# Some Hard Truths About Agriculture and the Environment


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Environmental problems in agriculture have proven difficult to address due to the spatial heterogeneity and temporal variability intrinsic to agriculture. Agriculture is largely a struggle against nature; both its sustainability and the prospects for improving environmental performance and farm income simultaneously are thus inherently limited. Agriculture's high degree of variability makes direct regulation inefficient. Subsidies for improving environmental performance can have negative consequences and have proven ineffective in practice, due largely to bureaucratic culture. Pollution taxes should be the most effective and efficient form of policy. Interdisciplinary research is needed to provide models for performance evaluation.



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Figuring out how to handle environmental problems in agriculture has been extremely difficult—for academics as well as policy makers. On the one hand, there is a long-standing tradition of viewing farming as an industry that is intrinsically in harmony with nature, at least when conducted as it ought to be. Recently, however, the popular conception of farming has tended more toward a diametrically opposite view. In many ways, agriculture was the catalyst for the contemporary environmental movement: Rachel Carson's 1962 treatise, *Silent Spring*, remains a standard reference for today's environmentalism. And agriculture has remained one of the "usual suspects" in environmentalists' lineup of malefactors.

The standard litany of environmental abuses of modern society contains numerous contributions from agriculture, including, among other things: ecological damage from pesticides such as wildlife kills and depletion of pollinator populations; human health risks from pesticides from worker exposures, spray drift, residues on foods, and from leaching into well water; surface water quality problems due to nutrient runoff and leaching like the notorious anoxic "dead zone" in the Gulf of Mexico, the disappearance of underwater grasses in the Chesapeake Bay, the salinization of San Francisco Bay, and BOD depletion in rivers and lakes throughout the country; nitrate contamination of well water from leaching of fertilizers and animal wastes; odor from concentrated animal feeding operations, notably hogs; bacterial contamination from spills from waste lagoons; and air pollution from animal feeding operations, burning straw, and dust.

Popular perceptions notwithstanding, the extent to which agriculture contributes to these problems remains fiercely contested in scientific circles. What policies to adopt are no less hotly debated. In this paper, I draw on almost three decades of scholarship and practical policy experience to offer some general lessons about how to devise policies for addressing these problems, the likely limitations of those policies, and how we as economists can best contribute to the formulation of better policies. I begin with a discussion of what I believe to be key inherent features of agriculture itself. I then consider the implications of those features for policy and for research.

In some important ways, those implications are not particularly heartening (hence the title of the paper). It turns out there are limits to what can be


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said and done about these problems: There are limits to our ability to generalize about them—which is a problem because policy discussions always revolve around generalizations—and there are limits to the degree of efficiency any policy can attain. Further, those policies likely to be most effective are unlikely to be popular with the farm community and governmental agricultural agencies—two of our most important constituencies. They may be equally unpopular with environmental groups and agencies, putting us in an uncomfortable position politically. Such a position might be an illustration of the popular saying "if all sides disagree with you, you must be doing something right"; but it's nonetheless disquieting. Finally, the research most needed to inform policy is of a kind that is especially difficult to conduct and often least rewarding from a disciplinary perspective.

## Agriculture as Resource Extraction

Farming is characterized by several fundamental differences compared to production in most other industries. First, it is, at bottom, a resource extraction industry where production occurs primarily under uncontrolled natural conditions. Like fishing or forestry, farming involves harvesting biota, i.e., living organisms (plants, animals). And also like fishing or forestry, this harvesting takes place out-of-doors in the habitat of the biota being harvested.

Farming is clearly managed more intensively than renewable resource industries which harvest naturally occurring wild populations, such as fisheries—farmers prepare and manipulate the habitat in which these biotic resources grow as well as establishing initial population sizes. But farming is clearly controlled to a much lesser degree than, say, manufacturing or services, where production occurs under tightly controlled conditions, i.e., where the quality of inputs and the production environment can be manipulated at will by the firm (think about the completely sterile conditions under which semiconductors are made).

Instead, farming takes place out-of-doors, where it's subject to all of the vagaries of the weather and where the physical, chemical, and biological characteristics of land vary in subtle, often difficult-to-measure ways. So even though farming involves more control than, say, fishing and forestry, the degree of control achieved is orders of magnitude below the standard in manufacturing or services.

Basically, crop farming amounts to trying to manipulate crop ecosystems so that the mix of plants favors desirable species and contains few of the undesirable ones. But because crop ecosystems are also being influenced by factors that cannot easily be observed or predicted, control over them is always limited.

