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Alternative Approaches to Pesticide Regulation

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Pesticide regulation has become a topic of increasing interest in recent years, owing to rising public concerns about residues on foods, in drinking-water wells, and damage to wildlife. Public-opinion polls and political responses to incidents like the controversy over Alar suggest that demand for government intervention to protect public health and the environment from pesticides is high. Pesticides are toxic by design; survey evidence indicates that they are perceived as riskier than other, more common pollutants like auto exhaust (see, for example, Horowitz). Pesticide residues are not easily observable (short of laboratory analysis), making averting strategies by individuals extremely difficult and/or excessively costly to implement.

Most economists studying macro-scale issues of pesticide regulation¹ have focused their attention on decisions about whether to allow the use (cancel the registration) of specific chemicals or classes of chemicals. For example, Knutson et al., and Osteen and Kuchler studied the effects of eliminating pesticide use on major crops in the U.S. Zilberman et al. examined the likely effects of California's "Big Green" initiative, which would have eliminated the use of many widely used chemicals on five major fruit and vegetable crops in that state. Cropper et al. investigated the political economic factors determining Environmental Protection Agency (EPA) cancellation decisions.

This emphasis on registration decisions is understandable: Bans are the most dramatic, visible tool of pesticide regulation and thus engender the most controversy. But the reality of pesticide regulation is more complex. Pesticide regulation as it

exists today utilizes a number of policy instruments other than all-or-nothing registration/cancellations or even other forms of direct restrictions on pesticide use. Moreover, even though our natural inclination is to concentrate on the total amount of pesticides applied, timing of application and the form in which the pesticide is applied are often equally important in terms of both productivity and negative spillovers.

This paper discusses some strengths and weaknesses of alternative approaches to pesticide regulation. It begins with a brief description of the goals of pesticide regulation and the various policy instruments used to address those goals. It then turns to alternative types of policies, such as pesticide taxes, liability law, and provision of information, and considers their potential for meeting the goals of pesticide regulation. Finally, it discusses needs for economic research in light of current knowledge about these alternatives.

Goals of Pesticide Regulation

Pesticides are regulated by the EPA primarily under two statutes: the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), most recently amended in 1988, and the Federal Food, Drug and Cosmetic Act (FFDCA). FIFRA governs pesticide use directly, while FFDCA affects it indirectly by giving EPA the authority to set tolerances for residues on foods.

Pesticide regulation is mandated to provide protection for (1) pesticide users, (2) the health and safety of humans exposed to pesticides, and (3) wildlife and the environment.

Pesticide-User Protection

The purpose of the original FIFRA legislation was to ensure that the chemicals farmers were being sold were actually effective in controlling the specific pests they were purported to. This function of regulation may be important for health and safety, as well as for permitting efficient use of materials.

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¹ There is a voluminous literature on the farm-level economics of pesticide use. Here we refer only to studies that have examined pesticide policy at the national level.

For example, Boardman attributes many of the health and safety, and environmental problems associated with pesticide use in Malaysia to the fact that farmers are sold mislabeled and adulterated chemicals.

Market failures in this regard arise from the fact that product quality cannot be observed without excessive cost. Thus, the goal of policy is to set up mechanisms that ensure that farmers know what they are purchasing.

Ecological Protection

Pesticides are designed to be toxic to living organisms. Because pesticide production is characterized by high fixed costs of research and development, most pesticides marketed affect a broad spectrum of organisms. Thus, it is not at all surprising that pesticides could have adverse effects on nontarget species. Adverse ecological effects range from acute (e.g., fish kills from runoff of synthetic pyrethroids or spills; bird kills from consumption of granular soil insecticides or exposure to drift and residues; bee kills from exposure to drift) to long-term effects, such as the declines in bird populations caused by bioaccumulation of DDT and similar persistent compounds.

