Economics and Environmental Markets: Lessons from Water-Quality Trading

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Water-quality trading is an area of active development in environmental markets. Unlike iconic national-scale air-emission trading programs, water-quality trading programs address local or regional water quality and are largely the result of innovations in water-pollution regulation by state or substate authorities rather than by national agencies. This article examines lessons from these innovations about the "real world" meaning of trading and its mechanisms, the economic merits of alternative institutional designs, utilization of economic research in program development, and research needed to improve the success of environmental markets for water quality.

Key Words: environmental markets, water-quality trading

The use of markets to efficiently achieve environmental-quality goals is one of the major conceptual innovations for environmental policy coming from economic research. Market mechanisms have gained much interest and increasing acceptance outside of economics—indeed, the case for markets seems to be made at least as much from advocates outside of the discipline as from within. Advocates include consulting and trading firms involved in varying aspects of the environmental trading business, associations representing such businesses, environmental think tanks, legislators, and government agencies (e.g., Jones et al. 2005, Organization for Economic Cooperation and Development (OECD) 2004, Talberth et al. 2010, U.S. Environmental Protection Agency (EPA) 2001, 2003, 2004). The benefits of markets touted by their advocates include potential efficiency gains and innovation incentives that have been the focus of economic research. But the claims of some advocates go further. Markets, it seems, can better and more quickly deliver environmental improvements that cost less than other policy instruments can. Economic experts are not always so enthusiastic because they understand that how markets are designed and implemented and the contexts in which they are applied are important factors in what they can achieve (Tietenberg 1999).

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To date, markets for environmental quality have figured most prominently in fisheries management and air pollution control, and successes in those areas have no doubt influenced expectations of what markets can accomplish for other resources. In recent years, attention has turned to markets for water. John Dales (1968) first proposed using markets to protect water quality in 1968, and experimental and demonstration water-quality-trading (WQT) mechanisms were established in the United States in the 1980s. Interest in the United States increased in the mid-1990s as state water-quality authorities explored mechanisms by which to achieve total maximum daily load (TMDL) levels for pollutants established by EPA. In 2003, EPA announced policies intended to facilitate trading and began providing financial support and technical assistance for WQT (EPA 2003, 2004, 2007). Over the last decade, Australia, Canada, and New Zealand developed WQT programs and countries surrounding the Baltic Sea studied them as a way to address nutrient pollution in the Baltic (Green Stream Network 2008, Selman et al. 2009).

In a 2008 survey, Selman et al. (2009) identified 26 programs with established WQT rules, 21 programs under consideration or in development, and 10 programs that were complete or inactive. The United States led in application of WQT, having originated all but 6 of the 57 programs noted in the survey. WQT in the United States has taken two general forms (Morgan and Wolverton 2005). One is an offset agreement. Traditionally, point sources of pollutants had to meet facility-specific emission limits under the Clean Water Act (CWA) by reducing their own facilities' emissions. Under offset agreements, they can meet the permit requirements through reductions of pollution at other facilities, providing a tool by which to resolve facility-specific permit compliance problems. Two prominent, successful examples (Rahr Malting Company in 1997 and Southern Minnesota Beet Sugar Cooperative in 1999) used agricultural and other nonpoint-source nutrient-pollution reductions to help industrial facilities on the Minnesota River meet the permit requirements. The second form of WQT in the United States, and the focus of the remainder of this discussion, is intended to facilitate routine trading between multiple sources that are contributing to pollution of specific bodies of water. These programs typically consist of mechanisms designed to attain a water-quality standard expressed as TMDLs or other limits (Morgan and Wolverton 2005, EPA 2007).

Several *ex post* evaluations of North American WQT programs have been conducted (e.g., Breetz et al. 2004, 2005, Hoag and Hughes-Popp 1997, Jarvie and Solomon 1998, King 2005, Morgan and Wolverton 2005, Newburn and Woodward 2012, Ribaudo, Horan, and Smith 1999, Ribaudo and Gottlieb 2011, Shabman and Stephenson 2002, Stephenson and Norris 1998), mostly on programs implemented prior to 2000. While some successes were reported, the studies' main findings were that there was limited participation by potential traders and a lack of trading activity. This suggests that either the programs were implemented in contexts in which there was little to gain from reallocations of emissions or that the market designs were not conducive to realizing potential gains. Program managers who were interviewed about the trading mechanisms (Breetz et al. 2004, Morgan and Wolverton 2005) attributed the limited trading to a lack of trading partners, lack of adequate regulatory drivers (e.g., limits on effluents were not sufficiently stringent to create demand for trades), uncertainty about the trading rules, legal and regulatory obstacles to trading, high transaction costs, cheaper alternatives, and that the programs were simply too new to permit trades. These obstacles suggest that there were flaws in the design of the marketplace in some cases and an absence of the underlying economic conditions needed for gains from trade in others. Accordingly, one might expect that better market designs could improve the amount of trading and the economic outcomes of those markets.