This dependence on natural conditions means agriculture is characterized by substantial, ineradicable spatial heterogeneity and temporal variability. Natural factors like soils, topography, climate, and pest pressure vary significantly from one location to another—sometimes within fields and farms just as much as between fields and farms. Other natural factors, like temperature, rainfall, solar radiation, and pressure from specific weeds, insects, and diseases, vary from day to day within seasons and from year to year.

While firms in other industries face spatial and temporal variability in production conditions because of location, differences in endowments of human capital, weather, and so on, that variability generally doesn't persist in the long run because firms can relocate, train or bring in new workers, construct plants and equipment designed to protect production from the weather or compensate for it, etc. But as long as farming takes place out-of-doors, and as long as crops are planted in natural soils, agriculture will be subject to spatial and temporal variability even in the long run. Another way of expressing this idea is that in agriculture it's not possible to replicate the least-cost technology production unit because the variability in natural factors like climate, soils, pest pressure, weather, and water availability can't be engineered away. Because these factors affect both agricultural production and environmental quality, both spatial and temporal variability persist even in the long run.

## Limited Generalizability of Environmental Problems

One implication of this resource- or ecosystem-based perspective is that it is very difficult to generalize about environmental problems associated with farming. Take, for example, the problem of nutrient runoff and leaching from fertilizer. A given application of nitrogen fertilizer can result in substantial emissions into surface water when growing conditions are bad, because under these conditions a lot of residual nitrogen is left in the soil at the end of the growing season. But exactly the same application on the same field can result in little or no runoff and leaching when growing conditions are good, because most of the nitrogen is taken up by the crop. Similarly, a given application of nitrogen can cause runoff and leaching on sandy soils which don't hold nutrients well, but little or no leaching on heavier soils with better water- and nutrient-holding capacity. As a result, high nitrate concentrations in groundwater are a serious problem in a few locations but extremely rare throughout most of the country (U.S. Environmental Protection Agency, 1990).

The same can be said about pesticides. A given application of some insecticides can cause fish kills when made to a field near a stream when the wind is blowing strongly enough in the right direction, and yet no damage at all when made to fields farther from the stream or at times when there is little wind. Similarly, atrazine applied to corn and soybeans shows up in surface water when heavy rainstorms occur shortly after application, but not otherwise. And atrazine is observed in significant concentrations in groundwater, but only in a handful of locations around the country where conditions are exceptionally favorable for leaching.

In sum, it's rarely possible to generalize broadly about environmental problems in agriculture for policy purposes, except in the vaguest terms. Such generalizations may prove useful for mobilizing political support by partisans of one side or another in policy debates, but they add little to substantive understanding of the scope of the problems under discussion and of the measures most likely to be productive in tackling those problems.

**Limits on Sustainability**

Another implication of this resource- or ecosystem-based perspective on the nature of agriculture is that there are real limits on the "sustainability" of agriculture. Agriculture itself is inherently unnatural in a fundamental sense, because it involves an attempt to maintain ecosystems unable to last without continuous human intervention. Rarely, if ever, do ecosystems as lacking in biodiversity as fields of crops, orchards, vineyards, or tree plantations occur in nature. If they do by some chance occur, they don't endure because of the bounty they offer to weed competitors, herbivorous insects, plant parasites, and diseases. They also don't endure because of evolutionary obstacles: Maintenance of these artificial ecosystems amounts to exercising natural selection pressure which essentially breeds better pests, i.e., organisms better suited to exploiting the ecological opportunities we insist on offering year after year.

It is not an exaggeration to say that all of agriculture is intrinsically a struggle *against* nature, an attempt to impose and maintain ecosystems dramatically distorted to serve human wants in the face of persistent countervailing ecological pressures. While it makes sense to exploit natural forces as much as possible, complete harmony with nature is impossible. The kind of productivity needed to sustain a standard of living high enough to support civilization cannot be achieved without fighting nature, as the history of agriculture, replete with periodic crop failures and famines, amply attests. [More recently, Olmstead and Rhode (2002) have documented the extensive breeding effort needed to simply maintain wheat yields at existing levels in the United States in the late 19th century.]

From this perspective, the accomplishments of contemporary agriculture, so often maligned as "factory farming" which produces tasteless food and degrades the environment, are truly remarkable. The fact that so few people and such little land are needed to produce such an abundance of food and fiber is a real testament to the productive power of contemporary agriculture, as is the fact that agricultural productivity has grown consistently at a rate of about 2% a year for the past 50 years (Ball et al., 1994; Gardner, 2002).

