Chapter 7

Research and Development

Research and development are important tools in reducing agricultural nonpoint-source pollution because they provide producers and society with more efficient ways of meeting environmental goals. However, producers and private firms will likely underinvest in research and development on improving water quality. Public involvement is therefore necessary either to carry out this research or to provide producers and the private sector with incentives (economic incentives or regulations) that result in more efficient research investments. Finally, R&D cannot independently provide a solution to water quality problems. Instead, it is a valuable component of other approaches.

Introduction and Overview

Extensive public and private resources are devoted each year in the United States to agricultural research and development. Research and development can provide producers with new or improved inputs, technologies, and management techniques that can address concerns such as productivity, net income, and environmental quality. In this chapter, we discuss the role of research in reducing water pollution generated by farming and the factors that generate demand for innovation. We show that incentives for private research are inadequate because many benefits of research are not captured by private markets. In other words, there are social benefits from research that do not result in returns to investors. Consequently, research will be underfunded relative to levels that would occur if investors were to consider these additional social benefits. Government can provide incentives for private research by establishing a system of intellectual property rights, and fund research that produces goods that are public in nature.

This chapter begins by discussing the types of innovations that can reduce water pollution from agriculture. Next, we show why appropriate incentives do not exist for investment in research leading to innovations to improve water quality when there is no government intervention to correct externalities. We then show how policies based on standards and economic incentives create incentives for private research. Finally, government's role in the research and development process is discussed, along with a description of how public support has influenced research and development programs in the United States.

Innovations That Improve Water Quality

Innovations having positive water quality impacts can broadly be classified as (1) augmenting factors, (2) reducing pollution, or (3) introducing entirely new inputs and technologies (see table 7-1), although an innovation may exhibit aspects of each.

Factor-augmenting innovations allow the same quantity of output to be produced with less of the augmented factors (i.e., inputs). Examples related to nonpoint pollution include more effective pesticides and fertilizers, new seed varieties that are higher yielding or require fewer inputs, and enhanced irrigation efficiencies. Factor-augmenting innovations may result in reduced use of polluting inputs and, consequently, reduced runoff and ambient pollution levels. This may not always be the case, however. The use of polluting inputs may increase due to input substitutions and changes in the scale of production. In a simulation of U.S. corn production, Abler and Shortle (1995) found that capital-augmenting innovations would increase fertilizer and pesticide use. They also found that pesticide use would be increased by land- and seed-augmenting innovations and decreased by pesticide-augmenting technologies.[1]

[1] Abler and Shortle's results were driven largely by the high elasticity of demand for corn.

Table 7-1—Types of innovations

Innovation type	Example
Factor-augmenting technology	Soil-nitrogen testing
	Integrated Pest Management Split nitrogen application Nitrogen breakdown inhibitors Subsurface micro-irrigation Conservation tillage
Pollution-reducing (runoff abatement technology)	Buffer strips Sediment basins Microbial phytase (feed additive)
Entirely new inputs	New pesticides and other chemicals

Pollution-reducing innovations have no impact on crop production relationships, but they do reduce runoff (and hence pollution) for any level of input use. This type of innovation is essentially an improvement in runoff abatement technology. For example, a pollution-reducing innovation may increase buffer strip effectiveness in filtering out nutrients before they reach a water body.

Advances in science may result in the **introduction of entirely new inputs** to agricultural production. For example, research on extracting atmospheric nitrogen for manufacturing explosives resulted in the introduction of inorganic nitrogen fertilizers to agriculture. Other examples related to nonpoint pollution include satellite and computer technologies for increasing precision application of chemicals and the development and introduction of new crops. Such innovations will likely result in producers' using new combinations of existing inputs and changing the scale of production (or possibly shifting to alternative commodities). Economically attractive innovations that allow producers to completely substitute polluting inputs with alternative technologies will improve environmental quality.

Private Incentives for Water Quality R&D

Research and development (R&D) is a process by which investment in scientific study leads to future technological innovations. Research programs may proceed along a variety of paths. For example, crop pest control may be improved by genetically enhancing the pest-resistance qualities of a particular crop, by enhancing current or discovering new pesticides, or by developing alternative cropping systems. Unfortunately, innovations are uncertain in terms of timing (if they occur at all), required investment costs, and importance. In the example above, the importance of an innovation in genetic research might refer to the amount of increased pest resistance relative to that of existing crop varieties. Years of effort may result in only a marginal improvement (if any) over existing crop varieties.