The discussion here approaches the lessons learned from WQT experiments from a different perspective. Environmental markets are a major conceptual innovation for environmental policy that came from research in environmental economics. As the concept moves from pages of books and journals to the menu of instruments available to policymakers, however, realized outcomes will depend on how the market programs are designed and implemented and the contexts in which they occur. I am interested in what can be learned from recent WQT experiments about how economists' ideas about markets are being implemented in the water-quality domain, about the economic merits of state and local innovations developed so far, about the content and communication of our environmental market research, and about our practical policy advice.

WQT is of significant and continuing interest to water-quality policymakers despite the lackluster performance of trading programs implemented in the 1990s. WQT has the potential to improve the economic efficiency of water-pollution controls. Also, unlike well-known and much-studied national trading programs for air-pollution emissions, WQT initiatives have come from state and local innovators. In addition, as is the case with many resource conservation issues, the physical and economic characteristics of water-quality problems do not match up well with the assumptions that are typical textbook models of perfectly competitive permit trading. Water markets consequently pose unique challenges for market design.

I base this discussion on seven WQT programs that I find particularly interesting (See Table 1). The programs were implemented more or less in the last decade and thus exclude experimental and demonstration programs from prior decades. Each can be viewed as either successful or as unproven but promising. Five of the seven address nutrient pollution, a major target of WQT programs (Morgan and Wolverton 2005, Selman et al. 2009). Five of the

Table 1. Water Quality Trading Programs

Program	Pollutant Type	Sources
Hunter River Salinity Trading Scheme (Australia)	Salinity	Point
California Grassland Areas (United States)	Selenium	Point
Connecticut Nitrogen Credit Exchange (United States)	Nitrogen	Point
South Nation River Total Phosphorus Management Program (Canada)	Phosphorus	Point, agricultural nonpoint
Greater Miami Watershed Trading Pilot Program (United States)	Nutrients	Point, agricultural nonpoint
Pennsylvania Nutrient Credit Exchange (United States)	Nutrients	Point, agricultural nonpoint
Lake Taupo (New Zealand)	Nitrogen	Agricultural nonpoint

seven involve agricultural sources, a prominent contributor to water quality. One of the appeals of trading in the context of North American water-pollution control is that it offers a new and potentially politically palatable approach to addressing water pollution from agriculture (Shortle and Horan 2008). Five of the programs involve both point and nonpoint sources, an essential form of trading if high-priority nutrient-pollution problems are to be addressed efficiently. Three are limited to point sources and one is limited to agricultural nonpoint sources.

The next three sections provide an overview of the selected programs based on the review in Shortle (2011) and are organized according to source: point-point, point-nonpoint, and nonpoint-nonpoint-nonpoint. Subsequent sections address lessons learned about innovators, the meaning and merits of alternative trading mechanisms, contributions by economists and others to the design of trading programs, and priorities for economic research. All dollar figures are U.S. dollars unless otherwise noted.

Point-Point Trading Programs

Textbook models of pollution trading generally assume that emissions are nonstochastic and observable by source. In a water-quality context, these assumptions apply reasonably well only when emissions are traded between industrial and municipal point sources.

Hunter River Salinity Trading Scheme, Australia

The Hunter River Salinity Trading Scheme in New South Wales, Australia, is an important example of successful methods and of the merits of WQT between point sources and is considered the most successful WQT program in the world. This point-point salinity trading program applies to coal mines and power plants. It was initiated as a pilot in 1995 and was made fully operational in 2002. The New South Wales Office of Environment and Heritage (formerly the Department of Environment, Climate Change, and Water (DECCW)) administers the program under the guidance of an operations committee that includes representatives from the state government, industry, and the community. Monitoring points along the river measure whether the amount of water is low flow, high flow, or flood flow. When the river is in low flow, no discharges are allowed. During high flow, limited discharges are allowed, and they are subject to restrictions based on a licensee's supply of tradable salt credits. An online trading platform was developed for exchanging credits with prices and credit transactions negotiated by buyers and sellers. Assessments indicate that the program has achieved established targets for water quality at a lower cost than the prior regulatory scheme would have and allowed expansion of economic activity that otherwise might not have occurred (Collins 2005, Kraemer, Interwies, and Kampa 2002, New South Wales DECCW 2010).