What this means is there are few, if any, easy ways to improve the environmental performance of agriculture. The scope for "win-win" solutions to environmental problems emanating from agriculture is limited. There is little prospect that farming more "naturally" will be adequate to maintain current living standards. In other words, tackling environmental problems in agriculture involves tradeoffs, i.e., substituting other scarce factors of production for the disposal capacity of the environment. The idea that tradeoffs are inherent in policy decisions is standard fare for economists. Yet many (if not most) in the policy arena cling to the notion it will be possible to solve environmental problems in agriculture in ways that benefit farmers.

**Limitations of Technological Fixes and "Win-Win" Solutions**

The scope for "win-win" solutions benefitting both farmers and the environment is further limited by the location- and time-specific nature of agricultural pollution problems, which make it very difficult to devise simple technological fixes that can be applied broadly. Agriculture has nothing equivalent to installing scrubbers on smokestacks or the chemical and biological processing used to remove nutrients and bacteria from wastewater.

To be sure, agricultural R&D efforts have been strikingly successful in developing some farming methods and equipment designed to reduce environmental spillovers. Many of these developments seemingly improve agricultural productivity while simultaneously protecting the environment, which makes them extremely attractive because they apparently involve such little pain and sacrifice. On closer examination, though, all of these technologies clearly involve substitution of management (in terms of both expertise and time expended) for nature.[1] Such a substitution may appear to increase profit because returns to management are a residual in the owner-operated farms that predominate in the United States. But the costs are all too real to farmers.

Consider, for example, the class of farming equipment which improves application efficiency, whereby a larger percentage of the inputs applied goes to the target rather than into the environment at large. This class includes what can broadly be considered precision agriculture systems such as low-volume irrigation systems that permit delivery of water (and dissolved chemicals) timed to match crop uptake, and thus reduce water application and drainage; variable rate application equipment that makes it possible to adjust fertilizer application rates in accordance with natural soil fertility; and improved pest monitoring methods and spray equipment that make it possible to reduce pesticide application rates and limit spraying to areas of high infestation (National Research Council, 1997).

The effects of these technologies on agricultural productivity and on environmental spillovers vary a lot from location to location and year to year. In some locations, in some years, they improve both agricultural productivity and environmental performance a great deal, while under other conditions they do very little. Moreover, the degree to which they improve productivity and reduce environmental spillovers, even on average, depends critically on the degree to which they are adapted to local and seasonal variations in natural conditions.

For example, getting efficiency improvements from low-volume irrigation requires knowledge of crop uptake rates, which vary according to the stage of plant growth, weather conditions, and soil quality—all of which vary from field to field and farm to farm. Similarly, precision fertilizer application requires knowledge of existing soil fertility levels, which can vary substantially even within fields of a uniform soil type. And it requires more sophisticated knowledge of crop fertility response than we have now (most fertilizer recommendations are rough rules of thumb with little solid conceptual or empirical basis). Precision application of pesticides requires monitoring of pest infestation levels, population counts of beneficial organisms that serve as natural pest controls, and knowledge about potential yield damage, which varies according to pest pressure and stage of plant growth.

In other words, use of these technologies requires sophisticated management, including on-the-spot adaptation to local conditions that vary in space (sometimes at the subfield level) and time. None of these technologies is a turnkey system just needing to be installed to get results; instead, each requires considerable customization and a great deal of skill and expertise.

This critical dependence on human skill and judgment makes agriculture very different from manufacturing in how it adapts to new technologies. In manufacturing, new technologies can be embodied in machinery and equipment. In agriculture, machinery and equipment are necessary but not sufficient conditions for technological improvements. Spatial and temporal variability make human skill and judgment absolutely critical in implementing new technologies. As a result, technical fixes involve more than just installing or using new equipment—they involve implementing new farming systems and adapting them to conditions that vary from place to place within farms (as well as between them) and from year to year. And they require farmers to adopt new forms of management and acquire new sets of skills.

Up until now, the principal policy for tackling environmental problems like nutrient emissions, soil erosion, and animal wastes has been to rely on public-sector development of new farming systems to provide technological solutions for these problems. As Huffman and Evenson (1993) have pointed out, the development of most agricultural technologies will be left to the public sector because their management-intensity and need for customization make intellectual property rights difficult to obtain and enforce, and consequently the returns from the development of new farming practices and/or management strategies are generally too low to justify significant private R&D.

[1] I am indebted to my colleague Doug Parker for this observation.

While such new technologies are a necessary condition for environmental improvements, they are by no means sufficient. Farming is a business. Farmers need to respond to the pressures of the market if they're going to be able to stay in business and, for the most part, farmers adopt new farming systems when and if they prove to be more profitable than the alternatives.