Ecological damages from pesticides are externalities, since the bulk of the damage is borne by disparate members of the general public rather than the farmers using the pesticides. The solutions to these problems are necessarily collective and generally require public intervention due to high transaction costs of organization and free-riding. It is important to recognize that the extent of damage is affected by the types, formulations, and timing of application of materials used, as well as by the total amount of material applied.

Protecting Human Health and Safety

Many pesticides are toxic to humans to some degree. Workers are exposed to pesticides during production, mixing and loading, application, or field work; the general public may be exposed via aerial drift, drinking water (leaching of pesticides into groundwater or runoff into surface water), or residues on foods. Acute poisonings among farm workers are well documented (see, for example, Coye), as are some cases of long-term hazards among chemical plant operatives (e.g., sterility caused by DBCP, cancer caused by chlordimeform). Animal bioassays suggest that pesticides may have other long-term (chronic) effects, such as cancer, birth defects, and genetic damage, al-

though this evidence is controversial (see, for example, Ames, Magaw, and Gold).

Worker safety and general public health problems differ in fundamental ways. It can be argued that the central market failure in worker safety is that workers may not be fully informed about the risks posed by the chemicals they are exposed to, hampering their ability to bargain over an adequate wage premium. Exposure of the general public is an externality problem in which privately organized solutions tend to be ruled out by the high costs of providing information, as well as by costs of organizing and free-riding.²

Dynamic Concerns

Because it must balance the risks and benefits of pesticide use, EPA's regulatory decisions are determined in large measure by the pest-management alternatives available. One of EPA's long-run goals is, thus, to encourage the development of safer pesticides or pest-management technologies that will allow it to increase the extent to which it protects human health and the environment.

Instruments of Pesticide Regulation

EPA uses multiple policy instruments to meet these multiple goals of pesticide regulation. The set of usable instruments is, of course, circumscribed by the legislation governing pesticide regulation, mainly FIFRA and FFDCA.

The main context in which EPA exercises regulatory authority is registration. FIFRA requires that pesticides be registered in order to be marketed. The conditions under which a chemical is registered specify (1) the crops it can be used on, (2) the areas (usually states, sometimes counties) in which it can be used for each crop, (3) the specific pests it can be used for on each crop in each area, (4) maximum allowable application rates by pest, crop, and area, (5) required safety precautions, and (6) specific restrictions on crop rotations, time of use, etc. According to FIFRA, these conditions of use must be such that the benefits from use of a pesticide outweigh the risks posed to the environment and to human safety and health. Benefits under FIFRA refer to consumer

² For example, it is extremely costly—and in some cases, technically infeasible—to analyze the residues of all the pesticides used on any given food or potentially occurring in drinking water. Labeling all of these products is also extremely costly. These issues are discussed at greater length below.

and farmer income; profits for the pesticide industry are specifically excluded from consideration.

The registration process begins when a manufacturer or formulator submits a request, along with specific data concerning effectiveness, environmental fate and transport, and acute and chronic toxicity for wildlife and humans.³ EPA can approve the request, disapprove it, or require the registrant to alter it in specific ways. If the registration is not approved, the registrant may respond with alterations of its own. The pesticide industry is relatively highly concentrated; there are only a few firms developing pesticidal chemicals. Large investment requirements in R&D, the dominant component of cost, deters entry. The risk-benefit balance of any given chemical, which determines EPA's regulatory posture, is conditional on the availability of substitutes and is thus amenable to strategic manipulation by manufacturers. As a result, the outcome of registration is the result of a bargaining process between EPA and the registrant, rather than a unilateral decision made by EPA.⁴

The registration process permits the use of a number of different kinds of restrictions on pesticide use; all are standards (quantity controls) rather than market incentives. They include the following.

