DISSERTATION

WATER QUALITY TRADING IN JORDAN LAKE, NORTH CAROLINA: ECONOMIC, HYDROLOGICAL, BEHAVIORAL, AND ECOLOGICAL ASPECTS

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ABSTRACT

WATER QUALITY TRADING IN JORDAN LAKE, NORTH CAROLOINA: ECONOMIC, HYDROLOGICAL, BEHAVIOURAL, AND ECOLOGICAL ASPECTS

I chose to use the three-manuscript option for my dissertation. The three topics addressed are related to water quality trading (WQT) in Jordan Lake, North Carolina. My goal was to advance our understanding of WQT programs and to provide practical, realistic information that policy makers in North Carolina could use in implementing the program in Jordan Lake, and other regions that may come along. Each topic and the resulting policy implications are relevant to stakeholders at the local and state levels. There is some redundancy in the articles, as each is written to stand alone and be submitted to an academic journal after my dissertation is finalized. Individual abstracts for each study follow:

ECONOMIC PERAPECTIVE OF WATER QUALITY TRADING PROGRAM

Nutrient pollution is a crucial issue for the Jordan Lake, NC. A WQT program is one of the main policies that have been suggested to address water quality, especially in the face of a rapidly growing urban sector that requires options to reduce its delivery of nutrients. Although a WQT program is appealing in theory, it has thus far failed to prove feasible in several attempts in the United States. This dissertation identifies and evaluates factors, called wedges that diminish the chance of WQT program's success in Jordan Lake.

The study shows why and how geographical, economic, and behavioral factors should be considered before implementing the emerging program in Jordan Lake. A unified economic

model was designed to examine how economic and non-economic factors can undermine an ideal WQT market, and in many cases make it infeasible.

PRODUCER PREMIUMS FOR WATER QUALITY TRADING

Although most of the discussed wedges for a WQT program are focusing on the tangible factors, there are some intangible elements that impede the success of these programs. Lack of social trust between the involved parties in a WQT program and unfamiliarity on the part of participants with program details are examples of intangible wedges that can reduce the rate of participation. In this study, I measured farmers' intangible costs for participation. I dubbed intangible costs as an innovation premium. A survey was done in person in the Jordan Lake watershed. The amount of farmers' willingness to accept for participating in WQT program was elicited and computed. The results of the survey showed that farmers are willing to participate in a WQT program, but they require a very high innovation premium that is much higher than their best management practice installation costs.

IMPACT OF RELATIVE EDMAND FOR ECOSYSTEM SERVICES ON STACKING ECOSYSTEM CREDITS

Consideration of the potential markets for ecosystem services raises intriguing questions about how such markets can and should interact with each other and what the implications of multiple markets are for cost and conservation objectives. Selling ecosystem service credits, along with other types of credits has been called credit stacking. I investigated the role of the demand for multiple types of credits with different attributes on ecosystem services stacking. I designed a credit staking market for total nitrogen (TN) and total phosphorus (TP) credit in a stacking framework for Jordan Lake, NC. The results showed that slope and intercept of TN and TP demand are playing profound roles in the success of a credit stacking program. In addition, if

the credit stacking market is not coordinated, double-dipping can undermine its benefits. Double dipping is a situation when credit suppliers are getting paid more than they would without stacking, while they do not provide any additional credits.

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CHAPTER 1. INTRODUCTION

1.1. INTRODUCTION

Water is a vital resource to life and the economy and plays a profound role in the proper functioning of the Earth's ecosystems. Water pollution can negatively affect all living creatures, the use of water for drinking, household needs, recreation, fishing, transportation and commerce (EPA, 2013). The 1997 Clean Water Action (CWA) Plan identified nutrients as a significant national problem contributing to water pollution. In the United States, 60 percent of assessed lakes, reservoirs, and ponds were threatened or impaired for their designated uses in 2006 and a significant number were impaired by nutrients (Selman et al. 2009).