California Grassland Areas Program, United States

The Grassland Drainage Area consists of irrigated agricultural land in the San Joaquin Valley. Drainage systems designed to remove excess irrigation water from fields transport naturally occurring selenium in the soil to waterways, which causes significant damage to ecosystems. Grassland Area Farmers

(GAF), an association of seven irrigation districts, was established in 1996 to implement measures designed to limit the amount of selenium entering the waterway. Among these was a trading program developed with funding support from EPA. The total allowable regional selenium load discharged into the San Luis Drain was allocated among the member irrigation districts, which could meet their load allocations through selenium reductions within the district and/or by purchasing selenium offsets from other districts. Trades were negotiated by the individual districts directly. The program produced 39 trades and met the drainage area's water-quality goals during the two years in which it operated. Trading was subsequently suspended because development of a drainage-recycling project eliminated the need for trading.

Several features of the program are interesting. Its cap on agricultural sources is atypical of North American WQT models that include agriculture. The norm is for no restrictions on agricultural sources with agricultural trades serving as offsets for point sources. Another significant and related feature is the "commodity" traded. Trading programs that involve agricultural land generally do not measure agricultural emissions because the nonpoint nature of those emissions makes routine accurate measurements infeasible. Instead, such markets use calculations of agricultural nonpoint pollution emissions. Trading in the GAF was based on actual emissions. This was possible because the trading was conducted between irrigation districts rather than between farmers and because the irrigation districts collected drainage water in sumps before pumping into the San Luis Drain. Useful discussions of this program are found in Austin (2001) and Woodward, Kaiser, and Wicks (2002).

Connecticut Nitrogen Credit Exchange Program, United States

The Connecticut Nitrogen Credit Exchange Program (CNCEP) was established in 2002 to allocate reduced nitrogen loads among 79 wastewater treatment plants that discharged into the Connecticut River. The reductions were required by a TMDL limit that was designed to protect Long Island Sound with the limit to be achieved in 2014. Wastewater plants are annually assigned individual discharge limits to achieve the increasingly stringent cap on nitrogen loads to the sound. Facilities generate credits when they reduce nitrogen discharges below an assigned limit. If a plant fails to meet its limit, it must acquire credits to cover the shortfall. The credit price is set by the Nutrient Credit Advisory Board (NCAB), a body appointed by the state legislature. Buyers and sellers do not interact in the market. At the close of each year, the state environmental agency determines each plant's actual discharges and credits earned or required to be in compliance. The agency also purchases more credits than are needed to achieve the aggregate emission cap. Economic incentives are clearly present in the CNCEP, but the exchange is not truly a marketplace in which buyers and sellers compete. Instead, the exchange essentially involves fixed administrative penalties for undercompliance and payments for overcompliance with effluent standards.

Annual reports to the state legislature from the NCAB indicate that the program is producing credit exchanges and that most of the facilities are participating. Typically, there are more credit buyers than sellers. For example, in the most recent report on the program's activity, for 2010, the value of credits purchased by the nitrogen credit exchange was $2,263,482 and the value of those sold was $3,274,823 (NCAB 2011). Forty-three facilities were required to purchase credits while thirty-five facilities had credits to sell. The imbalance between purchases and sales confirms that this program is not a marketplace.

Point-Nonpoint Trading

Trades involving nonpoint sources are challenging because nonpoint pollution cannot be metered by source and is inherently stochastic (Shortle and Horan 2008). Existing programs address this problem by substituting estimates of reductions in nonpoint-source pollution for metered reductions.

South Nation River Total Phosphorus Management Program, Canada

The South Nation River Total Phosphorus Management Program was established in eastern Ontario, Canada, in 2000 to allow new and expanding dischargers of industrial and municipal wastewater to meet stricter phosphorus limits by purchasing agricultural offsets at a ratio of 4:1. Since the inception of the program, all of the point-source operations have chosen to purchase offsets rather than incur the expense of upgrading their treatment facilities. South Nation Conservation (SNC), one of 36 conservation authorities in Ontario, operates the program. SNC has long been involved in working with landowners to implement conservation practices in the watershed. Farmers do not participate directly in trading; SNC negotiates the trades. Dischargers pay a price per credit that is intended to approximately cover the average cost of producing the credit. Payments to SNC are deposited in the Clean Water Fund, which is used to finance agricultural projects that generate credits. SNC credit sales augment other funding sources that finance implementation of best management practices (BMPs) in the watershed.

For 2000 through 2009, 269 phosphorus-reducing projects were established through the watershed's Clean Water Fund, and those measures reduced the amount of phosphorus discharged by an estimated 11,843 kilograms (Shortle 2011). During that period, the program spent $708,403 in Canadian dollars (C$) on grants for agricultural and other projects and C$173,225 for program delivery.