Quantity Restrictions

The best-known restriction on the quantity of pesticides that can be used is the all-or-nothing decision about whether to register a pesticide, that is, whether a pesticide can be used in the U.S. FIFRA also gives EPA latitude to engage in some fine-tuning by allowing it to alter the maximum application rate and number of treatments allowed per

season, and by permitting registration in some regions and not others. However, this flexibility is limited. For example, EPA can discriminate among farms only on a regional (state, county) level, even though in many cases discriminating among individual farms would be preferable. EPA also has relatively little control over maximum application rates and numbers of treatments allowed: Manufacturers set them to ensure adequate performance of the pesticide under unusually bad conditions as a way of protecting themselves against liability for damages suffered by farmers with bad infestations and are thus reluctant to accept substantial reductions.

Worker-Protection Measures

EPA can require specific worker-protection measures as a condition of registration. Farmers may be required to provide workers with information about the risks of pesticides and to notify them about the presence of residues in treated fields. EPA may also require the use of protective clothing or impose restrictions on production activities after treatment. For example, it is illegal to send workers into fields for a specified period of time after application of pesticides that pose high risks of poisoning. This form of regulation introduces rigidities in scheduling farm operations that affect the types of material chosen, application rates, and timing of application (Lichtenberg, Spear, and Zilberman).

Other Production Restrictions

As part of the registration process, EPA can specify the types of formulations that can be used (e.g., granular versus spray), impose restrictions on crop rotations, and set other conditions that alter the incentives for choosing one chemical or application method over another. For example, EPA recently cancelled the registration of granular formulations of the insecticide carbofuran because of bird kills; spray formulations remain in legal use because they do not pose the same risk. EPA prohibits feeding unused portions of crops (vines, straw, hulls) to animals after treatment with certain pesticides (e.g., aldicarb). In some cases where pesticide residues remain in the soil for more than one season, EPA can restrict the types of crop that can be grown in seasons after the pesticide was used. For example, EPA forbids planting numerous food crops for six months after the last treatment with aldicarb. These types of regulation can affect the selection of specific chemicals, types of formulation, and timing of application.

³ Two other important processes are the current re-registration process and the ongoing special-review process. The former aims at bringing registrations of pesticides that have been used for a long time up to current standards. The latter is concerned with pesticides currently in use which new information indicates may pose unforeseen problems. Procedural differences between these two and the registration process for new pesticides are not important for the discussion here.

⁴ The case of the EBDC fungicides illustrates this. When EPA announced it was reviewing the registration of this family of pesticides due to new information about risk, the industry responded by proposing voluntary cancellations on a sufficient number of crops to reduce estimated dietary risk to a level acceptable to EPA. EPA, too, had a preliminary list of potential cancellations—which differed substantially from the industry's. EPA ranked crops on the basis of grower and consumer welfare, while the industry ranked them according to its own revenues. The two lists differed because there were more alternatives available (hence benefits to growers and consumers were lower) for the crops that generated the most revenue. These differences were largely rendered moot by market-basket studies that showed much lower residues than EPA had assumed originally; but EPA would have had to accept much or all of the industry list had the data supported the original risk estimates.

Residue Tolerances

Regulation under FFDCA is aimed at protecting consumers of foods treated with pesticides from potential health effects from ingestion of pesticide residues or metabolites. EPA does this by setting a tolerance specifying the maximum concentration of a pesticide residue that may occur on foods.⁵ Residue tolerances are enforced by a Food and Drug Administration inspection program; foods violating residue tolerances are seized. The residue tolerance for pesticides not registered for use in the U.S. is automatically set at zero. If a pesticide does not degrade completely by the time the crop reaches the market, the residue tolerance effectively sets an upper bound on the amount applied and/or the timing of application. Foster and Babcock analyze the case of maleic hydrazide on tobacco, in which residue standards (on exports to Germany) are a binding constraint determining application rates.

Signals from Registration Decisions

To date, EPA's principal attempts to influence pesticide R&D have come indirectly through the signals it sends in making registration decisions. DDT provides a case in point. In banning DDT (and the entire family of chlorinated hydrocarbons in agriculture), EPA indicated that long-lived chemicals had too great a potential for long-run environmental damage to be allowable; that is, only relatively short-lived chemicals would be registered in the future. EPA is currently discussing the potential of more direct incentives for R&D using such instruments as expedited registration or waivers for certain testing requirements for pesticides meeting a set of specific criteria.

