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ECONOMICS AND PESTICIDES

by

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Abstract

This paper reviews the main accomplishments and limitations of these two strands of economic investigations of pesticide use, with a focus on how economics has contributed to policy. We discuss the evolution of micro- and macro-level studies as responses to EPA's evolving regulatory practice under FIFRA. As policy concerns regarding pesticides have become increasingly broad and pesticide policy decisions correspondingly complex, the narrower concerns of the past no longer suffice. Management models that integrate micro- and macro-economic models with agronomic and biomedical models are needed both for applied policy analysis and for the scientific insights they can produce.

ECONOMICS AND PESTICIDES

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 1960's. 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-farm and off 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 1980's. 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, consideration of distributional effects and impacts of multiple cancellations.

This paper 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 natural scientists into what we term integrated management models for assessing pesticide policies. We argue that this interdisciplinary approach is the most productive for additional research.

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 1950's these illusions were rudely dispelled by the recognition that pesticides could wreak havoc on wildlife, notably predatory birds. By the mid-1960's, it became evident in addition 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 integrated pest management 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, and so on, (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, 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 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 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 generalized this model further by allowing multiple pesticide applications.

A closely related task 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 compared the standard chemical control strategy for cotton in Arizona with and 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 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 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 (comparison of biological and chemical control methods for Mexican bean beetles); Zavaleta and Ruesink (comparison of resistant alfalfa strains and chemical use for control of alfalfa weevil); Lazarus and Dixon (comparison of crop rotation and chemical methods for control of corn rootworm in the Corn Belt); Lazarus and Swanson (comparison of crop rotation and chemical methods for control of corn rootworm in the Corn Belt under uncertainty); Zacharias and Grube (comparison of crop rotation and chemical methods for control of corn rootworm and soybean cyst nematode on Illinois farms); and Harper and Zilberman (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 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 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 that the difference between optimal and myopic pesticide use was not very great, however.

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 showed that uncoordinated control efforts by individual farmers is suboptimal in terms of both amounts of chemical 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 U.S., 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 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 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 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 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 non-chemical 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, Norgaard). Empirical evidence regarding the impact of risk aversion on chemical use and IPM adoption is extremely scanty, though. As far as crop insurance is concerned, a simulation study by Miranowski et al. 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, 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 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 integrated pest management 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. 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 have not been performed, however. 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.

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 (1986) 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 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 1970's and early

1980's.

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 non-negligible, 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 non-chemical 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 over all alternative to obtain an overall 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 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 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 non-users 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 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 on tree crops, Osteen and Kuchler on major grain crops and Lichtenberg, Zilberman and Harper 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 tend 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 for large classes of chemicals, though. 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 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 point of view of pesticide regulation, in this view, reductions in dead weight 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 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 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 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 harvest-time 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.

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 non-chemical 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 re-entry regulation. EPA sets re-entry intervals, i.e., the length of time after pesticide application during which workers cannot re-enter treated fields, to reduce the risk of acute pesticide poisoning to an acceptable level. (It sets pre-harvest 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 studies re-entry regulation using a model that combined an 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 re-entry 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 re-entry 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 presents a Bayesian model of optimal toxicity screening. Applying the model to pesticide regulation using standard estimates of the value of life saving, he shows that mutagenicity tests are suboptimal for chronic toxicity testing under a policy where only a single test is allowed. Lichtenberg 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 non-comparable, ruling out the application 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 tradeoffs 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 tradeoffs only ex post. This narrow vision can be overcome by establishing a unified, interdisciplinary process led by analysts focusing on assessing the tradeoffs 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 tradeoffs 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 tradeoff 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 tradeoff 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 <u>margin of safety</u> 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 <u>uncertainty-adjusted cost curve</u>, or tradeoff 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 tradeoffs between enhanced human safety/environmental quality and other social goals.

This approach can be viewed as an extension of the Baumol and Oates 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 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 applied this methodology in an empirical examination of excess cancer risk from contamination of drinking well water in California by the nematicide DBCP. They estimated uncertainty premiums ranging from 20 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.

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 integrated pest management 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. But 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 policy makers 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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