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Research article

Introducing nonpoint source transferable quotas in nitrogen trading: The effects of transaction costs and uncertainty

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ABSTRACT

Transaction costs and uncertainty are considered to be significant obstacles in the emissions trading market, especially for including nonpoint source in water quality trading. This study develops a nonlinear programming model to simulate how uncertainty and transaction costs affect the performance of point/nonpoint source (PS/NPS) water quality trading in the Lake Tai watershed, China. The results demonstrate that PS/NPS water quality trading is a highly cost-effective instrument for emissions abatement in the Lake Tai watershed, which can save 89.33% on pollution abatement costs compared to trading only between nonpoint sources. However, uncertainty can significantly reduce the cost-effectiveness by reducing trading volume. In addition, transaction costs from bargaining and decision making raise total pollution abatement costs directly and cause the offset system to deviate from the optimal state. While proper investment in monitoring and measuring of nonpoint emissions can decrease uncertainty and save on the total abatement costs. Finally, we show that the dispersed ownership of China's farmland will bring high uncertainty and transaction costs into the PS/NPS offset system, even if the pollution abatement cost is lower than for point sources.

1. Introduction

Emission trading is regarded as a cost-effective, market-based instrument for pollution control (Burtraw et al., 2005; Ellerman et al., 1997; Tietenberg, 2006). China has been researching and piloting emissions trading programs since the 1980s (Wang, 2002). From then on, a couple of pilot projects for the compensated transfer of emission quotas have been launched by the Chinese government (Dudek et al., 2004; Zhang et al., 2010). In 2008, the Ministry of Environmental Protection (MEP) and the Ministry of Finance (MOF) of China selected seven provinces as pilots to implement water pollution trading (WPT) programs (MEP, 2008). To date, there are more than ten provinces and cities which have carried out emissions trading programs and seven pilot carbon trading schemes in China (Lo, 2013).

Participants in the previous emissions trading systems were restricted to point sources. In fact, nonpoint source pollution from agricultural land, animal production and rural life constitutes a large proportion of total nutrient loadings in China (Ongley et al., 2010). For example, nonpoint sources accounted for 74% of Chemical Oxygen Demand (COD), 56% of Total Nitrogen (TN) and 23% of Total Phosphorus (TP) in the Tai Lake Basin (Qin et al., 2007). Efforts towards the reduction of nonpoint source pollution are scarce due to lack of resources and motivation from governments and peasants. However, the pollution abatement costs for nonpoint sources are much lower than those for point sources in China (Wang et al., 2004).

A pollution emission permits trading system which unregulated nonpoint sources participate in can be more cost-effective under the condition that nonpoint sources reduce pollution discharge at lower costs than point sources. (Collentine, 2005; Ribaudo et al., 2010; Ribaudo and Gottlieb, 2011). Emission trading between point and nonpoint sources at USA's Tar-Pamlico River has saved 75%–90% on abatement costs (Jarvie and Solomon, 1998). Peasants

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engaged in the credit trading can gain revenue from emission trading credit sales as their reward for taking conservation activities. The agricultural sector could earn \$45 million to \$300 million per year in new revenue, an amount comparable to the current levels of annual public funding for agriculture conservation cost-share programs for the bay, from a point/nonpoint source (PS/NPS) emissions trading program in Chesapeake Bay (Jones et al., 2010).

There are two obstacles, uncertainty and transaction costs, to including nonpoint sources in a permit trading system (Nielsen, 2012; Woerdman, 2001). First, the uncertainty of nonpoint source pollution emissions remains at a high level because of its sensitivity to weather-related factors, such as rainfall (Shortle and Dunn, 1986). The control efficiency of the measures taken to reduce emissions from nonpoint source is also uncertain due to their limited history in practice (Malik et al., 1993). Besides, the difficulties in monitoring and verifying nonpoint source loading make the measured value of nonpoint source loading uncertain. Therefore, the decision makers of a watershed will hesitate to involve nonpoint sources in a permit trading system because it would introduce too much uncertainty to the emissions reduction plan for the system. Research suggests that techniques for measurement and including practices specified as valid reduction measures by the authority can reduce the uncertainty to some degree (Brandt and Svendsen, 2011).