The successes we've had over the past 70 years show this quite clearly. Consider the case of soil erosion. The United States has been extremely successful in reducing erosion problems. U.S. soil erosion rates today are a small fraction of what they were just 70 years ago (Trimble, 1999; Trimble and Crosson, 2000; U.S. Department of Agriculture, 2000). This progress was the result of a great deal of public-sector effort, including the development of farming systems for reducing erosion under a wide variety of conditions, conducted by the USDA and by the land grant university system, as well as extensive promotion of these farming systems by extension and local soil conservation districts. But the use of soil conservation measures became widespread when it was economically efficient to adopt them. For example, widespread adoption of conservation tillage was due largely to changes in the relative prices of fuel and herbicides, making it more profitable than traditional tillage.

The case of integrated pest management (IPM) suggests market forces alone will generally not suffice to get farmers to make adequate use of the pollution-reducing technologies we already possess. The development of integrated pest management strategies was the result of intensive research effort at land grant universities, USDA's Agricultural Research Service, and other public agricultural research entities. Dissemination of IPM strategies among farmers was also due to intensive effort on the part of extension, including training IPM consultants in proselytizing the virtues of IPM among farmers. But widespread adoption of IPM was also due to the Environmental Protection Agency's (EPA's) aggressive use of its regulatory authority over pesticide marketing, which gave pesticide manufacturers good reasons for finding ways to fit their products into IPM systems and for including IPM in their usage recommendations.

More generally, the absence of regulation creates a bias against using precision application systems. Chemicals are cheap for farmers (especially when disposal of wastes into the environment is costless, as occurs in the absence of regulation), while management, which places a burden on farmers' time and expertise, is expensive. Without the incentives provided by regulation, it's more cost-effective for farmers to rely more on chemicals than on management—for example, by spraying pesticides preventively rather than monitoring fields and spraying according to an economic threshold, or by applying fertilizer at planting time rather than monitoring crop growth conditions and applying fertilizer in response to ongoing crop demand.

In a nutshell, new agricultural technologies—specifically, new farming systems—are a necessary condition for further improvements in the environmental performance of agriculture. But they are by no means sufficient. Without more stringent environmental regulation, there is little hope of substantial additional progress.

## Superiority of Incentives over Direct Regulation

The need for more stringent regulation raises the question of the appropriate form of regulation. To date, environmental agencies have relied mainly on forms of direct regulation. That approach has proven problematic, in large part because the local scope, spatial heterogeneity, and temporal variability characterizing both the environmental problems emanating from agriculture and the technical means for addressing them make it extremely difficult—if not impossible—to formulate direct regulations that make any sense.

Consider, for example, the case of nutrient management regulations in Maryland, legislated in response to the Pfiesteria crisis of 1997. Those regulations specify that commercial fertilizers and manure must be applied in accordance with a nutrient management plan formulated by a certified technician. As noted above, efficient nutrient application rates vary from year to year depending on soil moisture, temperature, sunshine, etc., and thus an application rate that is efficient in a good year can constitute gross overuse in a bad one. But a nutrient management plan must accommodate both contingencies—both good and bad years. In order to do so, it has to specify ranges of application rates, making the plan virtually meaningless as a regulatory instrument.

Most environmental problems in agriculture present the same kinds of difficulties—spatial heterogeneity and temporal variability make it virtually impossible to write regulations specifying exactly what measures farmers ought to take (and to verify the measures they have taken are appropriate). Of course, the predominance of spatial heterogeneity and temporal variability in and of themselves gives us a strong reason to believe direct regulations are inferior to incentives as a means of addressing environmental problems in agriculture.

A substantial body of research has demonstrated that spatial heterogeneity makes incentives superior to direct regulation. In fact, we know from general principles that the greater the degree of heterogeneity among firms, the greater the superiority of incentives over direct regulation (Caswell and Zilberman, 1986; Lichtenberg, 1989, 2002). Furthermore, applying Weitzman's prices-versus-quantities analysis to farming indicates that when farmers can respond to temporal variability, incentives are preferable to direct regulation unless marginal environmental damage is a lot more responsive to temporal variations than agricultural production (Lichtenberg, 2002).

