictions on pesticide use, etc. Net market benefits are a function of these policies, $B(X)$. Actual risk is similarly a function of these policies, $R(X)$, and is a random variable. Let R_0 be the acceptable risk level and P be the desired confidence level. The optimization problem is

$$\max_{X} B(X)$$

$$\text{s.t. } Pr\{R(X) < R_0\} > P.$$

The solution is an optimal policy vector $X^*(R_0, P)$ that is a function of the acceptable risk level and desired confidence level. Substituting into the net market benefits function gives the maximum net market welfare attainable given the risk objective and confidence level, $B(X^*) = B^*(R_0, P)$. By varying R_0, one obtains the set of trade-offs with a given confidence level P. Varying the confidence level as well gives a complete set of trade-offs between market welfare, acceptable risk, and the reliability of attaining the acceptable risk level. (The same set of trade-offs can be obtained from a dual problem of minimizing the risk objective subject to a constraint on net market welfare.)

Two key measures derived from this optimization problem are the marginal cost of risk reduction and the uncertainty premium. The marginal cost of risk reduction is the absolute value of dB^*/dR_0, the reduction in net market benefits associated with a small decrease in the level of acceptable risk. It increases as the level of acceptable risk falls, indicating that enhanced safety is increasingly expensive. The uncertainty premium is the absolute value of dB^*/dP, the reduction in net market benefits associated with a small increase in the confidence level. It indicates the additional cost required to increase reliability in meeting acceptable risk.

The information generated by this methodology can be used to determine policy using a variety of decision criteria, including cost-benefit and risk-benefit criteria. In cost-benefit analysis, the optimal policy equates the marginal cost of risk reduction dB^*/dR_0 with the monetary value of increased health and safety at the margin. There is a voluminous literature in economics on the estimation of social willingness to pay for marginal increments in health and safety. In risk-benefit analysis as proposed by Starr (1969), the appropriate policy equates the ratio of net market benefits to risk B^*/R_0 with the historical average.

The methodology can also be used to deduce implicit values of willingness to pay for reduced risk and risk-benefit ratios from existing policies—conditional on a given confidence level. This allows for uncertainty-adjusted comparisons of policies for consistency.

II. Case Studies

This methodology has been applied to three different problems: drinking water quality, shellfish sanitation, and farm worker safety. Each application emphasizes a different aspect of environmental health regulation.

Drinking water quality. The first case study involved residues of the nematicide 1,2-dibromo-3-chloropropane (DBCP) found in drinking water wells in Fresno County, California (Lichtenberg, Zilberman, and Bogen, 1989). DBCP had been used as a soil fumigant for orchard crops but was banned for all agricultural uses by the U. S. Environmental Protection Agency (EPA) in 1979 after having been implicated in adverse reproductive effects in chemical plant operators and oncogenesis in mice and rats. Because DBCP was no longer in use, the study focused on trade-offs between excess gastric cancer risk and the cost of developing clean drinking water supplies.

Monte Carlo simulation was used to construct probabilistic quantitative risk assessment of the excess cancer risk faced by an individual drawn at random from the population of the county as a multiplicative combination of the concentration of DBCP in drinking water, error in measuring that concentration, lifetime consumption of water, an interspecies dose equivalence factor, and a carcinogenic potency parameter. The distribution of DBCP concentrations in well-based water systems and the error in measuring DBCP concentrations were constructed from California State Department of Health Services data. The data presented by the International Commission of Radiological Protection were used to estimate a distribution of lifetime water consumption. The distribution of the dose-equivalence factor was estimated under the assumption that the two main hypotheses (calibrating dose on the basis of surface area versus body weight) were equally likely to be correct. The distribution of the carcinogenic potency parameter was estimated using maximum likelihood estimation of a multistage dose-response model using data from a feeding study of mice.

Costs of developing new water supplies differed between rural and urban areas. Drilling new wells was less costly for large systems, while installing filtration devices was cheaper for individual wells. Residential areas within the county thus differed in two ways: average DBCP concentrations in drinking water and cost of remediation. Least-cost strategies for meeting a risk standard for an individual drawn at random from the county population were derived for the entire feasible range of standards using an algorithm derived from the methodology described above. For ease of analysis, the relationship between risk standards and remediation costs were smoothed using a second-order polynomial regression of cost on the natural logarithms of the risk standard and confidence level.

obtained here indicate that the adjustment will be significant, suggesting that allowances for uncertainty account for a significant share of the observed discrepancies.

Shellfish sanitation. The second case study involved a shellfishery located in an estuary affected by dairy runoff (Lichtenberg and Zilberman, 1987). During rainstorms, wastes from dairies were washed into the estuary, resulting in microbial contamination of the oysters growing there and a concomitant risk of severe gastroenteritis for anyone consuming them. The analysis centered on source reduction because open access to the fishery ruled out fishery closure as an effective means of risk reduction.