Greater Miami Watershed Trading Pilot Program, United States

The Greater Miami Watershed Trading Pilot Program was established in 2005 (Water Conservation Subdistrict, Miami Conservancy District 2005) as an incentive mechanism aimed at accelerating water-quality improvements in the Greater Miami Watershed in southwestern Ohio. It provides regulated point sources of pollution with the opportunity to purchase nutrient-reduction credits from agricultural sources under favorable terms, and tighter restrictions are expected in the future once in-stream nutrient criteria are established. The Water Conservation Subdistrict of the Miami Conservancy District (MCD) manages the program. MCD was established in the early 1900s with a core mission of flood control. The Water Conservation Subdistrict serves as a clearinghouse; it buys pollution-reduction credits from agricultural sources and transfers nutrient-reduction credits to point sources. Five founding investors support the program: the cities of Dayton, Englewood, and Union; Butler County; and the Tri-Cities Wastewater Authority (representing three cities).

Point sources earn credits for nitrogen and phosphorus reductions by implementing agricultural BMPs. The baseline for credit calculation is the level of emission that occurred prior to implementation of BMPs. Activities that generate credits must be new, must have been undertaken voluntarily (not legally mandated), and cannot be funded by other conservation incentive programs. Trade ratios (pounds of nonpoint nitrogen or phosphorus required to offset a pound of point-source nitrogen or phosphorus) are designed to encourage early participation by point sources. Dischargers that purchase credits before new, more stringent restrictions are imposed can, with some exceptions, do so at a ratio of 1:1. Once the new restrictions are imposed, the ratio increases to 3:1.

The Water Conservation Subdistrict conducts periodic reverse auctions to purchase credits. To be eligible to sell credits, an agricultural producer must be located within a participating Soil and Water Conservation District (SWCD) and work with the district to develop projects and submit bids. SWCDs also provide post-award oversight. There are fourteen SWCDs in the Greater Miami Watershed that are eligible to participate and nine have been active in the program. The subdistrict obtains funds with which to purchase credits and operate the program from participating point sources and federal grants that support development of innovative trading programs.

As of June 30, 2011, nine rounds of project submittals had been completed and 345 agricultural projects had been funded, generating more than one million credits over the life of the projects. The credits are to be generated over the contractual period for each project (maximum of 20 years; minimum of 1 year). Slightly more than $1.5 million will be paid to agricultural producers and $89,000 has been allocated to the SWCDs for assistance and oversight.

Pennsylvania Nutrient Credit Trading Program, United States

The Pennsylvania Nutrient Credit Trading Program is potentially the most important emerging WQT effort due to the significance of the water-quality problem it addresses—the flow of nutrients from point and nonpoint sources in Pennsylvania to Chesapeake Bay, the largest estuary in the United States—and to the number of potential participants and expected regulatory cost savings. While only a little more than one-third of the bay's watershed is located in Pennsylvania, the state was the source of 56 percent of the nitrogen and 44 percent of the phosphorus estimated to have entered the bay in 2009.

Chesapeake Bay has been a focal point for federal and state initiatives to reduce nutrient pollution for decades. Beginning in 1983, EPA, the mayor of the District of Columbia, and the governors of Maryland, Pennsylvania, and Virginia agreed to establish the Chesapeake Bay Program, which was to set goals for nutrient reductions and develop strategies by which to attain those goals. Insufficient progress led EPA to establish TMDLs for the bay's tributaries in 2010.

Pennsylvania implemented a WQT program in 2005 as one element in a set of initiatives designed to meet its obligations under the Chesapeake Bay Program agreements and in anticipation of the TMDLs in 2010. Pennsylvania's Department of Environmental Protection administers the program, which assists regulated point-source operations in meeting effluent limits via nitrogen and phosphorus credits acquired from uncapped agricultural nonpoint sources and other point sources. Farmers earn credits by implementing BMPs. Unlike the Greater Miami Watershed trading program in Ohio, Pennsylvania's program does not use the level of emissions that otherwise would have occurred as the baseline for calculating nutrient reductions. Instead, farmers' are required to meet a set of baseline farming practice requirements to be eligible to earn and sell credits from further reductions. The program multiplies the estimate of eligible on-farm nutrient reduction by an "edge of segment ratio," a "delivery ratio," and 0.9 to determine the marketable credit. The first two ratios essentially estimate the reduction in loading of nitrogen and phosphorus to the bay while the third is a form of in-kind tax that funds a credit reserve intended to provide a buffer against defaults by credit suppliers. The program applies analogous rules to point sources that seek to generate credits by reducing emissions below the regulatory requirements.

Farmers and credit buyers can participate and compete directly in the market. The state funded development of an online tool for calculating and registering credits to facilitate their participation. In 2010, the state launched a nutrient credit clearinghouse that is managed by the Pennsylvania Infrastructure Investment Authority, a state agency (known as PENNVEST) that traditionally was charged with financing water infrastructure investments. Credit exchanges can be made through bilateral negotiations, but PENNVEST also conducts periodic double auctions to buy and sell credits. The program offers greater opportunities for dischargers and farmers to benefit from market-based trading than other North American WQT programs so far developed. Prior to creation of PENNVEST's clearinghouse, the program completed eight trades that all involved sales of agricultural credits. Seven of the trades were organized by market intermediaries that are commonly referred to as "aggregators" and that work with groups of farmers to provide a sufficient supply of credits to meet the needs of large point-source buyers. To date, PENNVEST auctions have produced little more.