Limitations of the Current Regulatory Framework

The preceding discussion indicates that the current framework for pesticide regulation does not consist simply of a broad, all-or-nothing decision about whether or not to register (or cancel the registration

of) a chemical. This framework does possess a considerable degree of flexibility in that usage restrictions can be calibrated to specific regions and in that instruments like re-entry regulation, rotational restrictions, and residue tolerances can alter incentives affecting the choice of type of pesticide, formulation, and timing of application.

There does remain the question of whether this framework is sufficiently flexible. Put another way, does this set of instruments correspond to the outcome of a general social optimization model? Would maximizing social welfare give a set of instruments with precisely these characteristics?

The type of solution corresponding to the current framework is one with a lot of corner solutions, that is, one dominated by the registration/cancellation decision. Loosely, cancellation or denial of registration is optimal in cases where the expected value of marginal damage to human health and the environment caused by small usage levels is large enough that it always exceeds the marginal contribution to national income. Registration without restriction is warranted whenever the opposite holds.

By and large, pesticide regulatory decisions made to date fit this characterization reasonably well. The benefits of pesticide use tend to be small whenever many substitutes are available, either alternative chemicals or land or labor (Zilberman et al.). Most of EPA's cancellation decisions have involved chemicals for which substitute chemicals of comparable efficacy and cost were available. For example, when DDT was cancelled, farmers were able to switch to alternative insecticides that were roughly as effective and as cheap. Cotton growers, for one, had been shifting steadily away from DDT into organophosphates by the time that DDT was cancelled, primarily because of the spread of resistance to DDT (Carlson 1979). Furthermore, most major crops have been in chronic excess supply due to farm commodity programs (Lichtenberg and Zilberman 1986b). The fact that there is ample land to bring into production as a substitute for pesticides on major crops (see, for example, Knutson et al.) also suggests that the marginal benefits of many cancelled pesticides were low. Thus, the social-welfare losses from cancelling the registrations of many pesticides have probably not been large.

In some cases, though, pesticide use may both contribute substantially to national income and pose significant risks to human health and the environment. So-called minor-use crops (particularly fruits and vegetables) come to mind in this regard. Commercial fruit and vegetable production is largely concentrated in a few places, and these

⁵ In most cases, pesticide residues on foods are regulated under Section 408 of FFDCA, which mandates that tolerances be set to balance the risks and benefits of pesticide use. In the relatively infrequent number of cases where the concentration of residues increases during processing, pesticides are classified as food additives and are regulated under Section 409, the Delaney Clause, which prohibits the use of any substance known to cause cancer in humans or animals but uses risk-benefit balancing for other types of health effects. For further discussion, see National Academy of Sciences.

crops are highly vulnerable to pest damage. In these cases, pesticide regulation should attempt to reduce the amounts of a pesticide applied, or change the formulation used or timing of application in a way that equates the expected value of marginal damage avoided with the marginal loss of income.

The capacity of the current framework to effect such changes in pesticide use is limited. Re-entry regulation can accomplish such changes in cases where worker protection is needed. Residue tolerances and preharvest intervals may help protect consumers exposed via residues on foods. But the current framework does not possess mechanisms for inducing marginal changes in pesticide use to protect wildlife, prevent runoff into surface waters or leaching into groundwater, etc. One might think that FIFRA does give EPA some flexibility in this regard, for example, by allowing it to set maximum application rates or numbers of treatments per season. As noted earlier, this option is usually infeasible. Manufacturers set maximum application rates and numbers of treatments per season with an eye toward preventing liability suits for product failure and thus calibrate them to ensure efficacy during exceptionally severe infestations. Similarly, FIFRA does not give EPA any mechanism short of cancellation to discourage the use of high-risk chemicals.

Alternatives to Regulatory Standards

The limitations on the flexibility of the current framework suggest that alternative mechanisms might be useful in supplementing the instruments currently in use. This section considers the potential use of three types of policy instrument: liability, provision of information, and taxes.