Water pollution, either from nonpoint sources (NPS) (e.g. agricultural or urban runoff) or from point sources (PS) (e.g. discharge pollutants into a waterbody via pipe, sewage treatment plants, and industrial facilities), can be damaging to the economy and it can be expensive to treat and prevent contamination. Damage costs can occur in three main forms: economic cost (e.g. less profitability of aquaculture, commercial fishing, and recreational damage), social cost (e.g. threatening human health or livelihoods), and environmental cost (e.g. damaging ecosystem service functions). Many estimates of the cost of pollution have been made, but overall, an accounting of the economic damages caused by poor water quality is lacking due to an inability to conduct accurate physical monitoring and difficulties in estimating economic costs and benefits (USDA, 2006). Tegtmeier and Duffy (2004) reported that external costs of agricultural production across different areas such as natural resources, wildlife, ecosystem biodiversity, and human health in the United States range from $5.7 to $16.9 billion annually.

Although water resource issues present special management challenges, many ways for decreasing environmental degradation have been proposed and implemented. There are three major ways to reduce water pollution: volunteerism, traditional regulatory approaches (command-and-control approaches), and economic incentive or market-based policies (EPA, 2013). In this dissertation, I will focus on marketable permit systems or trading programs. Trading programs have the potential to reduce the cost of environmental protection because firms are flexible to either reduce their own emissions or to purchase pollution allowances from other firms who could reduce their emission below their required level (EPA, 2013). The water quality trading (WQT) programs that I will focus on in particular are nutrient trading programs (NTP), which are designed to reduce nitrogen (N) and phosphorus (P) that terminate to the rivers or lakes.

The market-based approach to improve water quality that is the focus of this dissertation is based on a capped allowance system. Dales (1968) first proposed the idea of transferable discharge permits, and these have been promoted and grown in popularity ever since. WQT can be an environmentally cost-effective solution to improving water quality. Based on WQT economic theory, the gains of markets include allowing dischargers to benefit from economies of scale and treatment efficiencies, which can vary from source to source, reducing the overall costs of achieving water quality objectives in a watershed, encouraging further adoption of pollutant prevention and innovative technologies, involving more NPSs in solving water quality problems, providing complementary benefits such as improved habitat and ecosystem protection, and helping policy makers design incentives for water quality improvement activity from a full range of dischargers (EPA, 2004).

While WQT is an appealing approach to improve water quality in theory, its application in the real world has been challenging (Hoag and Popp, 1997). Breetz et al. (2004) and King and Kuch (2003), for example, show that out of all water quality trading programs in the United States, only four had experienced more than three trades. Many reasons have been postulated about why these programs have not worked as anticipated, such as a lack of trading partners, lack of sufficient regulation, uncertainty about trading rules, legal and regulatory obstacles to trading, high transactions costs, cheaper alternatives for PS to meet regulatory requirements than trading with NPS, the programs being too new to permit trades, or trust and communication barriers (Morgan and Wolverton, 2005; Breetz et al. 2004, 2005; Hoag and Hughes-Popp,1997; Jarvie and Solomon, 1998; King, 2005; Shabman et al. 2002; Stephenson and Norris, 1998). The contribution of each of these issues to the overall success of a WQT will be called a “wedge” here, which is a term that has been conventionally used to refer to policy scenarios by economists and others (Pacala and Socolow, 2004).

The goal of my dissertation is to build an economic model that can be used to more fully understand and explain when, where and how WQTs work. The framework will be a unified model and can be manipulated to evaluate wedges found in the literature in a more comprehensive way than looking at one wedge at a time. This model also will be applied to an emerging WQT program in Jordan Lake, NC to investigate how that program will function there.

1.2. QUALITIES OF EFFECTIVE WQT

Every trading program has the same properties but in different amounts because they must be adapted to different physical, social, political and ecological environments. These properties are described briefly below:

Pollution Limits: The Clean Water Act of 1972 required each state to implement total maximum daily load (TMDL)[1] by 1979. Establishing TMDLs will be the first of many steps that will need to be taken by state and local water quality regulators. In addition, states and often times local governments have additional requirements that must be considered.

Pollution Baseline: The second step for implementing a WQT is establishing a baseline (EPA, 2003). In most programs, a buyer must meet some technology-based effluent limit (TBEL) before being allowed to buy credits to meet its water quality-based effluent limit (WQBEL). A point source seller must also meet its most stringent effluent limitation before it can generate credits. Also a nonpoint source seller must meet its TMDL load allocation or, if there is no TMDL, it must meet any state and local requirements before it can generate credits. In some cases, the seller has no restrictions. This is particularly true for non-point sources such as agriculture.