## Superiority of Taxes over Subsidies

Perhaps the second most important policy approach to problems like nutrient pollution and animal wastes has been to offer subsidies for farmers adopting resource-conserving farming systems intended to reduce adverse environmental effects. Economic research has shown there are significant problems associated with those kinds of subsidies. They give farmers incentives to expand production onto land which could well be even more environmentally sensitive (Caswell and Zilberman, 1986; Lichtenberg, 2002). These subsidies are also prone to targeting problems that limit their effectiveness (Malik and Shoemaker, 1993; Lichtenberg and Smith-Ramirez, 2003). In many cases they are subject to implementation problems: Unless they are linked to durable changes in the landscape which can be monitored accurately at relatively infrequent intervals (and thus low cost), green payment contracts are not enforceable because of the difficulty of verifying the contracted actions have actually been taken by farmers (Lichtenberg, 2002).

There have been practical problems with these programs as well. The kinds of policies we've relied on in the United States are basically retooled policies for promoting soil conservation, paying farmers to divert erodible land or share the costs of installing conservation practices. They do not seem to have been adapted very well to handling broader problems of environmental degradation. As empirical studies of the Conservation Reserve Program have shown, these policies have been implemented in ways that maximize transfers to politically influential groups of farmers and, as a consequence, minimize their environmental performance (Reichelderfer and Boggess, 1988; Ribaudo, 1989; Babcock et al., 1997; Feather and Hellerstein, 1997). Empirical studies of cost sharing demonstrate similar problems—specifically, an emphasis on enhancing farm productivity to the detriment of protecting water quality, and the imposition of design requirements and other transaction costs that can actually reduce conservation effort (Bastos and Lichtenberg, 2001; Lichtenberg and Smith-Ramirez, 2003).

Bureaucratic culture may be one reason why conservation subsidy programs have not been adapted very well to meeting environmental goals. Agricultural agencies at the federal, state, and even local levels have a political constituency—the farm community. These agencies see themselves as being in the business of helping this constituency, both directly and by representing them in interagency debates within government. R&D is consistent with that mission, as is distributing subsidy funds. Regulation is not consistent with that mission, since it necessarily puts the agencies in an adversarial relationship with farmers.

As a result, when managed through an agricultural agency, every program aimed at promoting environmental goals is ultimately administered in a way that maximizes benefits to farmers, even when doing so minimizes the environmental achievements identified as the principal ostensible reason for the program in the first place. Enforcement of the conservation compliance provisions of existing farm legislation demonstrates this tendency: Sixty percent of non-compliance determinations were waived on appeal, mostly on grounds that did not seem very sound (U.S. General Accounting Office, 2003).

In sum, relying on conservation subsidies as the main policy for handling environmental problems in agriculture violates the principle of specialization in policy instruments. Generally speaking, each policy objective should be addressed with its own policy instrument. Adding consideration of bureaucratic culture suggests positive services rendered to farmers ought to be separated from functions like environmental regulations which are inherently negative and adversarial.

The upshot of this line of argument is that tackling environmental problems emanating from agriculture requires serious consideration of the use of negative incentives—specifically, taxes on polluting inputs used in agriculture or on ambient concentrations of pollutants known to emanate from agriculture. Such a message will obviously not be popular with the farm community. Consequently, it is likely to be equally unpopular with agricultural agencies at the federal, state, and local levels, all of whom view the farm community as their political constituency and recognize that policies which penalize farmers are at odds with their fundamental relationship with the farm community. Likewise, such a message may not be popular with environmental groups either; they tend to mistrust incentive-based approaches to environmental regulation because they don't necessarily require regulators to know concretely what actions regulated firms have taken, which creates an appearance of inaction.

## Efficiency of Agricultural Pollution Taxes

I have argued that pollution taxes are the most effective way to meet environmental objectives in agriculture. Nevertheless, it is important to recognize there will be limitations on how efficient those pollution taxes can be, due to (*a*) the nonpoint source nature of many of these pollution problems (which limits performance monitoring),[2] and (*b*) the fact that to be fully efficient, pollution taxes will often need to be adjusted for location, crop type, farming system, weather, and other factors—adjustments which may prove impractical or even infeasible. Even it proves infeasible to implement pollution taxes that are fully efficient, however, economic theory and practical experience suggest pollution taxes will outperform any of the other policy instruments at our disposal. In the words of a common Washington adage, "it is important not to let the perfect be the enemy of the good"—i.e., our inability to attain an ideal should not be a deterrent to implementing policies which perform well. And for many problems, we can expect pollution taxes to perform quite well.

