An Economic Inquisition of Water Quality Trading Programs, with a Case Study of Jordan Lake, NC

Abstract

A water quality trading (WQT) program was promulgated in North Carolina to address water quality issues related to nutrients in the highly urbanizing Jordan Lake Watershed. Although WQT programs are appealing in theory, the concept has not proved feasible in several attempts between point and nonpoint polluters in the United States. Many application hurdles that create wedges between success and failure have been evaluated in the literature. Most programs, however, face multiple hurdles; eliminating one may not clear a pathway to success. Therefore, we identify and evaluate the combined impact of four different wedges including baseline, transaction cost, trading ratio, and trading cost in the Jordan Lake Watershed program. Unfortunately, when applied to the Jordan Lake program, the analysis clearly shows that a traditional WQT program will not be feasible or address nutrient management needs in a meaningful way. The hurdles individually would be difficult to overcome, but together they appear to be unsurmountable. This analysis shows that there is enough information to pre-identify potential hurdles that could inform policy makers where, and how, the concept might work. It would have saved time, energy, and financial resources if North Carolina had done so before embarking to implement their program in the Jordan Lake Watershed.

Keywords

Water quality trading; Non-point sources; Wedges; Jordan Lake; North Carolina

1. Introduction

Over half of lakes, reservoirs, and ponds assessed in the United States are threatened or impaired by different types of nutrients (Selman et al. 2009). Many different policies have been used to improve water quality, including the increasingly popular concept of water quality trading (WQT). In theory, water quality can be improved at a lower cost using WQT than with other types of policies, such as command and control, by allowing individuals or firms with high abatement costs to trade credits with firms that have low marginal abatement costs (EPA, 2008; EPA handbook, 2004; Faeth, 2000; Greenhalgh and Selman, 2012; Willamette Partnership, 2014).

Although WQT is appealing in theory, WQT programs in the United States have struggled to show any meaningful success, especially when including non-point sources (NPSs) from farms (Smith, 2011; Shortle, 2013a; Ribaud and Gottlieb, 2011). For example, Morgan and Wolverton (2005) found that out of 19 WQT programs in the USA, only four had experienced more than three trades. A growing body of literature suggests that achieving an ideal WQT market is difficult because WQT programs have implementation hurdles that seriously impede or even preclude their success (Breetz et al. 2004, 2005; Hennessy and Feng, 2008; Hoag and Hughes-Popp, 1997; Horan, 2001; Jarvie and Solomon, 1998; King, 2005; Malik et al. 1993; Newburn and Woodward, 2012; Ribaud, et al. 1999; Ribaud and Gottlieb, 2011; Shabman and Stephenson, 2002; Stephenson and Norris, 1998; Stavins, 1995; Suter et al. 2011). However, to the best of our knowledge, no study has provided a comprehensive understanding of how these hurdles work together, either independently or with interactions, to make or break a market. Costly errors could be made if policy makers overcome one of these hurdles just to discover another hurdle follows – and another. The few programs that have found limited success have done so by skillfully navigating these hurdles (e.g., the Great Miami Trading Program in Ohio (Newburn and Woodward, 2012)).

A WQT market can be portrayed in a familiar supply-demand format. King and Kuch (2003) postulated that there might be three types of markets. If the credit supply and demand cross each other, an ideal (*i.e.*, frictionless (Smith et al., 2012)) market is possible. If there are hurdles, they act as wedges, driving supply and demand apart and creating a marginal market. A marginal market might be able to function if the wedges do not fully drive supply and demand apart, which would be an infeasible market.

The purpose of this study is to build an economic framework to examine multiple wedges simultaneously to investigate how these wedges effect a WQT market. We build supply and demand curves for an ideal market related to an existing program then add wedges to determine how they affect trading. Our case study is in the Jordan Lake Watershed where the State of North Carolina (NC) is currently attempting to implement a market for trading nutrients to improve water quality. This paper contributes to the literature by providing a structured framework to study wedges that may arise when WQT programs are implemented. Using this framework, wedges may be anticipated and evaluated in a comprehensive way to determine the combined effect on market viability before WQT programs are implemented. Markets with high potential to fail may be avoided where research shows that the combined effect of policy wedges is too great to overcome. The totality of how policy wedges stack up offers one explanation about why successful WQT markets are so elusive. In our case study, we demonstrate empirical estimation of the supply and demand, as well as evaluation of the impacts of four different wedges on supply and demand, to show why a functional WQT market in this study area is unlikely to succeed. This work should help policy makers determine a more precise setting for designing WQT programs and give some insight on how to implement policies that reduce the magnitude of any wedges where possible.