Second, transaction costs generated in the trading between point source and nonpoint source are higher than those of the trading without nonpoint sources (Jarvie and Solomon, 1998; Shabman and Stephenson, 2007). Transaction costs comprise expenditure on the search of traders and information, bargaining and decisions making, as well as monitoring and enforcement (McCann et al., 2005; Stavins, 1995). The costs related to information searching, bargaining, decision making, monitoring and enforcement will be larger for nonpoint sources than those for trading between point sources owing to lack of knowledge about nonpoint sources and their diffused nature. These transaction costs will be added to total pollution abatement costs directly and increase the total costs indirectly by affecting the trading volume. Many studies have raised the problem of transaction costs (Wang et al., 2004; Zhang and Wang, 2002). An empirical evaluation of a PS/NPS emissions trading program in Minnesota found that transaction costs increase the total cost of the trading program by 35% (Fang et al., 2005). Collentine (2005) also recognized the negative effect of transaction costs and therefore designed a composite market to provide information on pollution discharge, thus reducing transaction costs.

This paper aims to model the performance of an offset system for PS/NPS emissions trading system in China while taking uncertainty and transaction costs into consideration. Additionally, this paper analyzes the effects of uncertainty and transaction costs on the design and implementation of PS/NPS emissions trading. The key elements and influencing factors of the offset system were analyzed by using a stochastic programming model, which is used to simulate PS/NPS emissions trading (Horan and Shortle, 2005). The model established in this paper is applied to simulate PS/NPS ammonia nitrogen emission trading in the Lake Tai watershed. The results show that uncertainty and transaction costs have the potential to impact the performance of the PS/NPS emission trading. The remainder of this paper is organized as follows. Section 2 presents the theoretical model for PS/NPS emissions trading including uncertainty and transaction costs; Section 3 applies the model to a simulated PS/NPS ammonia nitrogen emission trading system in the Lake Tai watershed and outlines the results; Section 4 makes a discussion according to the results above; Section 5 concludes the study.

2. Methodology

2.1. Theoretical model

In the PS/NPS emission trading system, we view all the point sources as a whole, which trade with x identical nonpoint sources. The burden of pollution reduction is only borne by the point source in the initial stage; nonpoint sources are not required to control their emissions. The point sources can reduce their pollution emissions or purchase emission reductions from nonpoint sources, and transaction costs consist of the costs from bargaining and decision making and the costs for monitoring and measuring. We consider the uncertainty of emission reductions from nonpoint sources caused by natural factors and assume that the uncertainty follows the normal distribution. We assume the public is sensitive to risk.

This paper donates e_p to be a point source's unconstrained emission and $c_p(e_p)$ to be the emission abatement costs, which is monotone decreasing and strictly convex. On the other hand, the nonpoint source's unconstrained emission reduction is stochastic and denoted by $\xi(e_{n0} - e_n)$, where ξ is a normally distributed variable representing the stochastic weather-related events that influence nonpoint source emission reductions, e_n denotes the total expected emission loadings of nonpoint sources, and e_{n0} denotes their initial pollution loadings. Because it is assumed that nonpoint sources are identical to each other, the emission reductions from each nonpoint source which trade with the point source is $(e_{n0} - e_n)/x$. The abatement cost of each nonpoint source can be represented by $c_n(e_n/x)$, which is also monotone decreasing and strictly convex. The initial permits given to point sources, denoted by $\hat{e}_{p0}$, are lower than their initial pollution loadings, denoted by e_{p0}. Nonpoint sources can implement various emission reduction projects, either introduce a new, less polluting practice or reduce the polluting activities to generate emission reduction credits. Then the credits are sold to point sources to meet their emission limits. We raise an integrated stochastic programming model to examine the optimization problem that allows us to characterize the optimal trading state and analyze the feasibility of the offset system. When implementing PS/NPS emissions trading, loadings between point sources and nonpoint sources are distributed to minimize the social costs of achieving an emissions control target with a certain probability.

$$Min\ C = \left[c_p(e_p) + xc_n(e_n/x) + c_t\right] \tag{1}$$

$$s.t. P\left\{e_p - \xi(e_{n0} - e_n) \le \hat{e}_{p0}\right\} \ge \alpha \tag{2}$$

The first term in the objective function represents the total costs of compliance with emission control requirement, and c_t represents transaction costs of the offset system. The emissions control target determines that the aggregate emissions from point sources should not exceed the initial permits, $\hat{e}_{p0}$. This constraint restricts the probability of achieving the emissions control target to some level, α $(0 < \alpha < 1)$.

Two sources of transaction costs are considered in the model: 1) bargaining and decision making, and 2) monitoring and measuring. The first source represents the real resource costs to traders involved in entering negotiations. The second source is the cost related to measuring source emission loadings by monitoring or using physical process models. The two types of transaction costs are represented by c_{t1} and c_{t2}. That means

$$c_t = c_{t1} + c_{t2} \tag{3}$$

The first source of transaction costs, bargaining and decision