Liability

There has been a resurgence in recent years of interest in liability as an alternative to environmental standards and Pigouvian taxes. Segerson has argued that making farmers or (with appropriate provisions for diligence on the part of farmers) manufacturers liable for damages from groundwater contamination will provide optimal incentives for pesticide use.

Liability is already a part of pesticide regulation: Farmers can sue manufacturers for poor product performance. As noted above, potential liability considerations have tended to prevent manufacturers from lowering maximum label application rates. Thus, liability is useful in addressing one

class of goals of pesticide regulation, that of protecting pesticide users. But what about the remaining goals—protecting workers, protecting the health of the public at large, and protecting the environment? The use of liability for ecological protection is ruled out by the need to demonstrate damage to specific individuals. Wildlife and environmental systems are not private property, so no grounds exist for seeking private remedies. More broadly, Menell argues strongly that liability is a poor instrument for rectifying externality problems such as environmental damage or health and safety risks to the general public caused by pesticide use. Proving a causal linkage between pesticide use by specific individuals and damage to specific individuals is virtually impossible; yet such linkages are the fundamental basis of damage awards. Procedural requirements make use of the tort system difficult, and use of the legal system is very costly. In practice, damage awards are so variable that it is difficult to gauge how the incentives for pesticide use are affected by the observed outcomes. In short, high transaction costs, overly stringent informational needs, and excessive variability in jury behavior make liability an unattractive policy instrument for externality problems. Viscusi argues on similar grounds that the tort system is largely unsuitable for dealing with occupational safety issues.⁶

Information

One can envision several ways in which the provision of additional information could make it possible for individuals to reach efficient solutions to problems associated with pesticide use: (1) quantitative information on efficacy (e.g., comparative yields) could help farmers select among pesticides; (2) information on the risks of pesticide exposure could help workers bargain more effectively over proper compensating wage differentials; and (3) information on pesticides in drinking-water supplies or residues on foods could help consumers determine the appropriate averting behaviors. One would not expect the provision of information to be of much help in reducing the risk of environmental damage external to the farm given the assumption that farmers determine pesticide use patterns out of self-interest.

⁶ Viscusi argues that workers' compensation is more effective than tort liability for improving worker safety, citing econometric evidence indicating that injury rates would be far higher in the absence of workers' compensation. A simulation study by Davis, Caswell, and Harper suggests that experience-rated workers' compensation would be an effective way of enforcing re-entry regulations for pesticides.

Of these three, provision of information probably has the greatest potential with respect to (2), worker safety. There is considerable evidence that the functioning of labor markets generates wage differentials that compensate workers for bearing excess risk, at least for acute health effects. There is also evidence showing that workers respond to new information in a way that is consistent with optimizing behavior (Viscusi and O'Connor). Complete information about risk is, of course, a necessary condition for these wage differentials to compensate workers fully.

Provision of more information will not necessarily lead to greater safety for farm workers. Theory suggests that full information will permit workers to obtain full compensation for bearing additional risk on the job; these higher wages will induce employers to enhance safety only if the savings in wage premiums outweigh the cost of safety measures. Most farm workers are poor. Many are illegal migrants, earning far higher wages than they would expect to receive at home. It seems plausible that most would demand low compensation for risk-bearing relative to workers who are better off, suggesting further that job safety would not be affected much by additional information.

There are also theoretical grounds for questioning the efficacy of information in enhancing worker safety. Complete information may not be sufficient because workers may not be fully rational, in the strict economic sense of the term. For example, Akerlof and Dickens demonstrate that compensating wage differentials do not arise in cases where workers exhibit cognitive dissonance. It is also not clear whether workers fully take into account chronic risks in wage bargaining.

In sum, it seems that providing workers with information about the health risks of the chemicals used, about application rates, and about likely exposure could be an important adjunct to current pesticide policy, rather than a substitute for direct regulation. The regulations on worker safety recently issued by EPA do call for greater notification, although they fall short of full disclosure; interestingly, the farm community argued strongly against notification on the grounds of excessive cost.