2. Study area and methods

We proceed by building a framework to determine supply and demand in an ideal WQT market. We then build a marginalized market by introducing four of the most important wedges discussed in the literature. These include: how baseline is defined, transaction costs, the existence of trading costs, and policies that impose trading ratios. Lastly, we estimate an empirical supply and demand for credit trading in the Jordan Lake Watershed program, and apply empirical estimates for each of the same wedges to predict the potential for success in this emerging WQT market. In the end, we estimate whether that market is sufficiently marginalized to fail.

The Jordan Lake Watershed, located in the Piedmont region of North Carolina, is a significant water resource within the Cape Fear River Basin (Figure 1). In addition to serving as a crucial water supply, Jordan Lake was created to provide flood control, protection of water quality downstream, fish and wildlife conservation, and recreation services. Since its

impoundment, the lake has been declared as hyper-eutrophic by the Environmental Management Commission (NCDEQ, 2014).

Fig. 1. Jordan Lake Watershed study area.

We develop a mixed empirical and hypothetical model based on actual WQT program rules and goals, and then evaluate credit trading behavior based on cost and pollution data for individual farms in the Haw sub-watershed (which comprises 80% of the Jordan Lake Watershed area). In the Jordan Lake WQT program farmers can install riparian buffers as a conservation practice (CP) to reduce total nitrogen (TN) loads delivered to the lake, and sell credits for this pollutant reduction to new urban developers. In this program, new urban developers are held responsible for reducing the TN loads to the lake, while farmers' participation in this program is voluntary.

We begin by determining urban demand for credits. Urban developers minimize the cost to reduce expected TN loading to Jordan Lake as follows (Malik, et al 1993):

$$\begin{aligned} \min_{TN_u} [TC(TN_u)] \\ \text{s.t. } E[TN_u] \leq \overline{TN} \end{aligned} \quad (1)$$

TN_u denotes the urban developers' allowed TN loads to Jordan Lake, based on the WQT rules, and $TC(TN_u)$ is the urban abatement cost function that is decreasing and strictly convex in loading TN_u . The constraint restricts expected TN_u , or $E[TN_u]$, to be no greater than the target level $\overline{TN}$. We assume the $TC(TN_u)$ properties will ensure the minimization condition and an interior solution will be obtained.

Developers have two options to minimize their total costs. They can either (1) install or upgrade waste water treatment plants (WWTP) for TN reduction (TNR_{tech}) or (2) participate in a WQT program to buy credits for TN reduction (TNR_{trade}). Therefore, urban developers' total cost, $TC(TN_u)$, for achieving their water quality requirements is as follows:

$$TC(TN_u) = f(TNR_{tech}, t * TNR_{trade}) \quad (2)$$

Where TNR_{tech} and TNR_{trade} have above definition and t is the trading ratio. If the marginal cost of participating in the WQT program (MC_{trade}) is less than the marginal cost of installing (or upgrading) WWTP (MC_{tech}), developers can meet their $\overline{TN}$ requirements at a lower cost by buying credits from a WQT market.

$$(TNR_{tech}, TNR_{trade}) = \begin{cases} (0, TNR_u) & \text{if } MC_{trade} < MC_{tech} \\ (TNR_u, 0) & \text{if } MC_{trade} > MC_{tech} \end{cases} \quad (3)$$

Simply put, when urban developers find it less costly to purchase credits, rather than upgrade their plants, they demand credits.