Even in the absence of externalities, R&D programs will be underfunded without government intervention to ensure that innovators receive the economic benefits from the sale of the innovation. Underfunding occurs because the results of research often have the characteristics of a public good. Specifically, once an innovation occurs, it is not always possible to exclude others from acquiring the knowledge to use the innovation. Without a legal claim to this knowledge (e.g., a patent or copyright), only a share of the total economic benefits can be captured by private research organizations that develop innovations (Fuglie and others, 1996). A potential problem with intellectual property rights is that they convey monopoly power to the developers of new innovations (Fuglie and others, 1996; Moschini and Lapan, 1997). Under monopoly conditions, use of the innovation will generally be less and the price higher than if it were provided under perfect competition. The intellectual property right may reduce the social value of the innovation, but it is better than not having the innovation at all (Fuglie and others, 1996).

Market-Based Incentives and Externalities

Given that mechanisms are in place to protect innovators, private incentives for investment in R&D exist. Economic theory and empirical evidence show research organizations have incentives to invest in agricultural research devoted to factor augmentation or new innovations that shift production from relatively scarce (or costly) inputs toward relatively abundant (or cheaper) inputs (Hayami and Ruttan, 1985; Ruttan and Hayami, 1989; Antle and McGuckin, 1993). Continuing with the pest-resistance example, suppose current pest control methods rely heavily on pesticide use. A relative increase in pesticide prices creates an incentive to invest in any of the aforementioned research paths (i.e., genetically enhancing crops, altering cropping practices, etc.) that promise to reduce pesticide costs.

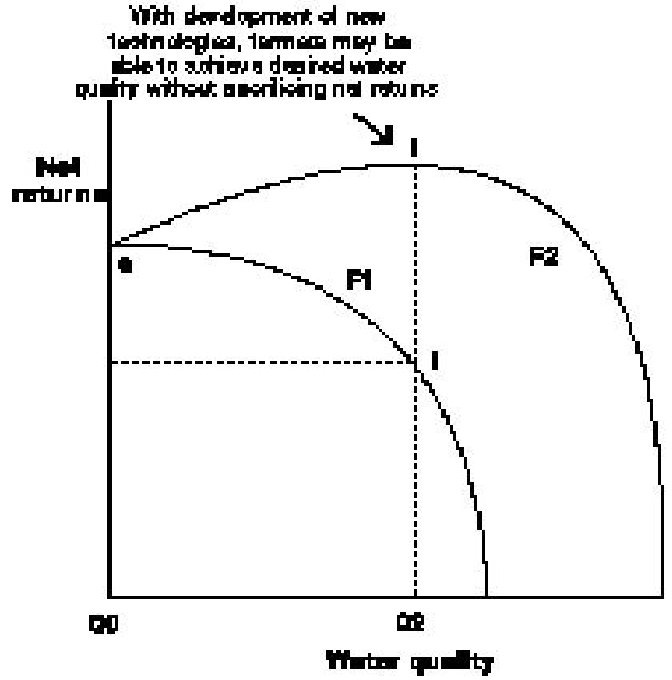
Moreover, economic incentives (created by market or institutional forces) are important determinants of the expected private return to investment for each potential research path. Consequently, these incentives also play an important role in the allocation of investments for each path.[2] For example, the expected marginal return to pesticide research may be small relative to that of genetic engineering research if chemical restrictions are expected to become more stringent relative to regulations on genetic-engineered products. Increased regulation of pesticides to make them safer to farmworkers and to the environment may have reduced the introduction of new materials (Ollinger and Fernandez-Cornejo, 1998).

Inputs that create (inhibit) nonpoint pollution are underpriced (overpriced) without government intervention because private markets do not reflect the social costs of input use. Private research organizations therefore do not have the economic incentives to invest efficiently in R&D programs that may lead to innovations in improving water quality.[3] For example, heavy use of nutrients in agriculture is widespread because nutrients have historically been relatively inexpensive and government regulation of the externalities caused by their use has been minimal or nonexistent. Consequently, incentives to develop new crop varieties that require fewer nutrients are not strong. Although nutrients have been seen as inexpensive in private markets, the social costs of nutrient use have been higher because they contribute to nonpoint pollution. R&D may have evolved along another path had nutrients been priced more appropriately.