EPA's ability to provide farmers with efficacy information is more problematic. The value of having such information is attested to by the success of integrated pest management programs across the country. The issue for EPA is whether it can play a role by requiring manufacturers to provide such information as part of the registration process. There is good reason to believe that this information is best generated and disseminated at

the regional or local level. Pesticide effectiveness depends heavily on environmental conditions such as temperature, rainfall, initial pest population sizes, population sizes of predator or competitor species, and so on. Effectiveness varies across production regions as well as from year to year. Factors that are important in one area may not be important in another area. Furthermore, training may be needed to give farmers sufficient understanding to utilize a more information-intensive pest-management strategy (Pingali and Carlson); training requirements, too, are likely to vary across regions. Efficacy information presented from a national perspective would likely be either overly simple or overly complex.

It is well known that averting behavior is generally an important component of efficient solutions to externality problems (Coase; Olson and Zeckhauser). Providing consumers with information about pesticide residues in drinking water or on foods could enable them to engage in efficient averting behavior and might make socially efficient pesticide regulation possible. However, the costs of providing this information are likely to be high. First, testing water or produce for all the pesticides of potential concern is extremely expensive when feasible and often can be done only by a few advanced analytical chemistry laboratories; for example, a key component of EPA's recent survey of pesticide residues in groundwater was the development of analytical methods for testing multiple residues. Most laboratories are not equipped to conduct such tests. Residue levels vary over time (groundwater) and shipments of produce, so continuous testing would be necessary. Publicizing this information, for example by labeling produce, is also likely to be costly. This is particularly true for foods, since the produce sold at the retail level generally comes from many different growers, each using a somewhat different mix of pesticides; thus, labeling would be difficult and expensive to implement. Finally, consumers would need to invest substantial time and effort in developing the necessary information base and skills for processing this information; this, too, is likely to be a very costly activity.

Another alternative would be to test and label produce as simply residue-free.⁷ Experience with experiments along these lines is not encouraging.

⁷ Yet another possibility would be to label produce as meeting EPA standards for residues in foods. If all produce marketed does meet these standards (as it should to be legally saleable), then this amounts to providing additional information about current regulation, rather than being an alternative to that regulation. Such labeling could be warranted, but it is obviously not a substitute for direct regulation.

Several supermarket chains have experimented with this approach. Others have tried organic-produce sections. All seem to have abandoned their experiments due to lack of demand: There does not appear to be a sufficient number of consumers willing to pay a high enough premium on produce to justify the expense of testing and labeling or of maintaining an organic-produce section. This does not mean that regulation is not at all justified, that is, the costs of regulating residues on foods outweigh the benefits. In the first place, these programs provide reductions in residues below the EPA's residue standards. In the second place, marginal private testing costs (or additional cost of producing and marketing organic food) are likely to exceed the marginal costs of the national monitoring program conducted by FDA. Thus, these experiences do not show that the costs of FDA's monitoring program outweigh the benefits of meeting EPA's residue standards, nor do they rule out the possibility that more stringent residue standards could be justified in some cases.

In sum, high transaction costs suggest that information is a poor substitute for direct regulation in this context.

Pesticide Taxes

A third alternative to direct regulation is to impose Pigouvian taxes, giving farmers an incentive to reduce pesticide use to socially optimal levels. As Zilberman et al. note, taxes permit greater flexibility than direct regulation. Carlson (1977) has argued that pesticide taxes are preferable to direct regulation in that they are likely to involve less error because (1) there is more uncertainty about marginal damage from pesticide use than about demand (marginal benefit) and (2) marginal damage is likely to be more inelastic than demand.⁸

Taxes can affect whether a chemical will be used at all as well as application rates. A given pesticide will be used by farmers for whom the marginal net benefit of zero use exceeds the tax, and each farmer will adjust pesticide use to equate the marginal net benefit with the tax. Thus, taxes allow fine-tuning at the farm level, while direct regulation can discriminate at best only down to the county level. In contrast to direct regulation, taxes allow regulators to influence application rates in a continuous (rather than all-or-nothing) manner. Furthermore, taxes can be varied accord-

ing to indicators of environmental risk, such as leachability and acute or chronic toxicity, allowing regulators to influence farmers' choices among pesticides. Taxes of this kind would also exert influence on pesticide R&D, thus addressing EPA's long-run concerns.