Consider the case of pesticides. Environmental damage from pesticides typically correlates with the formulation (and thus application method) used and the location of the field to which pesticides are applied. For that reason, it should be feasible to impose differential taxes on different formulations of any given pesticide active ingredient (e.g., liquid versus granular) (although additional measures may be required in some cases to prevent dealers or farmers from evading higher taxes by reformulating pesticides themselves). Similarly, it should be feasible to impose differential taxes on pesticides purchased in different regions (although it may be necessary to simultaneously implement enforcement measures to limit smuggling). In fact, existing pesticide regulation provides precedents for differential treatment like this: EPA has banned certain formulations while leaving other formulations of the same compound on the market, and has canceled the registrations of chemicals in specific states or growing regions while permitting legal use to continue in other areas. It should, moreover, be feasible to set differentials in tax rates so that they constitute a reasonable approximation to needed adjustments for risks to human health and the environment.

Erosion should also be straightforward to handle. Environmental damage from erosion (sedimentation, nutrient pollution) typically varies according to topography, soil characteristics, location (e.g., proximity to streams), crop choice, and farm production practices, all of which are observable at reasonably low cost. In contrast to variable input use, most farm practices with significant effects on erosion leave a lasting imprint on the landscape, so they're easily observed. In principle, then, it should be fairly easy to levy erosion taxes on farmland, adjusted for crop type and farming practices that come close to being first-best.

Nutrient runoff and leaching from fertilizers, on the other hand, are likely to be much less tractable than either pesticides or soil erosion. Environmental damage from fertilizers typically varies according to both cropping pattern and attributes of land quality such as slope and soil texture. As a result, first-best fertilizer taxes would have to vary by land quality, technology, and seasonal conditions—which would be difficult to do. Because farmers use the same fertilizer formulations on different crops and different types of land, it would be hard to

[2] The nonpoint source nature of agricultural pollution problems arises largely from persistent spatial heterogeneity and temporal variability, which make it excessively costly to monitor emissions from individual farms. Pollutants tend to be diffused within each field, with small amounts of emissions entering the environment from many different places in each field. Farms (and even individual fields) differ in terms of soils, topography, and other factors that influence crop uptake, the ability of soils to hold nutrients and pesticides, factors that attract or repel animals, etc. As a result, emissions differ within fields and across farms, creating a need for excessively extensive monitoring. Unfortunately, one cannot use a representative farm as a sufficient statistic for all—or even large classes of—farms. While it might be possible in principle to measure factors that influence leaching, runoff, air emissions to use as proxies for emissions, there is enough heterogeneity across fields to make measuring those factors very expensive. And current knowledge is inadequate to permit derivation of formulas reliable enough for policy. In addition, emissions vary stochastically, making monitoring by random periodic inspections too inaccurate for policy purposes. That randomness makes it too easy for periodic inspections to miss significant emissions, which often occur during rare weather events like major rainstorms.

impose differential taxes at the point of sale. Variations in yield can't provide a basis for a differentiated fertilizer tax because yield variations are caused by many factors, including ones which are not readily observable (e.g., seed variety, pest infestation levels, microclimate), making it difficult to infer fertilizer application rates from observed yields. Also, the degree to which fertilizer use causes problems depends critically on weather conditions, so it varies markedly from year to year. As noted previously, the same amount of fertilizer can result in absolutely no runoff and leaching under some growing conditions, and significant runoff and leaching under others—which means fertilizer taxes would have to be adjusted for weather in order to induce a first-best.

A number of economists have suggested using mechanism design as a basis for developing fertilizer taxes, arguing fertilizer use is subject to problems of hidden information (see, for example, Wu and Babcock, 1995, 1996). Their underlying postulate is that farmers know a lot about conditions on their farms and make their fertilizer use decisions accordingly, while regulators can't observe those conditions or farmers' fertilizer use and can't infer fertilizer use from things they can observe, like yields.

Unfortunately, hidden information mechanisms don't really work for agricultural chemicals because they're not self-enforcing. In essence, a mechanism designed for hidden information is a nonlinear pricing scheme (in our case, a nonlinear tax scheme), allowing the regulator to acquire information that is the farmer's private property. This process of information acquisition occurs only when certain conditions are met. First, information must be linked to something observable and subject to market transactions. Second, market transactions for this good or service must be equivalent to revealing the private information. This is the essence of the standard monotonicity condition—it means one can infer private information from market transaction. Third, the linkage between the amount of good or service purchased and private information must be firm, i.e., the two have to be nonseparable. Resale, collective purchases, and storage suffice to break this linkage. Only in the absence of these secondary markets will truthtelling be self-enforcing in the sense that market transaction actually reveals the private information.