Producer Incentive To Adopt Innovations

The incentives for private R&D on pollution-reducing innovations are virtually nonexistent without government intervention, even with intellectual property

Figure 7.1
Tradeoff between net returns and water quality with introduction of new technology



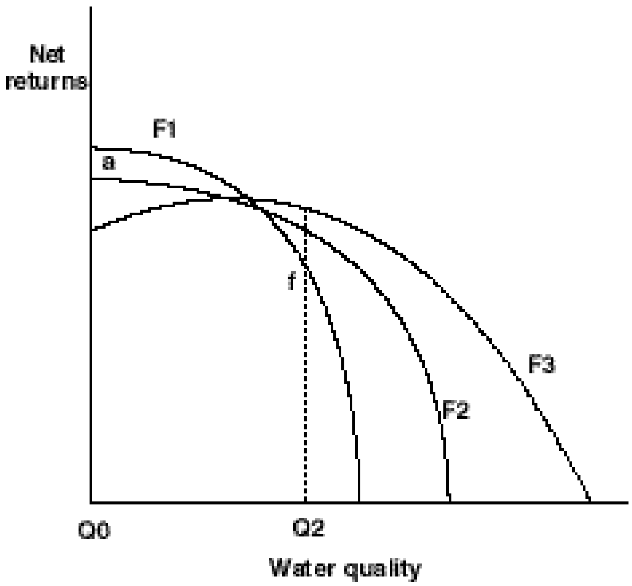
rights. Pollution-reducing innovations are not likely to generate private benefits to producers because they have no positive impacts on profitability.

If incentives are inadequate for private research on innovations that improve water quality, the public sector can fund research on such innovations. Even if such innovations occur, however, there is no assurance that producers will adopt them. In this case, the innovation would not be truly successful. A producer's adoption decision depends greatly on profitability. In a competitive market without government intervention, producers who consider water quality impacts may lose a competitive edge because of the inherent tradeoff between profitability and water quality. Figure 7.1 illustrates that a water quality innovation would need to change the shape of the water quality-net return frontier from F1 to F2 (so that a producer maximizes profit at point i as opposed to point a) in order for adoption to be profitable. In this case, both water quality and profitability are improved. However, profitability must still be weighed against the cost of adoption and the profitability of existing technologies and other innovations.

[2] Assuming investors are risk-neutral and profit-maximizing, investment will occur where marginal expected returns are equated across each path. Factors that influence expectations about returns include the probability of a successful innovation, the expected importance of the innovation, and other relevant economic and institutional factors (such as the current or expected policy environment).

[3] The social effectiveness of research can be measured by the social rate of return on research, defined as the social benefit/cost ratio of research (Fuglie et al., 1996). Research on environment-enhancing technologies compares poorly with other research opportunities when environmental benefits either are not considered or are undervalued.

Figure 7.2
Tradeoff between net returns and water quality with introduction of new technology and an expected water quality constraint



Government Intervention Changes Incentives for Water Quality R&D

Even with the appropriate signals, the private sector will underinvest in environmental research due to its nature as a public good. Private research will focus on innovations that it can control, such as new chemicals, nutrients, machinery, and plant varieties. Research on management-oriented innovations, such as timing nutrient applications, rotations, and tillage practices, will most likely be carried out in the public sector. Furthermore, public sector R&D aimed at developing cheap and effective water-quality-monitoring techniques and devices could remove barriers now preventing the efficient use of standards. An effective R&D policy must remain responsive to price and regulatory signals provided by the economy and society (Fuglie and others, 1996).

Effective intervention requires that investment incentives be altered to reflect the costs that nonpoint pollution imposes on society. Investment incentives can be altered by policies that either assign prices to externalities or increase the relative price of pollution-causing inputs or technologies (see chapters 3 and 4). Regulations and economic incentives are one way of increasing the price of polluting inputs relative to nonpolluting inputs. The increased relative price of polluting inputs causes producers to seek alternative practices that require less of these inputs. For example, producers would benefit from innovations that shift the frontier in figure 7.2 from F1 to F2 or F3 when a standard requires that production results in an expected water quality level of *Q2*.[4] Regulations and economic incentives therefore provide producers and their input suppliers with incentives to invest in research that considers more effective ways of meeting environmental objectives and to adopt resulting innovations.