Pollution Cap and Cap Allocation: The third step is cap allocation based on TMDL or other relevant limit. As soon as a specific cap has been defined for a watershed, the cap has to be allocated among all regulated entities. A cap determines how much pollutant load a lake or stream can assimilate.

Pollution Levels: After cap allocation, every entity with a cap must compute its current nutrient loss and potential reductions. Direct measurement, site specific calculation, and pre-determined nutrient reductions for practices regardless of location are three approaches for calculating the nutrient loss from each site.

Trading Ratio: Often, to make trades comparable, many times trades are subject to a trading ratio, which specifies how much emissions must be reduced at one source to offset a 1-unit

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[1] Total Maximum Daily Load (TMDL) addresses the sum of all point source loads, loads associated with nonpoint sources and the uncertainty in the response of the waterbody to loading reductions.

increase in emissions at another source (Horan and Shortle, 2011). There are different types of trading ratios that are normally used for WQT such as delivery ratio, uncertainty ratio, equivalency ratio, retirement ratio, and insurance/reverse ratio.

Credit Exchanges: Finally, there has to be a mechanism for trades to occur. Pollution trading markets can be categorized into four main classes: exchanges, bilateral negotiations, clearinghouses and sole-source offsets. The most important element that can differentiate these markets is transaction cost. Transaction cost is an inevitable result of market structure and typically transaction costs vary across alternative structures. The goal of any successful program is to find the most efficient form of trading market structure (Woodward and Kaiser, 2002).

1.3. QUALITIES OF INEFFECTIVE WQT

The World Resource Institute (WRI) has assessed 57 WQT programs worldwide. Of these, 26 are active, 21 are under consideration or development, and 10 are inactive. Out of these 57 programs, all but six are located in the United States (Selman et al. 2009). Based on this report, there are 26 active WQT markets. Kieser and Fang (2005) reported WQT has not generated the vibrant national (or even regional) credit market that many had hoped. Nor can it be compared, in magnitude or effectiveness, to more successful programs such as the Acid Rain Trading Program in the US. In this dissertation, I investigate reasons to explain why this program has not worked properly when applied.

Several ex post evaluations of WQT programs have attempted to explain why WQT programs have not been that successful (Breetz et al. 2004 and 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, 2007; Stephenson and Norris, 1998; Malik et al. 1993; Horan, 2001; Hennessy and Feng, 2008; Stavins,1995). These studies have identified many hindrances, or wedges, for having an environmentally effective WQT programs. Conceptually, these wedges shift water quality trading supply or demand to a level where there is no crossing point, or equilibrium, and a trade will not occur. Some wedges shift supply back and others shift demand back, ultimately devaluing the market.

A summary of these wedges is listed below:

Stochasticity: textbook models of pollution trading generally assume that emissions are non-stochastic. Yet, emitted pollutants from nonpoint sources have a stochastic nature. For example, agricultural pollution emissions are categorized as NPS pollution, which are stochastic variables because the emission from each farm depends on non-deterministic parameters, such as the amount of precipitation, slope of farm, type of farmed cropped, conservation practices, etc. Traditional pollution trading textbook models typically do not consider stochasticity, and even when they do, it is extremely difficult to implement, which might be one of the reasons why WQT models are not successful in reality.

Thin Market: based on almost all of WQT literature, WQT market models have been applied to the perfect competition market condition. In the perfect competition market, lots of buyers and sellers are participating in the program, while in reality most of WQT markets are thin. With relatively thin markets in specific watersheds, prices are higher than where only one or two participants invest in lower cost abatement technologies (Suter et al. 2011).

Uncertainty: one part of uncertainty is related to the stocasticity concept behind NPS pollution but there are other sources of uncertainty that together hinder successful trading. For example, in addition to uncertainty from weather and physical flow, uncertainty can be found about the source of payment for credits, about trading rules, and about modeling (predicted emissions).