On the supply side of the Jordan Lake WQT program, farmers who opt to participate in the program are required to install riparian buffers as a CP. Since participation in the Jordan Lake WQT program is voluntary for farmers, a farmer maximizes his/her profit by selling crops and TN reduction (TNR_f) credits as follows:

$$\max_{x,Z} \pi = P_Y Y(x) + P_N TNR_f(Z) - TC(Z) - r_x x \quad (4)$$

where π is profit, and x and Z are traditional crop production inputs and the inputs required for installing conservation practices, respectively. P_Y is the price of crop (Y), and P_N is the price of TNR credits to the farmer and r_x is the price of traditional cropping inputs. $TC(Z)$ includes the total cost of installing a riparian buffer, total opportunity cost (lost cropping profits), and the cost of maintaining and monitoring the installed buffer. Typically, not all of the pollution a farmer prevents is allowed to be sold as credits. Often credit is only given for pollution prevention above some baseline determined by the program. TNR_f in Equation (4) indicates the amount of TN load reduction beyond the baseline that can be sold from installing a riparian buffer. That is:

$$TNR_f = TN_r - TN_0 \quad (5)$$

where TN_r shows the TN load after installing riparian buffers and TN_0 is the baseline. In the Jordan Lake program, baseline is set to the average TN loads from 1997–2001. In the ideal market, the baseline wedge is unbinding; therefore TN_0 is set to zero and all TNR_f can be sold. Farm supply of credits is determined by maximizing equation 3. As P_N goes up, so does the supply.

2.1. A marginalized market

The ideal market changes when wedges are added. Each wedge pushes supply and/or demand away from each other, reducing tradable credits. The addition of more wedges causes more shifts in supply/demand, and an increasingly marginalizes the market. In this section, we investigate the roles of four wedges in supply and demand that are often identified in the literature: baseline, transaction cost, trading ratio, and trading cost.

2.1.1 Baseline

Establishing a baseline is one of the first steps in implementing a WQT program. The baseline defines the amount of pollution reduction that must be achieved before WQT is allowed. Stephenson et al. (2010) and Ghosh et al. (2011) found that a baseline that is more stringent than current practices increases the cost of agricultural credit and the expenses of entering a trading program. A baseline can affect credit buyers by requiring a minimum threshold of abatement before allowing credits to be purchased, or affect credit suppliers by setting a minimum pollution reduction to be achieved before credits may be sold. The baseline truncates (eliminates) the lower end of the supply function by requiring a farmer to reduce the nutrient load up to the baseline at their own expense. Likewise, the baseline requirement truncates the upper portion of the demand function, requiring urban developers to achieve the first units of abatement by other methods besides WQT (Duke et al. 2012; Savage and Ribaud, 2014). Baseline could have a profound influence on the feasibility of a WQT market (EPA, 2007).

In our case study, we designed two baseline scenarios for the supply side of the Jordan Lake WQT program: (1) The control period (C): average 1997-2001 TN loads, and (2) Stringent Baseline (B): 92% of C, which meets the 8% targeted reduction in loading stated for the Jordan Lake program. In both cases, pollution reduction is the difference between TN loads in the

baseline and loading in 2012 after riparian buffers were installed (R). For the demand side, we applied the regulated storm water management baseline requirement to urban developers.

2.1.2 Transaction cost

Transaction costs are those additional costs on top of the price of the trade that would be required to make trades happen. The transaction costs associated with a given environmental policy can be divided into policy transaction costs (such as bureaucracies necessary to run the program) and market transaction costs (such as legal representation required for contracts) (Herath and Weersink, 1999). Adding either type of transaction cost increases the cost of participating in a WQT program for both urban developers and farmers (Woodward and Kaiser, 2002), and shifts or tilts both ideal demand and supply curves.

“A few studies have attempted to estimate transaction costs of environmental markets or conservation programs” (Chesapeake Bay Commission. 2012, pp. 26), prompting us to also make assumptions based on literature estimates. Galik et al. (2012), McCann and Easter (2000), and Heimlich (2005) estimated a range for transactions costs of between 10% and 50% of the other costs of generating credits. Fang et al. (2005) estimated a 35% transaction cost factor for a nutrient trading program in the Minnesota River Basin. The Chesapeake Bay Commission (2012) adopted 38% adjustment factor for calculating transaction cost of nutrient trading program. For purposes in this study, we assumed transaction costs are 35%.

