Extended abstract for PhD Dissertation

A Stochastic Agent-based Market Model for Water Quality Trading Using Evolutionary Simulation Techniques

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Water quality credit trading is the most significant policy innovation in water pollution control policy since the Clean Water Act was implemented in 1972. Water quality credit markets are more complex than the cap-and-trade markets that have proven highly successful in controlling air emissions due to the economic and technical challenges posed by nonpoint source emissions. The design of water quality credit markets necessitates significant departures from the design of classical textbook emissions markets.

The existing literature has focused on the optimal design of markets under the assumption of perfectly competitive market equilibrium. While important insights have been derived in the prior water quality market literature, the assumptions that the markets will be perfectly competitive and without transactions costs strongly depart from the realities of these systems. Water quality markets in the U.S. tend to be thin, unorganized, and populated by agents who have substantial uncertainty about market rules, market prices, and potential gains from trades. Furthermore, the unobservable and stochastic nature of nonpoint emissions implies high transactions costs for trading as well as for monitoring and enforcement. These characteristics imply that a perfectly competitive equilibrium is not a plausible condition to assume when evaluating water quality markets. In addition, experience with these markets to date is very limited, making robust ex post assessment impossible.

The broad objective of this research is to develop a better understanding of the outcome of water quality markets. In particular, it is of interest to investigate the challenges posed to markets when attempting to achieve the least cost allocation given uncertainties in design parameters and agents' interactions. A stochastic agent-based model is developed to examine bilateral negotiations between point and nonpoint source polluters in a partially capped water quality credit trading market. Agents in the market make participation, pricing and trading decisions under multiple sources of uncertainty. The introduction of these issues into water quality trading evaluation yields highly nonlinear, non-convex and stochastic topologies in the individual agents' decision spaces, their objective functions and the overall objective function. Finding a robust solution for this problem is a difficult task. By adapting the state-of-the-art Differential Evolution algorithm, this research seeks to identify "robust" best-known least cost solution and their transient search dynamics, given alternative specifications of trade ratios and environmental targets, the influence of transaction costs, as well as the inherent uncertainties and complexities in agents' interactions.

The resulting market outcomes are not viewed as predictions of market equilibria. This is because the underlying strategies are selected by a mechanism, the DE algorithm, which is not available to the decentralized market. It is noted that the stochastic agent-based model is formulated to capture only the lower bound complexity expected in actual WQT markets. The lower bound complexity case should maximize the potential for WQT markets to attain their theoretical potential. With this design, high levels of economic performance in the simulated markets do not imply that actual markets can be expected to do well, but low levels of performance imply that actual markets are likely to face significant challenges in realizing efficient allocations.

The results suggest that it is difficult to attain a "robust" best-known least cost solution when there are multiple sources of uncertainties, complex agent interactions and discrete costs. The high rate of failure by the market in converging to its best-known least cost solution suggests that there is a distribution of market cost outcomes for given sets of trading rules and market structure, which implies that in designing markets for water quality trading, the planner cannot assume that the market will achieve the least cost solution to its problem. Moreover, market outcomes are state contingent because the initial tendencies of agents' behaviors in markets are shown to influence their ultimate performance. Transaction costs are found to reduce market efficiency, participation rates, the number of trades, and subsequently the proportion of abatement requirements achieved by trading. Increases in trade ratios put a negative impact on the above market efficiency measures. Tightening the environmental target, however, has mixed effects on market efficiency in the presence of transaction costs and different assumptions on cooperative behaviors among agents. In the absence of transaction costs, offers being initiated at random result in trades that are clustering near the receptor. When including transaction costs, a local clustering of trades resulting from initial random offers is observed. This supports the fact that spatial dependence of nonpoint emissions cannot be ignored when designing the market for water quality.

Our findings suggest that expectations of gains from trade should be tempered. The presence of positive gains from trade relative to the no-trading solution is only a necessary but not a sufficient condition that warrants the achievement of the least-cost solution to the planner's problem. As the market organized by bilateral negotiations has a high probability of failing to attain its least cost solution given alternative specifications of market design parameters, it is reasonable to reconsider the negotiation mechanisms and encourage mechanisms that enhance coordination such as a clearinghouse market.

Finally, while our analysis has been motivated by interest in water quality trading, our results apply more generally to applications of trading to environmental management contexts with similar characteristics. Such contexts can be expected as use of the trading mechanism is extended to smaller scales and more complex pollutants than those traded in large regional or national air emissions markets.