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Analysis

Integrating Watershed Hydrology and Economics to Establish a Local Market for Water Quality Improvement: A Field Experiment

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ABSTRACT

Innovative market mechanisms are being increasingly recognized as effective decision-making institutions to incorporate the value of ecosystem services into the economy. We present a field experiment that integrates an economic auction and a biophysical water flux model to develop a local market process consisting of both the supply and demand sides. On the supply side, we operate an auction with small-scale livestock owners who bid for contracts to implement site-specific manure management practices that reduce phosphorus loadings to a major reservoir. On the demand side, we implement a real money, multi-unit public good auction for these contracts with residents who potentially benefit from reduced water quality risks. The experiments allow us to construct supply and demand curves to find an equilibrium price for water quality improvement. The field experiments provide a proof-of-concept for practical implementation of a local market for environmental improvements, even for the challenging context of nonpoint pollution.

1. Introduction

Ecosystems provide many services that society values, but some ecosystem services are threatened by development and pollution (De Groot et al., 2002). Water quality is one such ecosystem service that provides benefits including drinking water, recreation, aesthetics, and nonuse values, but is at risk from pollution (Brauman et al., 2007). Pollution stemming from agricultural practices can introduce excess nutrients into freshwater bodies, causing harmful algal blooms and deteriorated water quality (Correll, 1998; Carpenter et al., 1998). This nonpoint source pollution is difficult to address because of the large number of actors involved, the complex feedback relationships between land management decisions and hydrology, those who are affected by pollution often differing from those who cause the problem, and the fact that water quality is a public good. The benefits of a public good cannot be made exclusive to those who pay for them, resulting in free-riders who benefit from the public good without paying for it. Therefore, we expect public goods like water quality to be systematically undervalued and underprovided when their existence depends on private donations. Our research addresses this challenge by introducing and testing an economic market that connects demand for improved water quality with farmers to fund manure management practices.

Market mechanisms (e.g., auctions) are increasingly recognized as effective ways to incorporate the value of ecosystem services into the economy (Banerjee et al., 2013). Markets work by providing incentives for generating or preserving ecosystem services and aligning public and private interests. In fact, conservation auctions have been implemented at various scales in the United States (e.g., Thurston et al., 2010; Hellerstein et al., 2015), Canada (Hill et al., 2011), Australia (Eigenraam et al., 2006), Europe, and elsewhere. However, the vast majority of these markets have been one-sided, only considering either demand for conservation or supply of ecosystem services (e.g., Swallow et al., 2008; Jack et al., 2009; Thurston et al., 2010; Boxall et al., 2013).

To address this gap, we present a field experiment to demonstrate a market approach for water quality improvements. We integrated a supply-side auction for improving water quality with a demand-side auction to fund local water quality improvements. Our setting involved livestock owners within a reservoir watershed as “sellers” in the supply-side auction and local residents of that watershed as “buyers” in the demand-side auction. The market addressed nonpoint source pollution caused by phosphorus contained in animal manure. In the supply-side auction, we solicited bids from livestock owners to install gutters that

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redirect rainwater from manure piles and to install better manure storage, thereby improving phosphorous levels in the watershed. In the demand-side auction, we solicited bids from local residents to pay for marginal improvements in phosphorus levels. Together, these auctions allowed us to determine an equilibrium price and quantity of phosphorus reductions. We found a positive willingness to contribute for reducing cow manure by farmers improving their manure management. Residents' payments coupled with an external funding funded three actual manure management projects, demonstrating the viability of this market approach.

The first primary contribution of this research is integrating the supply-side auction and demand-side auction within the market. In contrast to a one-sided auction, having an auction process on both the demand and supply sides of the market can lead to a more efficient market. Our approach allows the organization running the market (the market maker) to compare the supply cost to demand for ecosystem services at the margin, allowing the market maker to endogenously determine the quantity of services provided and price received by suppliers. In designing such a market, the auction mechanisms used should generate the price signals from the participants in a manner reflecting their true value or cost of the good or service provided in order to realize market efficiencies (Griffiths et al., 2012; Boyd and Krupnick, 2013). Therefore, we also tested the effectiveness of a recently developed type of auction aimed to reduce incentives for free-riders, who benefit from a public good without paying their full value for it, an Individualized Price Auction (IPA) (Smith and Swallow, 2013; Swallow, 2013). We coupled this demand side with a procurement auction designed to identify the least-cost providers of water quality improvements.