Problems involving chemicals don't meet these conditions and are thus not susceptible to the standard hidden information approach. For example, a mechanism featuring a marginal tax on fertilizer that increased with the quantity purchased could easily be circumvented by farmers buying fertilizer in smaller quantities than they wish to use, i.e., by farmers making more trips to the supply store than they otherwise would. Similarly, a mechanism featuring a marginal tax on fertilizer that decreased with the quantity purchased could easily be circumvented by collective purchase—having farmers join together to buy their fertilizer in bulk, then splitting up the fertilizer after purchase.

For all these reasons, it seems to me that environmental problems associated with fertilizer runoff and leaching present the greatest difficulty for devising efficient policies, and thus are the problems most in need of creative new thinking. Because they are also the most widespread environmental problems here in the United States, creative ideas have perhaps the highest payoff in terms of potential policy improvements.[3]

## Concluding Observations

To be fair, there has been a great deal of progress in dealing with some of the adverse environmental effects of modern agriculture, most notably with pesticides and soil erosion. Nevertheless, the opportunities afforded by existing policies seem to be reaching their limits. In the case of pesticides, of course, direct regulation was sufficient for removing the most damaging compounds from the market and for helping convince farmers of the need to use pesticides more judiciously (lest careless use lead to removal of still more pesticides from the market). But the tradeoffs we now face are increasingly complex, putting them beyond the scope of what direct regulation can accomplish with any degree of efficiency. We've had much less success in dealing with nutrient emissions and animal waste problems, which have received little or no regulatory oversight.

I have argued here a shift to pollution taxes would make regulation easier and more effective. The reasons I gave mirror the classic arguments for the superiority of the price system as a means of

[3] Jim Shortle has suggested that taxing excess, rather than total, nutrients (as has been used in Belgium and the Netherlands) might improve the performance of fertilizer taxes. Such an approach could provide a reasonable adjustment for weather-induced variations in leaching and runoff, but would likely involve enforcement problems similar to those encountered under nonlinear tax schemes. The central difficulty involved in devising efficient policies for fertilizers is the sheer number of dimensions of variability.

allocating resources. Incentives allow farmers to adjust their actions to the conditions they face, which is important given the spatial heterogeneity and temporal variability inherent in agriculture. Incentives also allow farmers to adjust their actions to their individual level of expertise and management ability. And incentives economize on the information regulators need to have—they put the emphasis back on monitoring environmental performance rather than trying to second-guess what farmers might do. Since theory and experience have taught us that subsidies don't work well for reasons of both basic economics and sound administration, pollution taxes are left as the instrument of choice.

Agricultural pollution taxes face some formidable administrative and political challenges. But I think there are some grounds for optimism, provided that, as a profession, we persist in our advocacy. After all, the introduction of emissions trading into air pollution regulation was feasible largely because the economics profession consistently advocated it in the policy arena and in the classroom.

Aside from political problems, there remains an important technical obstacle to tightening up environmental regulation of any kind aimed at agriculture—the lack of reliable means of monitoring performance. The nonpoint source nature of most agricultural pollution problems makes it extremely difficult to monitor policy performance directly. Instead, it's necessary to rely on a combination of observations of ambient environmental quality and models that allow us to attribute changes in ambient environmental quality to various sources (National Research Council, 2001).

Unfortunately, most of the models currently in use do a very poor job of linking farming activities with ambient environmental conditions. Standard simulation packages like EPIC or the Universal Soil Loss Equation attempt to model impacts only at field boundaries, ignoring transport and environmental fate. As a result, the estimates they produce provide very little information about linkages between changes in farming and changes in ambient environmental quality, as Trimble and Crosson (2000) have demonstrated for soil erosion [see also Braden et al. (1989) for a discussion of the importance of transport and environmental fate processes for policy formulation].

This dearth of models needed for policy analysis suggests it is absolutely essential for economists to get our hands dirty in the interdisciplinary work of producing models linking farming with actual ambient environmental quality. Unlike many disciplines, training in economics emphasizes analytical and systems thinking and the primacy of performance over process, conceptual foundations which give economists a better sense of how to formulate and utilize models for policy analysis than natural scientists. But that training alone does not suffice; economists need to learn enough of the natural science to be able to extract from the scientific literature and from interdisciplinary interactions a sense of which processes and parameters are key, of what can be simplified productively and what cannot.

There are many ways in which this kind of interdisciplinary work is frustrating. It takes time to form compatible partnerships and establish productive working relationships. Interdisciplinary work also involves greater academic risks. It is often difficult to publish interdisciplinary work in journals that matter the most in terms of disciplinary academic recognition. Nevertheless, the rewards on the policy side may provide some compensation for those risks (as may the chance of high impact publication). The fields of agricultural and resource economics both evolved from our broader discipline of general economics in response to a need to address specific policy questions. Continuing that tradition today requires training ourselves and our students in the scientific aspects of agricultural pollution problems; without that training it will not be possible for us to make real contributions to policy in this area.