Maryland, Virginia, and West Virginia also recently implemented nutrient credit-trading programs. They lag Pennsylvania's in market development and trading activity. Their participation requirements are more rigorous and development of market mechanisms has been minimal. Managers with EPA's Chesapeake Bay Program are studying development of a nutrient trading program that would allow for trades across state borders in the Chesapeake Bay watershed.

Nonpoint-Nonpoint Trading

I previously noted that trading programs that involve agricultural nonpoint sources are designed to reduce the cost of point-source compliance using agricultural reductions as low-cost offsets. An exception is the Lake Taupo agricultural nonpoint-nonpoint trading program recently developed by Environment Waikato of New Zealand. Lake Taupo is the largest freshwater lake in New Zealand (Duhon, Young, and Kerr 2011). Nitrogen leaching from grazing-based farming systems and other sources causes nutrient pollution, which led Environment Waikato to seek a 20 percent reduction in nitrogen loads. The program is exceptional in that it is designed as a true cap-and-trade program with a primary objective of reducing nutrient loads from agriculture. This distinguishes it from partial-cap programs that dominate WQT applications in North America and that function primarily as mechanisms for reducing the cost of industrial and municipal point-source compliance.

Landowners receive nitrogen allowances based on their historical land uses. In addition, the program developers envision market-like allowance trading among farmers. Farmers seeking to increase nitrogen discharges above the levels allowed would be required to acquire allowances from others. Environmental authorities for the region established the Lake Taupo Protection Trust in 2007 to administer an NZD$81 million public fund for activities designed to achieve the 20-percent reduction goal, including purchasing a permanent reduction in the nitrogen allowances. The program is too new to assess.

Lessons

The Innovators

Leadership in WQT has come from innovators at the state (provincial) level or below. In Ohio and Ontario, the initiatives were led by long-established conservation agencies. In Connecticut, New South Wales, Pennsylvania, and Waikato, leadership came from the states' environmental agencies. In California, innovation came from an association of irrigation districts. Several U.S. initiatives received EPA support but remain distinctly local products.

These WQT programs emerged as mechanisms to address specific local challenges. The point-nonpoint trading programs in Ohio, Ontario, and Pennsylvania offer regulated point sources the opportunity to comply with tighter or anticipated effluent standards at a lower cost by purchasing credits from uncapped agricultural nonpoint sources. The point-point trading programs in California, Connecticut, and New South Wales and the Waikato program were all similarly motivated by a desire to reduce the cost of complying with increasingly tight water-quality standards. Implementation of these trading programs generally required devoting significant effort to developing acceptance among stakeholders, and the programs' designs and management structures are, to varying degrees, the result of choices made to gain acceptance. O'Grady's (2011) description of development of the South Nation River program is especially useful for understanding the political economy of innovating WQT programs. Powers (2005) is similarly useful for its description of the Connecticut program and the New South Wales DECCW (2006) for the Hunter River.

The Meaning of "Trading"

Economists describe emission trading as a market-based method for allocating emissions between various sources. Traditional air- and water-pollution regulations entail imposing limits on emissions from specific sources (e.g., smokestacks, outfalls) and requiring that those limits be met at the source. Emission trading introduces flexibility into how emission limits can be met. A source may meet the limit on its emissions in part or in whole (depending on trading rules) by acquiring offsetting emission reductions from other sources. Under the purely market-based trading envisioned by the concept's originators, trades result from voluntary transactions of property rights between polluters or through market-oriented intermediaries, and competition in the marketplace is desired to achieve efficiency in pollution allocations.

The concept of WQT is being applied not only to mechanisms that correspond to this vision but also to ones that present little or no opportunity for buyers and sellers to interact or compete. Current programs offer a range of exchange mechanisms; some provide significant opportunities for market-like participation while others do not. The models for the Hunter River, Ohio, Pennsylvania, and Lake Taupo were designed to facilitate exchanges between willing individual buyers and sellers and market pricing. The California Grassland Farmers model entailed voluntary exchanges with irrigation districts representing the farmers. In contrast, the Connecticut and South Nation River schemes involve no direct exchanges between entities that supply emission reductions (which earn "sellable" credits) and those that demand such reductions to offset emissions in excess of regulatory standards. Credit prices are determined by agencies that manage the programs. In the South Nation River program, revenue from credit sales goes not to credit suppliers but to a fund for agricultural projects by South Nation River Conservancy. Thus, WQT in North America has come to refer to mechanisms that allow source-specific emission limits to be achieved by reductions performed by other sources without specifying the mechanism through which trades are executed.