2.1.3 Trading cost

Trading cost encompasses two influential components of a WQT program, including transaction costs and an adoption premium (AP), which are necessary costs for doing business in a WQT program. The innovation premium can be viewed simply as a premium over and above the direct costs and transaction costs that would be necessary to prompt a producer to adopt a system. The concept of an AP was distinguished from transaction costs by Motallebi et al. (2016) and is meant to account for abstract factors that are not typically included in transaction costs (Peterson et al. 2007). These costs are difficult to assess, such as how much value a farmer puts on their lack of trust for government programs or hesitance to adopt unfamiliar systems (Breetz et al. 2005; Mariola, 2012). Moreover, sometimes a WQT program is too new to permit trades and the

new trading rules and regulations produce uncertainties for the WQT participants (Morgan and Woverton, 2005; Shortle, 2013a, 2013b).

We measured the AP by subtracting installation cost and transaction cost from a farmers' willingness to accept (WTA) a payment to adopt a CP (see Motallebi et al. 2016 for more details). WTA was elicited from an in-person interview with 90 farmers whose farms are located in the Jordan Lake Watershed (O'Connell et al. 2016). For example, if a farmer's WTA was \$5,000 to adopt a CP, and the cost to implement and maintain the CP was \$2,000, with 35% transaction costs (\$700), the farmer is asking for a premium, or additional incentive of \$2,300 ($= 5,000 - 2,000 - 700$). Adding an AP tilts the supply curve to the left, decreasing the amount of the available credits.

2.1.4 Trading ratio

Trading ratio (t) is "equal to the marginal rate of substitution of emissions between two sources which ensures no net change in ambient pollution" (Horan and Shortle, 2011, pp: 61). EPA (2007) indicates that the trading ratios encompass the equivalency ratios to adjust for trading different forms of the same pollutant, and uncertainty ratios to adjust for uncertainties associated with NPS trades (EPA, 2007). The stochastic nature of NPS emission makes the loading reduction efficiency of a given CP uncertain and increases the risk that water quality goals may not be achieved (Horan, 2001). A high trading ratio could reduce the economic attractiveness of trading programs because it discounts credits from NPSs (Corrales et al. 2013) and tilts WQT demand to the left.

For equivalency, we derived individualized delivery ratios for every unique field using SPARROW¹ coefficients (Smith et al. 1997) on the supply side. To account for the trading ratio associated with uncertainty, we used chance constrained programming (CCP) on the demand side (Charnes and Cooper, 1965). Uncertainty makes the WQT model stochastic. CCP addresses uncertainty by specifying a confidence level (α) for uncertain constraints. Essentially, our uncertainty ratio accounts for the uncertainty of achieving at least $\alpha\%$ of a pollution abatement goal (Ghosh and Shortle, 2009). Zhang and Wang (2002) utilized the CCP method to calculate the trading ratio of a WQT program in Taihu Lake in China.

2.2. Case study: Jordan Lake water quality trading program

¹ SPATIally Referenced Regressions On Watershed attributes

Jordan Lake has been declared hyper-eutrophic since its impoundment in 1983 (NCDEQ, 2014). In its 2005 draft Cape Fear Basin Plan, NC Division of Water Quality (DWQ) identified the entire Jordan Lake Watershed as nutrient-impaired based on chlorophyll *a* data, and placed it on the Clean Water Act 303(d) list and requiring a Total Maximum Daily Load (TMDL) to meet the criterion for Chlorophyll *a*. A WQT program has been suggested by the North Carolina Department of Environment and Natural Resources to address water quality issues facing this rapidly urbanizing watershed, and to reduce nutrient delivery to Jordan Lake (NCDENR, 2013). In this study, we focus on the Haw sub-watershed where trading is most likely.