There is a qualitative difference in the ability of economic incentives and standards to provide incentives for research. Economic performance or design-based incentives provide a "reward" for continued reduction in polluting activities in the form of reduced tax burden or increased subsidy. Standards, on the other hand, do not provide incentives to improve water quality beyond the level defined by the performance standard or the design standard. There is no "reward" for providing an extra measure of control. For example, if a standard is set for a polluting input and a producer is already meeting the standard, there is no demand from the producer for innovations that result in less of the input being used. If instead a tax is placed on the input, an incentive is created for innovations that result in less of the taxed input being used, regardless of a particular water quality goal.

Applying incentives or regulatory policies to different bases will provide different incentives for investment in R&D. Bases that are closer to the externality (i.e., performance bases, expected runoff) are generally more effective in providing the appropriate incentives for investment in each of the three types of innovations. Input- and technology-based instruments are somewhat effective in promoting investment in factor-augmenting innovations and the development of new inputs, depending on the impact the innovation will have on profitability relative to water quality (that is, incentives will be smaller for innovations that lead to improved water quality but do not enhance production). However, input- and technology-based instruments that are related only to production do not induce producers to consider water quality impacts of innovations that are not related to production and do not have positive impacts on profitability. Therefore, input- and technology-based instruments may produce only small incentives for investment in pollution-reducing innova-

[4] Neither of these technologies would be attractive if there were no constraints on water quality.

Table 7-2—Incentives from different instrument bases for investment in water-quality-improving innovations

Instrument base	Factor-augmenting	Pollution-reducing	New inputs
Performance-based	Good	Good	Good
Design-based			
Expected runoff	Good	Good	Good
Input- and technology-based	Fair-Good	Poor	Fair-Good for inputs that enhance production; poor for inputs that do not enhance production (i.e., pollution-control inputs)

Note: These rankings are subjective, based only on theoretical properties as opposed to empirical evidence. A more reliable table would be based on empirical results that compare each type of policy according to a consistent modeling framework that is representative of the nonpoint problem.

tions or the development of new inputs that affect only water quality (and not productivity).

Effective government intervention also must provide producers with the appropriate incentives to *adopt* innovations that provide cost-effective pollution control. As shown in chapter 2, producers would have an incentive to adopt the most socially efficient innovations if all externalities were priced at their efficient levels. Applying incentives or regulatory policies to different bases will provide different incentives for the adoption of innovations. The adoption incentives provided by each base (table 7-3) are almost identical to those provided for R&D investment (table 7-2). Bases that are closer to the externality are generally more effective in providing the appropriate incentives for the adoption of each innovation type, including pollution-reducing innovations. Input- and technology-based instruments are somewhat effective in promoting adoption of factor-augmenting innovations and the development of new inputs, depending on the impact the innovation will have on profitability relative to water quality. In addition, input- and technology-based subsidies and standards are likely to be effective in inducing producers to adopt pollution-reducing innovations that are not related to production because these instruments make it profitable (or necessary) for producers to consider these impacts.

The second-best incentive or regulatory policies that are most likely to be implemented (due to the information, administration, and implementation costs associated with efficient policies) will not necessarily provide producers with incentives to adopt cost-effective water quality innovations as they become available. When input-based standards or economic incentives are used, the resource management agency needs to adjust the standards or incentives on all inputs or technology to reflect the new innovations. Not doing so will result in a level of pollution control that is not cost effective.

Has Research Helped?

Public and private research has had a few successes in developing complementary technologies that enable producers to both achieve water quality improvements and increase net returns. For example, some Integrated Pest Management (IPM) categories use enhanced information and multiple pest control strategies (chemical, biological, and cultural) to manage pest populations in an economically efficient and ecologically sound manner. A review of 61 farm-level economic evaluations concluded that IPM was generally profitable (U.S. Congress, OTA, 1995). This finding is supported by the fact that more than half the fruit, nut, corn, soybean, and fall potato acreages were using an IPM approach during 1991-1993 (Vandeman and others, 1994).