## References

Babcock, B. A., P. G. Lakshminarayan, J.-J. Wu, and D. Zilberman. (1997). "Targeting Tools for the Purchase of Environmental Amenities." *Land Economics* 73, 325–339.

Ball, V. E., C. Bureau, R. Nehring, and A. Somwaru. (1994). "Agricultural Productivity Revisited." *American Journal of Agricultural Economics* 79, 1045–1063.

Bastos, G. S., and E. Lichtenberg. (2001). "Priorities in Cost Sharing for Soil and Water Conservation: A Revealed Preference Study." *Land Economics* 77, 533–547.

Braden, J. B., G. V. Johnson, A. Bouzaher, and D. Miltz. (1989). "Optimal Spatial Management of Agricultural Pollution." *American Journal of Agricultural Economics* 71, 404–413.

Caswell, M. F., and D. Zilberman. (1986). "The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology." *American Journal of Agricultural Economics* 68, 798–811.

Feather, P., and D. Hellerstein. (1997). "Calibrating Benefit Function Transfer to Assess the Conservation Reserve Program." *American Journal of Agricultural Economics* 79, 151–162.

Gardner, B. (2002). *American Agriculture in the Twentieth Century: How It Flourished and What It Cost.* Cambridge, MA: Harvard University Press.

Huffman, W. E., and R. E. Evenson. (1993). *Science for Agriculture: A Long-Term Perspective.* Ames, IA: Iowa State University Press.

Lichtenberg, E. (1989). "Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains." *American Journal of Agricultural Economics* 71, 187–194.

———. (2002). "Agriculture and the Environment." In B. L. Gardner and G. C. Rausser (eds.), *Handbook of Agricultural Economics* (pp. 1249–1313). Amsterdam: Elsevier.

Lichtenberg, E., and R. Smith-Ramirez. (2003, July 28–30). "Cost Sharing, Transaction Costs, and Conservation." Paper presented at annual meeting of the American Agricultural Economics Association, Montreal, Canada.

Malik, A. S., and R. A. Shoemaker. (1993, June). "Optimal Cost-Sharing to Reduce Agricultural Pollution." Technical Bulletin No. 1820, Economic Research Service, U.S. Department of Agriculture, Washington, DC.

National Research Council. (1997). *Precision Farming.* Washington, DC: National Academy Press.

———. *Assessing the TMDL Approach to Water Quality Management.* Washington, DC: National Academy Press, 2001.

Olmstead, A. L., and P. W. Rhode. (2002). "The Red Queen and the Hard Reds: Productivity Growth in American Wheat, 1800–1940." *Journal of Economic History* 62, 929–966.

Reichelderfer, K., and W. G. Boggess. (1988). "Government Decision Making and Program Performance: The Case of the Conservation Reserve Program." *American Journal of Agricultural Economics* 70, 1–11.

Ribaudo, M. O. (1989). "Targeting the Conservation Reserve Program to Maximize Water Quality Benefits." *Land Economics* 65, 320–332.

Trimble, S. W. (1999). "Decreased Rates of Alluvial Sediment Storage in the Coon Creek Basin, Wisconsin, 1975–93." *Science* 285, 1244–1246.

Trimble, S. W., and P. Crosson. (2000). "U.S. Soil Erosion Rates—Myth or Reality?" *Science* 289, 248–250.

U.S. Department of Agriculture. (2000, December). "Summary Report: 1997 National Resources Inventory (revised)." USDA/Natural Resources Conservation Service, Washington, DC.

U.S. Environmental Protection Agency. (1990). "National Survey of Pesticides in Drinking Water Wells, Phase I Report." EPA Pub. No. 570/9-90-015, Washington, DC.

U.S. General Accounting Office. (2003, April 21). "Agricultural Conservation: USDA Needs to Better Ensure Protection of Highly Erodible Cropland and Wetlands." Pub. No. GAO-03-418, Washington, DC.

Wu, J.-J., and B. A. Babcock. (1995). "Optimal Design of a Voluntary Green Payment Program Under Asymmetric Information." *Journal of Agricultural and Resource Economics* 20, 316–327.

———. (1996). "Contract Design for the Purchase of Environmental Goods from Agriculture." *American Journal of Agricultural Economics* 78, 935–945.