2.2.1 Supply from farmers in the Haw sub-watershed

The Jordan Lake WQT program encourages farmers to adopt and maintain riparian buffers close to streams on their farms (NCDENR, 2013). Riparian buffers preserve land near streams with permanent vegetation to reduce the discharge of nutrient and sediment lost from agricultural fields, improve water quality, and provide other ecosystem services (e.g. wildlife habitat). Several cost-related assumptions are included in our WQT model. First, based on the Jordan Lake WQT program rules (hereafter referred to as “Jordan Lake rules”) (NCDEQ, 2014), riparian buffers should be installed on the edge of fields, adjacent to a stream. The required width of the buffer is 15.24 m. We assumed the opportunity cost for crop and livestock farmers is equal to the net returns loss from crops or hay that could not be harvested due to devoting a portion of the field to the riparian buffer. Yield and price data for NC crops and hay were obtained from National Agricultural Statistics Service (NASS, 2014). The costs of producing hay and crops were extracted from NC State University and A&T State University Cooperative Extension (2014). A discount rate of 4.6% in perpetuity was used to annualize the investment costs (NRCS, 2009). Installation costs were estimated at \$1,110 per ha for crop producers and \$5,400 per ha for livestock farmers (NRCS, 2011).

We used the Soil and Water Assessment Tool (SWAT 2012) (Arnold et al. 1998) to simulate the TN loads from agricultural fields and their reductions due to installing riparian buffers. TN loads were then multiplied by delivery ratios from SPARROW to determine the amount of abatement to Lake Jordan for each field. SWAT is a semi-distributed process-based watershed model which has been used in the literature extensively for simulating hydrologic and water quality processes as well as water quality benefits of agricultural conservation practices

(Arabi et al., 2007; Tasdighi et al., 2016; SWAT Literature Database, 2016). The SWAT model has predefined routines for evaluating the effects of agricultural conservation practices such as field strips, riparian buffers, grassed waterways. The model was calibrated for the period of 1997 to 2007 using the daily stream flow and monthly TN loads at 5 stations across the watershed producing good to very good results based on the criteria described in Moriasi et al (2007). The Nash-Sutcliffe efficiency was > 0.60 and $|\text{relative error}| < 17\%$. The performance of the model was then tested for the period of 2008 to 2012 generating satisfactory to good results (Nash-Sutcliffe efficiency > 0.53 and $|\text{relative error}| < 15\%$).

We found 10,835 fields located in the Haw sub-watershed based on the available common land units dataset (CLUs)². According to the Jordan Lake rules, fields with forest land were ineligible for WQT (NCDENR, 2013), which qualified 3,753 out of 10,835 fields as eligible for trades. The calibrated SWAT model was used to simulate the TN loads on eligible fields for the control-period (C), 1997–2001, and in 2012 after the riparian buffers had been installed (R) (Motallebi, 2015). We design two baseline scenarios for individual farmers participating in the Jordan Lake WQT program. Our results show how changing the baseline scenario will change the amount of total available WQT credit in this region.

2.2.2 Demand from urban developers

According to Jordan Lake rules, new urban developers are responsible for installing one WWTP, including bio-retention, sand filters, ponds, or wetlands to reduce TN loads to achieve their storm water management requirement. If the urban developer's load reduction after installing the WWTP is less than the total required reduction, the developer has two options. They can either upgrade or expand their current WWTP, or trade with farmers to achieve the required reductions.

In this study, the cost of installing WWTPs, including construction cost, 20-year maintenance cost, and opportunity cost were extracted from a report on the economics of structural stormwater best management practices (BMPs) for NC (Wossink and Hunt, 2003). Net present value (NPV) of these costs, with a discount rate of 4.6%, was used to calculate the total cost of installing or upgrading a WWTP in 2014. Also, we used the Jordan Lake Nutrient Loading Accounting Tool (NCDENR, 2007) to calculate the TN loads reduction after installing

² “A Common Land Unit (CLU) is the smallest unit of land that has a permanent, contiguous boundary, a common land cover and land management, a common owner and a common producer in agricultural land associated with USDA farm programs.” (USDA, 2012).

or upgrading WWTPs for a new urban development. Details about the cost of WWTP's are provided in Table 1. The required TN threshold for total storm water management for urban developments (*i.e.*, urban developers' baseline) in the Haw sub-watershed is 4.26 kg/ha/yr. We used the results from a 17.5 ha residential and commercial development located in the city of Durham as a proxy for the region. The new urban developer WWTP installation costs are reported in Table 1. As shown, a 1.6-ha residential portion of the new urban development is required to reduce its pollution by 2.7 kg/ha/yr. Currently, the bio-retention pond used by the developer reduces TN by only 2.35 kg/ha/yr. Therefore, the developer needs to reduce the load by an additional 0.34 kg/ha/yr, either by expanding the current WWTP or by trading with farmers. If the developer chooses the first option, they require 0.62 kg offset per year for their 1.6 ha portion. For this portion, the additional cost of expanding the current WWTP to reach the required reduction of 0.62 kg is 9,946 (\$/kg). Likewise, the other portions of this development project would cost \$12,969, \$42,240, and \$56,074 per kilogram of TN load reduction to expand their current WWTPs for reaching the required TN reduction.