In theory, taxes can substitute completely for usage restrictions. As a practical matter, setting the optimal tax for each chemical remains problematic. Optimal Pigouvian taxes should be set to the expected value of marginal damages at the optimal level of pesticide use. But the expected value of marginal damages is difficult to quantify; certainly, numerical estimates are not available. The difficulty is compounded by the fact that the optimal tax should vary across chemicals and regions, suggesting that computing these taxes may be extremely costly. Furthermore, we have very little evidence about the productivity of specific pesticides or about pesticide demand at the level of individual chemicals; yet this information is necessary to estimate optimal taxes.

Comparing ideal taxes to an admittedly imperfect system of direct regulation is obviously unfair. A more reasonable comparison would be between taxes and direct regulation aimed at reducing the total amount of a pesticide used to a predetermined level believed to involve acceptably low risks to human health and the environment. The key difference here is that setting taxes requires information about pesticide demand, which direct regulation does not. The trade-off is that taxes are potentially more efficient and thus involve lower losses of income to achieve the desired level of environmental protection. Whether this is true is an empirical question, and one worth investigating.

There are forms of direct regulation for which taxes probably cannot substitute. Taxes cannot be counted on to alter timing of application: pesticides are storable, so that purchasing and use decisions can be separated in time. This suggests that taxes cannot substitute for re-entry or preharvest intervals, or for residue tolerances, both of which are used to control timing of application and/or other farm operations.⁹

Implications for Economic Research

Pesticide regulation has assumed a heightened importance in recent years. As time passes, more and

⁸ In Weitzman's terminology, price instruments like taxes are preferable whenever the benefits function has low curvature relative to the cost function (pesticide demand is more elastic than damage); greater uncertainty about damage increases this advantage.

⁹ A system of fines for excessive residues on foods could be used for food safety but would not ensure the safety of harvest workers.

more is known about the adverse effects of pesticide use, leading to increased demand for regulation. Pesticides seem to have captured the public imagination as a major source of risk, further increasing demand for government intervention. At the same time, the re-registration process currently underway at EPA has led to voluntary cancellations of many pesticide uses; this is particularly true for fruits and vegetables and other "minor use" crops, in whose production pesticides play a major role.

In this context, it is important to develop ways of improving the efficiency of pesticide regulation. The instruments currently used to regulate pesticides tend to permit relatively little flexibility. The predominant instrument is an all-or-nothing decision about whether to permit use of a chemical. Selective registration by region or crop and alternative instruments such as re-entry regulation or residue tolerances give EPA some flexibility in dealing with specific problems, but this, too, is limited.

This paper considers three alternative approaches: liability law, provision of information, and taxes.

Liability law currently affects manufacturers' efforts to provide efficacious products, addressing one of EPA's three main goals. It is unlikely to be of much use for dealing with externality or worker-safety problems.

Provision of information is likely to be most useful in addressing worker-safety issues: more complete information should, in theory, allow workers to bargain more effectively over wage-safety trade-offs and thus be compensated adequately for the risk they bear (although greater safety will result only if the increased wage differentials exceed the cost of enhancing safety). The extent to which information can substitute for direct regulation, though, is not clear. We do not know whether wage differentials compensate workers for chronic risks, for instance. There is also reason to believe that the illegal-immigrant status of many farm workers allows growers to exert market power. Many farm workers are poorly educated; their ability to process risk information is also open to question. Finally, direct regulation may prove to be less costly than providing sufficiently complete information. In this regard, it is noteworthy that growers oppose greater notification during the recent negotiations over farm-worker protection regulations. It would be interesting to know whether they did so on political-economic grounds (because their own costs would be lower, for example) or because they felt that direct regulation would be more efficient. Further research along these lines is needed.