The second contribution of this study is testing the viability of a market approach to improve a highly localized public good, of which water quality is a prime example. In contrast to other ecosystem services such as carbon sequestration, improvement in water quality primarily affects only local residents whose values may vary widely (Keeler et al., 2012). We address the need to understand the ecological process that links actions (e.g., of livestock owners) to the provision of ecosystem services valued by individuals at the relevant spatial scale (Keeler et al., 2012; Boyd and Krupnick, 2013). Previous studies on markets for water quality are often not quantitatively linked to changes in management, land use and other actions that lead to water quality improvement (Bateman et al., 2011). To do so, we use a spatially explicit hydro-ecological model of watershed flux (SWAT). Using this model, we estimate the effects of specific manure management practices at particular farm sites on the level of nutrients within the reservoir system. This model allows the market to prioritize funding for farms that can achieve the largest reductions in pollution at the lowest costs. Doing so enhances allocative efficiency by providing the specific level of water quality preferred by and paid for by resident contributions. Additionally, our approach is unlike other market-based approaches to water quality under, for example, a cap and trade institution that relies upon government regulatory power to obviate the need for a beneficiary-driven demand sector (Shortle, 2013). Although the size of this pilot experiment is too small to restore the water quality of the watershed and hence serves as a proof-of-concept, the intent of the experiment is to evaluate the market approach, and to inform design in scaling up the effort if the approach is found viable. Our approach demonstrates a way to integrate a hydrological model with an economic market that establishes a protocol that the public accepts for linking action to impact, thereby enabling public consumers to focus on changes in the impact and its value to themselves.

2. Design of Field Experiment and Implementation

2.1. Study Area

We conducted the field experiment in the Scituate Reservoir Watershed in Rhode Island. The watershed is 242 km^2, composed of a number of interlinked basins with a total surface area of 18.6 km^2. The reservoir system supplies water to > 600,000 residents including the capital city of Providence, over 60% of the state's population (Bellet et al., 2003). The Providence Water Supply Board (PWSB) conserves and manages 25% of the watershed with the goal of maintaining, and ultimately improving, water quality of the reservoir system (Nimiroski and Waldron, 2002; Bellet et al., 2003).

While the system as a whole maintains good water quality, studies have found one of the reservoirs in a mesotrophic state, with heightened levels of nutrients in the water (U.S. EPA, 2014). Studies also found evidence of excessive nutrients in the water, or eutrophication, driven by high levels of phosphorus (U.S. EPA, 2014). Nutrient-rich waters provide good conditions for algae to grow. One particularly harmful type of algae is cyanobacteria, a species of blue-green algae capable of producing neurotoxins and hepatotoxins. Cyanobacteria have been reported in the study reservoir (ESS Group, 2011). Blue-green algal blooms increase the concentration of organic matter in the water. When this organic matter is combined with chlorination used in the drinking water treatment process, it can foster trihalomethanes, chemical compounds known to increase risk of cancer in some people (U.S. EPA, 2014). The presence of conditions capable of supporting cyanobacteria blooms makes prevention of further degradation in this sole-source drinking water reservoir a pressing health concern.

Excess phosphorus in the reservoir system is predominantly from rural, nonpoint sources, including small farm operations (< 3.5 ha) which constitute 35% of all farms in Rhode Island (USDA NASS, 2014). Many of these farms raise livestock and contain areas of heavy livestock use with animal waste. However, these heavy-use areas often lack the necessary infrastructure or livestock owners lack the best management practices to prevent nutrients from the animal waste from entering the reservoir. Small-scale livestock operations in particular have substantial risk of off-site contamination due to a combination of high manure loads and low soil infiltration rates (McCullough et al., 2001). Off-site contamination could be curtailed with the use of well-tested management practices adopted by larger operations (USDA ARS, 2006). However, small farm operations typically lag larger ones in adopting such practices, in part because they are not required by existing regulations (Fuglie and Kascak, 2001).

While ongoing conservation and outreach efforts to reduce nonpoint source pollution like phosphorus from livestock farms are essential to improving water quality, market mechanisms could serve as a key additional watershed management tool. Designed to address these traditionally difficult-to-influence nutrient sources, markets could fill the gap of watershed management tools to maintain and ultimately improve the conditions in this reservoir and others with similar diffuse nutrient sources.

2.2. Supply-side Auction

The objective of the supply side is to replicate the marginal cost curve for phosphorous reductions. To do so, we conducted an auction with small-scale livestock farmers operating within the reservoir watershed who were recruited through collaboration with local conservation organizations, focus groups, mailings, and a door-to-door recruitment campaign. Seven farmers with operations ranging from 2 to 250 livestock participated in the auction. An expert and extension staff person visited each farm to understand the scale of operation and current manure management practices, conduct soil tests for nutrients and a wetlands evaluation, and evaluate safety and legal restrictions for participation in the study. They then recommended one or both of two projects to improve manure management: i) construct a concrete containment pad to store manure, and ii) install gutters to redirect rainwater from areas with manure. We selected these two projects because they are appropriate for small-scale livestock farms and require

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