Rainfall was assumed to be the only random element affecting the risk of acute gastroenteritis which was modeled as a multiplicative combination of parameters describing microbial contamination in runoff per cow, microbial uptake in oyster population, the probability of contracting acute gastroenteritis upon consumption of contaminated oysters, and the number of cows contributing to runoff. Microbial contamination in runoff per cow was estimated from maximum fecal coliform counts observed around oyster beds in the estuary. The fraction of oysters contaminated was estimated by applying regression analysis to data in a study examining the usefulness of fecal coliform counts as an indicator of bacterial contamination of oysters. The probability of contracting acute gastroenteritis after consuming contaminated oysters was derived from epidemiological studies. The number of cows contributing to runoff in any size rainfall event equaled the number of cows at dairies with runoff control facilities with insufficient capacity of the amount of rainfall. The probability distribution of rainfall events was derived from data on local rainfall.

The dairies in the watershed differed in terms of topography and, therefore, in terms of the cost of constructing runoff control facilities adequate for any given size rainfall event. Data on these costs for each dairy in the region were obtained from a detailed engineering study. Least-cost patterns of runoff control facility construction and trade-offs between gastroenteritis risk and source reduction expenditures were estimated using an algorithm derived from the methodology described above.

The optimal policy involved building holding ponds only at dairies with the lowest marginal costs. The optimal capacity at each dairy was determined by the confidence level required, and the total number of dairies subject to undertaking source reduction measures was determined by the risk standard. Because topography, and therefore cost, differed markedly at different sites, different dairies received markedly different treatment under this policy. Runoff control facilities were required at only a few sites to meet lax risk standards. As the risk standard became more stringent, the number of sites investing in source reduction grew. The optimal set of standards thus implied marked inequities among dairies, with some dairies required to undertake substantial investments in source reduction while others continued with unregulated emissions.

Economists have long argued that taxes can be used to achieve pollution control aims instead of imposing standards. In the case at hand, the per-cow tax required to meet any desired risk standard with a given confidence level equaled the marginal cost of installing runoff control facilities of the requisite capacity at the most expensive site needed. Holding pond construction patterns remained the same, but dairies not needing to invest in source reduction had to pay taxes on runoff generated. The result was a much more equitable set of losses. Figure 2 shows tax payments as a fraction of total expenditures for runoff control for different risk levels. When the risk target is lax, very few dairies find it less costly to build runoff control facilities than pay the tax, so tax payments account for almost all runoff control expenditures. As the risk target becomes more stringent and the optimal tax increases, more and more dairies find it less costly to build.