Taxes appear to be the most useful instrument for either supplementing or replacing direct regulation in most instances. Properly calibrated taxes should induce socially optimal application rates. At the very least, taxes can be used to meet the same goals that direct regulation now does: sufficiently high taxes should eliminate the use of certain pesticides except for emergency situations. Furthermore, varying taxes according to indicators of potential ecological or human-health damage should encourage the use of safer pesticides and discourage the use of more hazardous ones, and, in the long run, encourage R&D to focus on more desirable pesticide characteristics. Taxes are probably preferable to direct regulation in the second-best, Weitzman sense because pesticide demand is most likely more elastic than marginal damage from pesticides and because uncertainty about damage is large.

We do not, however, have an information base that would permit us to implement pesticide taxes, even to achieve risk standards comparable to those used today in direct regulation. We know too little about the productivity of and demand for classes of pesticides, much less individual chemicals. We know too little about substitutability between individual chemicals and between pesticides and other factors of production like land and labor. We know too little about the expected value of external damages from pesticide use. We probably know too little even to set targets for total applications in a region in anything but a rather arbitrary way. We do know that all of these vary across regions and that they are stochastic, making estimation more complex.

At present, estimates of pesticide productivity and demand are derived from the opinions of crop-production experts. These generally come in the wrong form to fit economic models: they are estimates of average, rather than marginal, changes in yield and cost due to registration or cancellation of a chemical. Moreover, they are often distorted by special pleading (see for example Ayer and Conklin). It would be preferable to have productivity and demand estimates based on observed behavior under field conditions, that is, econometric estimates. At the very least, such estimates could be used to validate expert opinion. There has been some progress in this regard in recent years, mainly at the level of classes of chemicals. Lichtenberg and Zilberman (1986a) developed a framework for understanding pesticide productivity, and Babcock, Lichtenberg, and Zilberman, and Carrasco-Tauber and Moffitt have applied it to apples and major crops, respectively. Foster and Babcock have demonstrated a method for estimating pesticide demand in cases where residue con-

straints are binding. Considerably more information is needed, however, especially at the level of individual chemicals and their production relationships with alternative chemicals and other factors of production.

Data availability has been a major limitation on the ability to estimate pesticide productivity econometrically. We need information at least at the level of classes of chemicals, at best at the level of individual chemicals. This information should be collected from a single growing region to ensure similarity of growing conditions. It also needs a time-series component to capture price effects, since pesticide prices tend not to vary much within a single region. It would be preferable to have observations on pest-infestation levels, or at least on environmental conditions (heat and humidity over the season, etc.) that could serve as proxies for them. Very few databases of this kind exist. Some data of this sort have been collected as part of integrated pest management efforts, but these data sets are usually designed by entomologists or plant scientists and tend to skimp on economic information such as pesticide prices or the use and prices of non-pest control inputs. Data on farm production collected by the Economic Research Service (e.g., the Farm Costs and Returns Survey) are designed for budgeting purposes. In most cases, it is impossible to obtain both prices and quantities simultaneously. More detailed surveys conducted by the Economic Research Service on specific crops contain information on acreage treated with numerous individual pesticides but no information on application rates or prices.

A final item of interest is the structure of the pesticide industry. The industry does not fit the perfectly competitive model well. Production costs are dominated by the high fixed costs of R&D, which tend to deter entry. The terms of pesticide regulation, that is, the specifications listed on the pesticide label, are determined by bilateral bargaining between the registrant and EPA. The context for this bargaining is determined by the supply of pest controls, which comes from an imperfectly competitive industry. Thus, the context in which EPA makes its regulatory decisions is dominated by the structure of the pesticide industry, making that structure an interesting and important topic for further study.

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