The Merits of Trading

The textbook economic case that trading is a more efficient mechanism for pursuing environmental goals than traditional emission regulations assumes that trading is market-based. If there are no significant informational or other barriers that prevent market participants from discovering and negotiating mutually beneficial trades, a market would be expected to maximize potential cost-savings from trading, which implies that the cost of pollution control would be minimized (Montgomery 1972). However, North American WQT programs are being developed not to replace traditional regulations but to improve the efficiency and effectiveness of traditional regulatory systems. This trajectory is consistent with the history of emission trading programs generally—they tend to be considered and adopted after traditional regulatory approaches have failed (Tietenberg 1999).

Looking at the United States, water pollution control since the early 1970s has been regulated largely through emission limits applied to industrial and municipal point sources of water pollution. Agricultural and other nonpoint sources of pollution have been addressed through an array of local, state, and federal initiatives that emphasize voluntary adoption of pollution-control practices with subsidies as incentives. These initiatives generally have fallen short of meeting their established water-quality goals (Ribaudo 2009). Additional problems have come from the historical structure of water-pollution control programs. For example, the water-quality gains that were realized were overly expensive because the regulatory framework did not allow point sources to use offsets and because of constraints on technological choices contained in pollution permits (Davies and Mazurek 1998, Ribaudo 2009, Shabman and Stephenson 2007, EPA 2001). Regulation of point and agricultural nonpoint pollution sources in Canada is much the same as in the United States (Weersink et al. 1998).

Since established water-quality goals were not met, lawsuits were filed that required EPA to implement the TMDL provisions of the CWA in the mid-1990s. Those provisions required state water-quality authorities to establish goals for pollution loads for both point and nonpoint sources in waters that did not meet the water-quality targets and to develop programs to achieve the designated goals (Ribaudo 2009). Interest in WQT emerged in this context as a means of achieving TMDLs, expanding the reach of water-pollution controls to include agricultural nonpoint sources, and improving the economic efficiency of water-pollution-control allocations among and between point and nonpoint sources (Shortle and Horan 2008). The North American model by which point sources trade with agricultural nonpoint sources entails using the agricultural nonpoint sources as offsets and thus reducing the cost of compliance for point sources. This model is consistent with the "pay the polluter" strategy that has dominated agricultural nonpoint-source-pollution control efforts (Shortle et al. 2012).

Given this background, it is clear that the results of emerging WQT programs must be evaluated via comparisons to what would have occurred without the innovation. While not corresponding to a simple market-based trading model, programs like those for point sources in Connecticut and point and nonpoint sources in the South Nation River appear to reduce the cost of controlling pollution significantly.

Might they be better if they were truly market-based? Perhaps, but setting up and operating markets can be expensive. For example, in the Little Miami program, the WSC's operating costs averaged about $200,000 per year through 2011 without including funds allocated to participating SWCDs for assistance to farmers and oversight of agricultural projects (Shortle 2011). In addition, economic agents will not necessarily participate and trade in markets just because the opportunity exists. The Pennsylvania model, despite being the most market-oriented of the North American programs, has yet to demonstrate value. Water-quality markets can pose unique design challenges when the program must serve dual goals of water-quality protection and cost-minimization. The textbook vision of efficient emission trading assumes that such emissions can be standardized into a homogenous commodity that can be accurately metered for each regulated emitter and are substantially under the control of the polluter and that the spatial location of emissions within the market does not affect the environmental outcome. It also assumes that trading is done by perfectly competitive agents and that transactions costs are minimal. A number of these assumptions will not hold even approximately in many, and perhaps in most, water-pollution-control contexts (Olmstead 2010, Horan and Shortle 2011, Nguyen et al. 2013, Woodward and Kaiser 2002, Woodward, Kaiser, and Wicks 2002).

WQT programs are emerging from agencies that seek to realize the benefits of trading while simultaneously addressing a variety of hydrological, informational, economic, cultural, and regulatory water-pollution challenges. The cases reviewed here show a variety of interesting institutional innovations that employ an assortment of economic incentives to varying degrees. The much-discussed failures of early WQT experiments result not from coordination failures but from little or no participation by eligible agents. Institutions and mechanisms that can successfully engage participants (even if they do not know they are being recruited, as in the South Nation River project), who will then reduce the cost of compliance, are fundamental to success. Involvement of agencies well-known to and trusted by farmers in the Little Miami and South Nation River regions was crucial to the accomplishments of those programs (Breetz et al. 2005, O'Grady 2011). In contrast, Pennsylvania's strongly market-oriented program has made no use of comparable farm-oriented institutions. The cases reviewed here suggest that people developing trading programs must be as attentive to the requirements for an effective marketplace as to the rules that will govern trading to satisfy their water-quality objectives.