According to the Jordan Lake Watershed model report (TETRA TECH, 2014), the imperviousness between 1999 and 2010 increased by 13,450 ha in the Haw sub-watershed, or by 1,223 ha per year. We assume that the imperviousness growth rate indicates the urban development growth rate. For simplicity and clarity, we assume that urban development in the Haw sub-watershed will continue to grow at 1,223 ha per year, and that all growth will have the same impact on TN loads in our case study.

3. Results

3.1 *The ideal market*

The ideal supply and demand for the Jordan Lake program is illustrated by the solid lines in Figure 2 and given in Table 2. The supply curve depicts the cost to supply credits from the 3,753 fields by installing a riparian buffer. It slopes up because credits from fields close to the lake are relatively cheap compared to credits from fields that are farther away when TN delivery to the lake is considered. Demand is plotted from Table 1 and slopes down because at higher prices buyers would demand less, opting to upgrade their plants rather than buy credits. The

equilibrium quantity traded in an ideal market with no wedges, where supply crosses demand, is 1,916 kg, with an average price of \$4,778 per credit.

The social value of a program can be determined by the amount of social surplus it generates. Buyers that pay a price lower than they were willing to pay, the region above price and below the demand curve in Figure 2, earn a consumer surplus (CS). That is, if you were willing to pay \$100 but only had to pay \$70 based on the equilibrium price, you would have \$30 of surplus to spend on something else. Likewise, producers that receive a higher price than they needed to supply credits, the region below price and above supply, earn a producer surplus (PS). When added together, this market yields a social surplus (SS) of \$36.6 million. SS can be thought of like new money generated for society by adding the trading program, which is a valuable welfare measure of a program's success.

Fig. 2. Supply and demand, with and without wedges, for WQT program in Jordan Lake, NC. C is the TN baseline based on the control period, 1997-2001, B is 92% of C, and R is the TN load after conservation practices have been installed.

3.2 Adding wedges to the supply side

We redraw supply and demand in Figure 2 to account for one wedge at a time and for all wedges together. Supply shifts in, as shown, when baseline and trading costs are added, and demand

shifts in when transaction costs and trading ratios are added. Each of these shifts drives the price up and supply traded down.

On the supply side, credit producers (farmers implementing CP) in the Jordan Lake Watershed face two potential baselines that effect trading as follows:

Liberal baseline: the difference between average TN loads for the control period from 1997-2001 (C) and after riparian buffer installation in 2012 (R), or $C \rightarrow R$, and

Stringent baseline: the difference between 92% of the control-period (B), and after installation of riparian buffers (R), or $(B \rightarrow R)$.

Implementing a baseline truncates credit supply by reducing the number of eligible farmers that can participate in the program and concurrently raises the cost of trading. A total of 3,659 fields are eligible to participate in Jordan Lake's WQT program under the liberal baseline, while only 806 fields are eligible in the more stringent scenario. As shown in Table 3, the maximum supply of credits is 1,991 kg for the $B \rightarrow R$ scenario and increases to 9,967 kg for the $C \rightarrow R$ scenario. The cost of cheapest unit (first field in at the bottom of the supply curve) is \$1,148 with the liberal baseline and \$521 with a stringent baseline, and rises to several million dollars for the last unit of TN reduced (top of the supply curve). Buying one unit of TN load reduction under the $C \rightarrow R$ scenario is cheaper than buying the same amount of reduction under $B \rightarrow R$ scenario due to the high baseline requirement.