Conservation tillage is a family of tillage practices that leave at least 30-percent of the planted soil surface covered by crop residue to reduce soil erosion by water and polluted runoff (U.S. Congress, 1995). Conservation tillage has been shown to be profitable for a number of crops in many areas (Fox and others,

Table 7-3—Incentives from different instrument bases for adoption of water quality-improving-innovations

Instrument base	Factor-augmenting	Pollution-reducing	New inputs
Performance-based	Good	Good	Good
Design-based			
Expected runoff	Good	Good	Good
Input- and technology-based	Good with subsidies or standards. Otherwise, fair-good	Good with subsidies or standards. Otherwise, poor	Good with subsidies or standards. Otherwise, fair-good for inputs that enhance production; poor for inputs that do not enhance production (i.e., pollution control inputs)

Note: These rankings are subjective, based only on theoretical properties as opposed to empirical evidence. A more reliable table would be based on empirical results that compare each type of policy according to a consistent modeling framework that is representative of the nonpoint problem.

1991). As a result, its use has steadily grown in recent years (USDA, ERS, 1997).

Another technological innovation that improves water quality is improved soil nitrogen testing. This enables more accurate nitrogen applications, resulting in fewer over-applications and consequently less runoff and subsurface leaching. This technology is most appropriate where there has been a history of manure applications (Fuglie and Bosch, 1995; Musser and others, 1995). A related technology, subsurface micro-irrigation, reduces water use and can place nutrients more precisely in the root zone compared with center-pivot irrigation. It is more profitable than conventional center pivot irrigation on small fields, but not on large fields (Bosch, Powell, and Wright, 1992) and also results in reduced runoff and leaching.[5]

Other new technologies that may result in improved water quality are not yet profitable and will require a subsidy or regulation to become widely used. For example, microbial phytase as a feed additive can reduce phosphorus in swine and poultry excretions by 50 percent or more (Simons and others, 1990; Coelho and Kornegay, 1996). Similarly, USDA's Water Quality Program discovered several new or improved methods of applying pesticides and fertilizers for corn-soybean agriculture in the Midwest. These application methods, which include pesticide banding, fertilizer banding, and ridge tillage, could reduce polluted runoff. However, without any regulatory or economic incentives, these practices were not adopted by producers because they did not increase net returns (Iowa MSEA, 1995; Missouri MSEA, 1995).

Private research has been found to be responsive to regulations. Ollinger and Fernandez-Cornejo (1995) examined the effect of the Federal Insecticide, Fungicide, and Rodenticide Act on innovation in the agricultural chemical industry. They found the regulations resulted in the development of pesticides that were often less toxic and shorter lived than traditional pesticides (Ollinger and Fernandez-Cornejo, 1995).

Summary

Research and development is an important part of a policy for reducing agricultural nonpoint-source pollution because it provides producers and society more efficient ways of meeting environmental goals. It may also, if directed toward monitoring technology, facilitate the eventual use of more efficient standards-based approaches to even nonpoint-source water quality improvement. Given the length of time it takes to develop and introduce new technology, R&D may require patience and a willingness to invest substantial private or public funds. However, since producers and private firms will necessarily underinvest in R&D for water quality improvements, the public sector will have to either carry out this research or provide producers and the private sector with incentives (through economic incentives or regulations) that result in efficient research investments. Price and regulatory signals that correctly reflect society's valuation of environmental problems can ensure that research is consistent with environmental goals.

[5] The research described above was not initiated specifically for the purpose of improving water quality.

Finally, it is important to recognize that while research is often viewed as one of the tools available for addressing water quality and other environmental problems (e.g., Clean Water Action Plan, USDA Water Quality Program), it cannot stand on its own as a tool to control water pollution. Instead, it is an extremely valuable component of other approaches that include performance or design incentives and standards. R&D cannot independently provide a solution to water quality problems because technology is only one component of water quality improvement. Even with the most efficient, environmentally friendly technology, producers have incentives to over- (under-) apply inputs that contribute to (inhibit) nonpoint-source pollution. Economically sound water quality policies will consider all aspects of the nonpoint problem to determine cost-effective solutions.