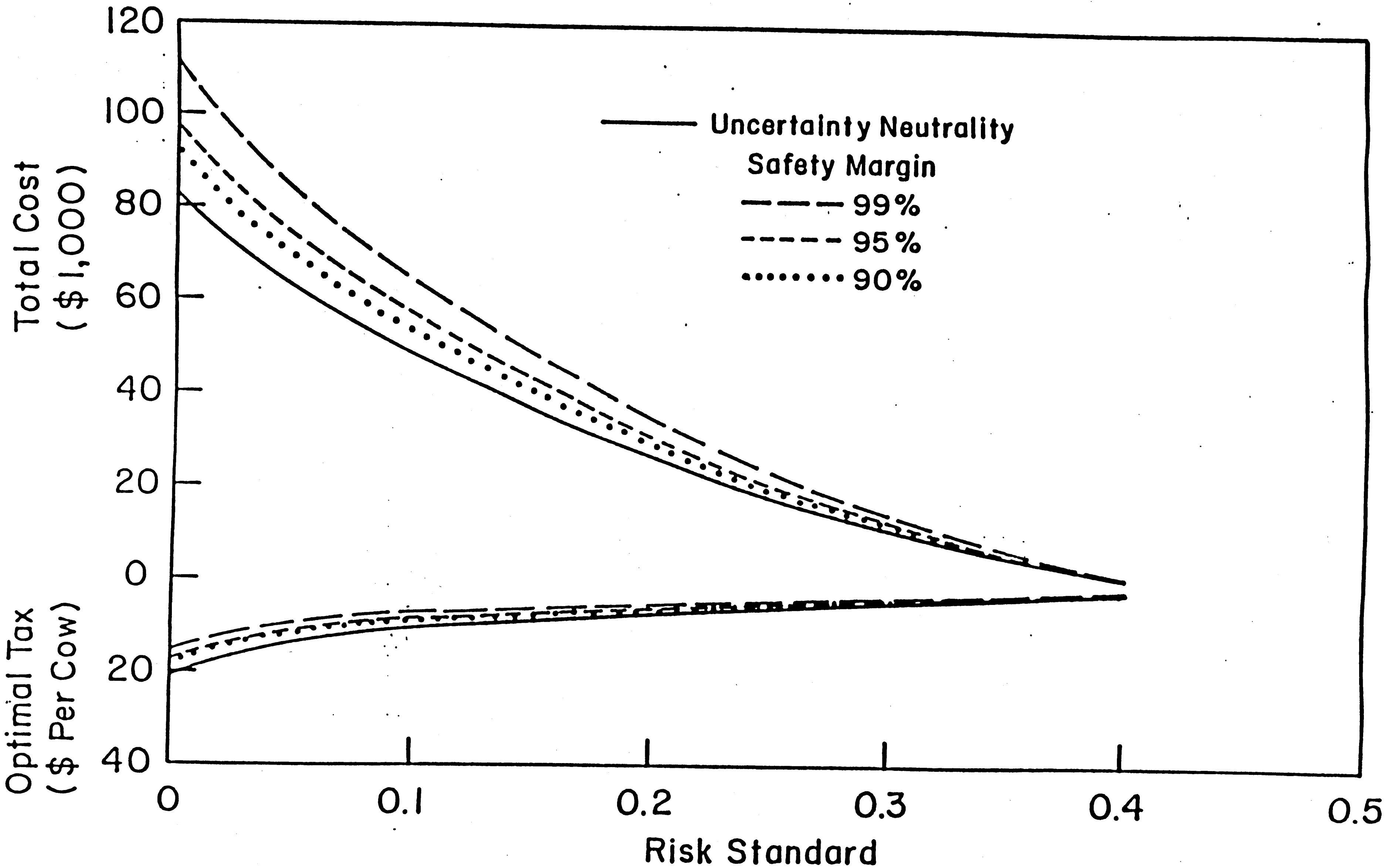

FIGURE 2. Total Cost and Optimal Taxes --Alternate Risk Standards

III. Further Remarks

The case studies discussed above were originally concerned with setting appropriate levels of a single policy instrument for development of clean water supplies and source reduction of dairy runoff. In was found that multiple policy instruments are actually available, and a key task facing policymakers is to choose the appropriate mix of instruments. Theoretical analysis of the methodology suggests that every risk reduction policy has two effects: an effect on average risk and an effect on uncertainty about risk. The optimal set of risk reduction policies will be a portfolio of measures, some of which are relatively more efficient in reducing risk on average and some of which are relatively more efficient in reducing uncertainty about risk. Thus, information-gathering activities such as monitoring, development of improved models for quantitative decision analysis, and long-term research into environmental fate and human toxicology play an essential role in regulatory strategy, even in the short term. An example of such a portfolio of policies is simultaneous monitoring of air pollutant emissions to reduce uncertainty about health risks such as respiratory and cardiac ailments combined with regulation of emissions to reduce these risks on average.

The uncertainty-reducing effect of any policy depends on three factors: the overall level of uncertainty about the risk, the tractability of that uncertainty, and the weight that decision makers place on uncertainty. The fact that absolute uncertainty matters, coupled with the empirical finding that making allowance for uncertainty increases regulatory cost substantially, suggests the critical importance of long-term research. As improvements in knowledge reduce uncertainty about risks, policymakers can enact increasingly efficient risk-reduction policies.

The analysis also indicates that the marginal cost of risk reduction depends on several factors including the confidence level demanded, overall toxicity, and the background level of uncertainty. In particular, the marginal cost of risk reduction decreases as the level of background uncertainty increases, so that more stringent risk-reduction efforts become warranted. This fact may shed some light on supposed inconsistencies in federal safety regulation. It has long been noted that safety standards for nuclear power plants are much more stringent than those for coal mines, even though the number of deaths per unit of energy produced attributable to coal far exceeds the number attributable to nuclear power (Crouch and Wilson, 1981). However, there is far more uncertainty about the risk of accidents in nuclear power plants. Once the effect of this additional uncertainty has been factored in, the estimated marginal costs of risk reduction in the two cases may well be comparable.

In practical applications, economists have tended to treat the benefits of safety regulation, expressed in terms of willingness to pay for risk reductions, in terms of average values derived from labor market or consumer behavior studies, which are assumed constant over the range of risks considered. Economic theory, of course, posits that willingness to pay should be a function of the size of the risk (Zeckhauser, 1979). Psychological studies indicate that it should depend on factors such as dread or controllability as well. Analysis of the methodology presented here indicates that still other factors should be considered, including the level of background uncertainty and the confidence level demanded. Willingness to pay is thus best conceived of as a function of risk levels and characteristics of the risk, including uncertainty about the risk, rather than a single number.

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