Inclusion of trading costs (transaction cost plus AP) also reduces the quantity of trades. The results of adding trading costs are shown in Tables 2 and 3. Results based on Motallebi et al. (2016) show that livestock and crop farmers' AP was 2.35 and 2.36 times higher, respectively, than the installation cost of the riparian buffers. The minimum cost of trading, after adding the trading cost increases from 1,148 to 1,320 (\$/kg) for the liberal baseline and from 521 to 601 (\$/kg) with a stringent baseline. On average, costs increase by about 77% and 85% respectively when trading costs are added.

Table 3 shows how wedges individually and jointly affect a WQT program. For example, simultaneous addition of a stringent baseline and trading cost to the ideal WQT market will increase the price of each credit by \$799 (the difference between \$1,320 and \$521), while adding only trading cost to the ideal scenario will raise the minimum price of each credit by \$80 (the difference between \$521 and \$601). That is, implementing a stringent baseline or adding trading cost individually will raise the minimum credit price by 220% and 110% respectively, compared

to the ideal situation. Adding these two wedges to the model simultaneously raises the minimum price of each credit by 250%. The effect of these wedges on the market equilibrium are presented in Table 2 and shown in Figure 2. The combined effect of both wedges together would reduce tradable emissions from 1,916 kg of TN to 775 kg of TN in the watershed. SS is reduced from 36.6 to 34.1 million dollars with introduction of the trading cost wedge (about 7% reduction) and to 14.3 million dollars with simultaneous inclusion of baseline and trading cost (about 60% reduction) for Haw sub-watershed.

3.3 Adding wedges to the demand side

Unlike producers, there is no ambiguity about whether urban developers need to achieve a baseline before trading. The Jordan Lake rules explicitly indicate new urban developers must first implement required WWTPs before trading. The estimated demand therefore already includes that requirement. A trading ratio (t) and transaction cost are the two main wedges that we add to the demand side. The uncertainty component of TN load reduction efficiency in the trading ratio of our study was calculated using the CCP method. CCP minimizes the total abatement costs with a constraint of targeted emission (see Wang et al. 2004 for more details). In this study a trading ratio greater than 1.0 was expected. Shortle (1987, 1990) noted that a $t > 1$ is appropriate when the NPS loading variance increases by the level of NPS abatement effort. Assuming the probability of achieving the TN load reduction in this program is 95%, the t would be 2.5, indicating that an urban developer should buy 2.5 kg of credits to offset one-unit of TN emission to the lake.

Similarly to the supply side, we added a 35% adjustment factor to the demand side of WQT program to include the transaction cost. The impact of demand wedges are shown in Table 2 and Figure 2. The combined effect of both supply wedges and trading ratio was to reduce the tradable emission of TN to 656 kg, and to reduce welfare (SS) by nearly 80% to 7.8 million dollars. The combined effect of all considered wedges on both supply and demand sides reduced the tradable emission to 486 kg of TN and welfare to 5.7 million dollars (nearly 85% reduction).

Table 2 displays the changes in the WQT market equilibrium in different scenarios. The maximum amount of credit provided at the lowest price will happen in the ideal market in 1,916 kg TN/yr at a price of \$4,778. Adding trading cost (*i.e.*, transaction cost and AP) will drop the amount of tradable credits by about 7% and increase the equilibrium price by 47%. A

stringent baseline will reduce the potential number of fields that can supply credits from 3,659 to 806, and increase the credit prices. All wedges combined reduce the tradable credit by about 75% from 1,916 kg/yr to 486 kg/yr, and increase the credit price by about 50% from \$4,778 to \$6,978; welfare is reduced by about 85% from \$34.1 million to \$5.7 million. These results are illustrated in Figure 2, where the impact of wedges is shown through a series of shifts in demand and supply.

4. Additional Considerations

The ideal Jordan Lake WQT market is severely weakened by the four wedges that we considered, but still has a positive price and quantity. This implies the market is marginalized, but still feasible. However, the actual program has another problem that is not mentioned as a wedge in the literature. Demand and supply are seriously mismatched. Demand will consume all of the credits that agriculture can provide at reasonable cost in a single year. The remaining supply will be so small and so expensive that the market is infeasible after the first or second year. Therefore, a WQT program in the Jordan Lake Watershed is virtually impossible because the annual demand is about two-thirds as much as what agriculture can ever supply.