We Are Not the Experts at the Table: Adverse Choices Are a Result

The economic literature on WQT design is limited but still addresses a number of key issues associated with dual goals of water-quality protection and cost-minimization. Among them are selection of the commodity or property right to be traded in the market, participation requirements, baseline allocations, trading rules meant to assure that exchanges do not violate restrictions on water quality, and selection of market structures (Horan and Shortle 2011, Shortle and Horan 2008). The results from this literature have generated little or no mention in real world program development, and program designs are often at odds with what the literature would suggest.

One example is selection of a key parameter that is commonly referred to as the point-nonpoint trade ratio. To assure compliance with water-quality targets, WQT programs typically translate spatial (geographic distribution) and source (point and nonpoint) heterogeneities of the pollutant load into equivalent water-quality results using trade ratios that specify how many units of emission of one type or from a particular location may be exchanged for units of another type or location. This is particularly important in programs in which point sources trade a metered unit of commodity while nonpoint sources trade a predicted (estimated) unit of commodity. Point-nonpoint trade ratios are typically defined in terms of the reduction in nonpoint emission required to offset a unit of point-source emission. When trades are based on predicted emissions, the market contains no explicit information about the reliability of the pollution reduction that will be achieved by nonpoint sources. Consequently, WQT programs that use predicted emissions as a commodity usually implement restrictions on trade that are intended to address that uncertainty. The point-nonpoint trade ratios used in programs developed so far nearly all exceed unity, implying that more than one unit of nonpoint reduction is required to offset a unit of point-source emission.

A number of economic studies have addressed the design of point-nonpoint trade ratios (Horan et al. 2002, Horan, Shortle, and Abler 2002, Horan 2001, Horan and Shortle 2005, Malik, Letson, and Crutchfield 1993, Shortle 1990). Three insights are essential. First, uniformly applying a single point-nonpoint trade ratio to all point-nonpoint trades diminishes the efficiency and ecological effectiveness of the mechanism. Second, the ratio for point-nonpoint trades that best manages nonpoint risk may be less than 1:1. Finally, the selection of trade ratios should be integrated with decisions about other design parameters, such as the commodity to be traded, baseline requirements, and the emission cap. Design parameters do not have independent effects on a program's outcomes. In actual practice, point-nonpoint trade ratios are nearly always uniform across nonpoint sources, usually exceed (often substantially) 1:1, and were specified independently without regard to other WQT design parameters (Shortle and Horan 2008). In a survey of trading programs, Selman et al. (2009) found no instance in which point-nonpoint ratios had been derived from scientific information. Instead, the ratios generally were set at a value thought to be politically acceptable to stakeholders. Yet methods for estimating these ratios have been developed in the scientific literature on trading (Shortle and Horan

2008). The use of ad hoc approaches when developing key program parameters despite the availability of scientific methods to support appropriate choices indicates a need to better engage science when establishing WQT programs.

Another example is baseline participation requirements. Economic theory and research suggest that trading programs are more efficient when barriers to entry in the form of baseline pollution-reduction requirements are eliminated (Ghosh, Ribaudo, and Shortle 2011). Yet such requirements are a feature of many programs (Selman et al. 2009).

So who are the experts? Conferences and workshops for WQT practitioners are populated by experienced practitioners and representatives of consulting firms, nongovernmental organizations that serve or advocate for the trading business, and regulators. Technical guidance comes primarily from the same population. Studies in economics that specifically address the design of WQT have little presence.

Research Needs

While bottom-up innovations should be encouraged and applauded, WQT remains largely an experiment that can benefit from additional economic research and more effective economic outreach. As noted previously, economic research to date has focused on the design of rules to optimize the efficiency of markets in achieving water-quality outcomes. This research generally has assumed that WQT markets would result in perfectly competitive equilibria and that planners have perfect information about polluters' costs. Both assumptions are problematic.

One useful line of research for water-quality markets generally is experimental and behavioral research to improve our understanding of factors that determine whether and how agents of various types participate in markets to improve the "choice architectures" of those markets. The concept of choice architectures has been used in behavioral economics to describe the phenomenon that the choices that people make are influenced by the way in which the choices and their consequences are presented (Sunstein and Thaler 2008). The same phenomenon can be expected to occur in environmental markets, suggesting that "good" outcomes will require attention to aspects of the presentation of choices and their outcomes within these markets. The goal should be to reduce the cost of complexity of participation and to provide understanding of the market to help traders make informed decisions. Because ecosystem services often are a function of management of working lands, lessons garnered about how and why farmers (the leading nonpoint polluters) participate will likely be instructive for other environmental markets and vice versa. The issue is partly one of incentive design, a subject of active research, but noneconomic factors also appear to be important. For example, research by Breetz, et al. (2005) found that trust and communication barriers have contributed significantly to minimal rates of participation by farmers in trading experiments that engaged agriculture.