5. Conclusion

Despite their attractiveness on paper, cost effective conservation practices such as WQT programs may not always be the most applicable approaches. Implementing these programs requires knowledge that comes from a well-defined economic model that includes as many implementation wedges as appropriate. In this paper, a WQT economic model was developed for Jordan Lake Watershed, NC. Four wedges, baseline, transaction cost, trading cost, and trading ratio, were added. The results revealed that adding all wedges simultaneously will reduce the tradable credits by three quarters and society's welfare by 84%. Therefore, the results indicate that the four wedges marginalize the market in Jordan Lake Watershed NC, but alone do not result in zero credits traded. However, spending the time, effort, and financial resources on a program for so few credits is likely infeasible. In addition, the total amount of supply is inadequate to keep up with demand over time, rendering the market unviable over longer time periods.

The Jordan Lake WQT market offers a perfect example of a program moving forward without sufficient information and analysis. Had the analysis been done prior to implementation, the North Carolina State may have saved time and money. The framework offered here is cost-effective and can be done in most locations with current data and modeling tools.

Overall, while the WQT program in Jordan Lake watershed, NC, shows some potential, it does not appear to be applicable. Assessing all effective wedges on the WQT program will assist policy makers in evaluating the likely success or failure of this policy for Jordan Lake, NC.

This study helps show policy makers how to navigate the growing number of studies that find wedges in order to determine if WQT is viable at a location, and if so, how to reduce marginalization of the WQT market by wedges through thoughtful program design.

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Table 1. New urban developers' WWTP size and WWTP cost based on case study in Durham County, NC

Development	Type	Size (ha)	Location	WWTP type	Current Reduction (kg/ha/yr)	Required Reduction (kg/ha/yr)	Total individual offset (kg/yr)	TC (NPV) for current reduction (\$)	TC (NPV) for required reduction (\$)	MC (\$/kg)
The Villas at Hope Valley	Residential	1.62	Durham	BRC w/IWS ³	2.35	2.7	0.56	123,051	129,199	9,946
City Center	Commercial Building	0.3	Durham	BRC w/IWS	4.9	7.6	0.81	35,612	45,338	12,969
Hendrick South Point	Commercial Auto Mall	13.08	Durham	2 Ponds and Sand Filter	2.6	4.3	22.36	3,840,143	4,767,501	42,240
BCBS of NC	Commercial	2.6	Durham	Wetland and Sand Filter	2.5	5.5	7.8	921,651	1,362,092	56,074

Table 2. Price and quantity of credits traded and social surplus in ideal and marginalized WQT market in Jordan Lake Watershed, NC

Scenario	Quantity (kg/yr)	Price (\$)	Consumer Surplus (CS)* (\$)	Producer Surplus (PS)** (\$)	Social Surplus (CS + PS)
Ideal demand and ideal supply	1,916	4,778	35,118,134	1,514,208	36,632,342
Ideal demand and adding trading cost to supply	1,791	7,036	30,805,480	3,306,587	34,112,067
Ideal demand and adding stringent baseline and trading cost to supply	775	11,629	11,239,033	3,089,318	14,328,351
Adding trading ratio to the demand and adding stringent baseline and trading cost to supply	656	9,423	2,036,156	5,768,229	7,804,385
Adding transaction cost and trading ratio to the demand and adding stringent baseline and trading cost to supply (marginalized market)	486	6,978	919,815	4,803,161	5,722,976

*CS is the difference between what urban developers are willing and able to pay for credits relative to its market price **PS is the benefit that farmers receive for selling the credits in the WQT market.

³ Bio-retention cell with or without internal water storage

Table 3. Total Nitrogen (TN) load reduction, Marginal Cost (MC), area and credit supply in different baseline scenarios

	Scenario	MC (\$/kg) before adding trading cost	MC (\$/kg) after adding trading cost	Credit supply (kg)
Min (bottom of supply curve)	B→R	1,148	1,320	1.1
	C→R	521	601	0.7
Max (top of supply curve)	B→R	487,865,912	904,963,792	1,991
	C→R	4,237,838	6,571,250	9,967
Average	B→R	937,915	1,664,703	1,542
	C→R	110,469	204,389	7,206

C is the TN baseline based on the control period, 1997-2001, B is 92% of C, and R is the TN load after conservation practices have been installed