In addition to improved choice architectures, participation would likely increase and trading decisions could be improved by reducing the amount of uncertainty in the markets (Cao, Wang, and Zhang 2005). Uncertainty has been established as a barrier to participation in new markets. The decisions required of participants in environmental markets involve large investments, and participation is sure to be hindered by uncertainty about trade volume and/or prices. So far, economic research on trading has focused on market design, not market prediction. Research aimed at predicting environmental markets has often assumed that equilibrium will be achieved by cost-minimizing allocations so it has estimated those allocations rather than behavioral outcomes (Nguyen et al. 2013). Economic research that models behavioral outcomes using agent-based models or other similar procedures could greatly enhance our understanding of what to expect from environmental markets (Roth 2002).

Finally, as previously noted, emerging markets that involve nonpoint sources of contaminants generally use estimates of steady-state nonpoint emissions as the nonpoint commodity. In a recent paper, Horan and Shortle (2011) demonstrated that, to design a market that will address nonpoint risk and minimize the cost of pollution abatement, the regulatory authority must be able to predict the market equilibrium. That essentially implies that the authority must have perfect information because the current models directly address only one element of nonpoint risk—the mean. Variance and other relevant moments are determined indirectly by polluters' choices about how to minimize the cost of achieving the mean emission reduction. This information requirement would seem to diminish the appeal of a market. The economic case for trading is that regulatory authorities can use markets to achieve efficient allocations without knowing individual polluters' abatement costs. From that perspective, future research would identify new models of WQT that could define the nonpoint commodity in terms of multiple risk attributes to better predict the effect of the market for the commodity on water-quality conditions (over a steady-state expectation) (see also Ghosh and Shortle (2012)). Another concern with current models is that they treat contemporaneous point-source emission reductions and mean nonpoint reductions as substitutes. Increasingly, the literature on management of nutrient pollution is focusing on lags in nonpoint pollution, which implies that current nonpoint reductions are substitutes for future point reductions (Meals, Dressing, and Davenport 2010). The implications of lags for market design have not been significantly addressed (Shortle and Ribaudo 2012).

Concluding Comments

Water-quality goals in the United States and elsewhere have been pursued largely through stringent and costly point-source controls rather than less costly nonpoint-source controls. Compounding the cost of this misallocation is that point-pollution reductions have not been achieved at the lowest cost because regulation of that pollution came from highly inefficient, technology-based, uniform effluent standards. WQT is emerging within this context as a mechanism that can reduce the cost of achieving increasingly stringent water-quality goals by allowing reallocation of additional reductions in loads to cheaper sources. Some of the WQT programs involve trades among point sources, others between point and nonpoint sources, and some among nonpoint sources.

The interest in WQT is emerging from economic theory and from real-world experiments in air emission markets that indicate that market-based trading can achieve environmental goals less expensively than traditional regulatory approaches. The concept of WQT is being applied not only to mechanisms that correspond to this vision but also to mechanisms that present little or no opportunity for buyers and sellers to interact or compete. It is interesting that the rhetoric of market-based trading is used widely in the WQT domain to make a case for mechanisms that do not, in fact, involve markets. More interesting is that these mechanisms are, in several cases, successfully reducing the cost of pollution control by reallocating emissions from high-cost to low-cost sources. The range of models currently in use provides useful lessons for water-quality managers seeking to improve the efficiency and effectiveness of their water-pollution control programs and for economists who wish to understand environmental policy innovations and provide research that improves the design and selection of economic instruments.

While WQT experiments offer interesting lessons for economists, the enterprises themselves can benefit significantly from additional economic research and more effective economic outreach. I have suggested two lines of research that I believe would be particularly beneficial. One is experimental and behavioral studies to improve our understanding of factors that influence whether and how agents of various types participate in markets with the objective of improving the "choice architectures" of these markets. Another is research aimed at reducing uncertainty in predictions about the outcomes of markets. More accurate economic predictions would improve individual decision-making related to whether and how to participate in markets. Better predictions would also improve market design by providing policymakers with a realistic understanding of the potential cost savings and of how the design of the market influences the economic and ecological performance of trading. Useful predictions would abandon the conventional paradigm of modeling the trading equilibrium as the least costly pollution-control allocation. Instead, the model would directly address challenges specific to water-quality markets. Those challenges come from many factors: constraints imposed by the CWA, multiple interacting policies, imperfect and asymmetric information about costs, heterogeneous agents, stochastic processes in pollution generation and movement through watersheds, the inability to meter most emissions from nonpoint sources, and spatially heterogeneous and dynamic relationships associated with human activities that generate emissions and affect the impact of those emissions on water quality.

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