Lag: another concern with current models is that they treat contemporaneous point-source emission reductions and mean nonpoint reductions as substitutes (Shortle, 2013). Some of the literature on management of nutrient pollution is focusing on lags in NPS, which implies that current nonpoint reductions are substitutes for future point reductions (Meals et al. 2010). The implications of lags for market design have not been significantly addressed (Shortle and Ribaudo, 2012).

Transaction Cost: transaction costs can be divided into three broad categories such as search and information cost, bargaining costs, and monitoring, policing and enforcement costs. Transaction costs based on who is responsible to pay them can shift either the supply or demand curve and change the WQT market from a successful to marginal or even to a nonexistence one.

Minimum Waste Treatment Requirement (Baseline): baseline determines the amount of pollution reduction credit (sellers) or need (buyers) for WQT program participants. It is also often used as a reference hurdle point that must be met before participating in the program. If this baseline is too high for either credit sellers or buyers, the supply and demand curve might not cross and trade will not happen.

Social Trust: Breetz et al. (2005) found that trust and communication barriers have contributed significantly to low participation rates for farmers in trading that have engaged agriculture. Trust plays a significant role in the speed, quality, and reliability of WQT program. It is closely associated with transaction costs because of its nature to add to the traditional costs considered.

Innovation and Behavioral Wedges (Premium): WQT can compensate farmers’ direct costs, but financial incentives may be necessary to compensate fears about significant risks to participants that are unseen, due to the newness of the program. The risks of participating in a WQT program produce an innovation premium (IP) cost and impede the program from achieving its designed goals.

Regarding to these issues, we can say that, although WQT programs have potential to be cost effective for improving water quality, there need to be very well-defined rules that seek to reduce these wedges. In addition, any program's success will be linked to the wedges associated with each unique location. Without considering different issues related to the water quality, trading might not achieve its desired goals. In the next session, I will focus on WQT program in Jordan Lake, NC where I can apply and investigate the mentioned properties for successful programs.

1.4. A CASE STUDY: JORDAN LAKE, NORTH CAROLINA

Jordan Lake is a significant water resource within the Cape Fear River Basin (Figure1.1). It was created by the US Army Corps of Engineers to provide drinking water to the growing cities of Cary, Apex and Morrisville, as well as to Western Wake and Chatham counties. 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. The lake has been declared as hyper-eutrophic since its impoundment when it was classified as Nutrient Sensitive by the Environmental Management Commission. Limits were put on wastewater discharges soon after the reservoir was constructed but there was no water quality improvement. In 2002, North Carolina Division of Water Quality (DWQ) placed the Upper New Hope arm of Jordan Lake on the 303(d) list and identified it as a segment requiring a Total Maximum Daily Load (TMDL) to meet criterion for Chlorophyll a. In its 2005 draft Cape Fear Basin-wide Plan, DWQ identified the entire lake as nutrient-impaired based on chlorophyll α data, and the entire lake is currently on the 303(d) list.

The Jordan Lake Watershed is located in the Piedmont region of North Carolina. The 4367 km^2 watershed is comprised of three sub-watersheds: Haw, Upper New Hope and Lower New Hope, covering 80%, 13% and 7% of the total watershed area, respectively. The Jordan Lake Watershed has a land use composition of 46% forest, 21% urban/suburban and 22% agriculture, of which a large portion is pasture. Upper New Hope sub-watershed is heavily urbanized and Lower New Hope sub-watershed is being rapidly developed. The majority of the agricultural activities are pasture operations in the Haw sub-watershed, although several urban areas also exist.

A draft of TMDL was developed by NC DWQ and submitted for public review in April 2007 (NC DWQ, 2007). The TMDL utilized loading results from 1997-2001 to establish a background condition for the three management zones upon which reductions were based.

The TMDL specifies a 35 percent reduction in point and nonpoint source total nitrogen (TN) delivered to the Upper New Hope Arm and 8 percent delivered from the Haw River. Also based on the TMDL requirements total phosphorus (TP) reductions were specified as 5 percent for both the Upper New Hope Arm and the Haw River. TN and TP loadings in the lower New Hope Arm of Jordan Lake were to remain at baseline values (1997-2001 annual loads).

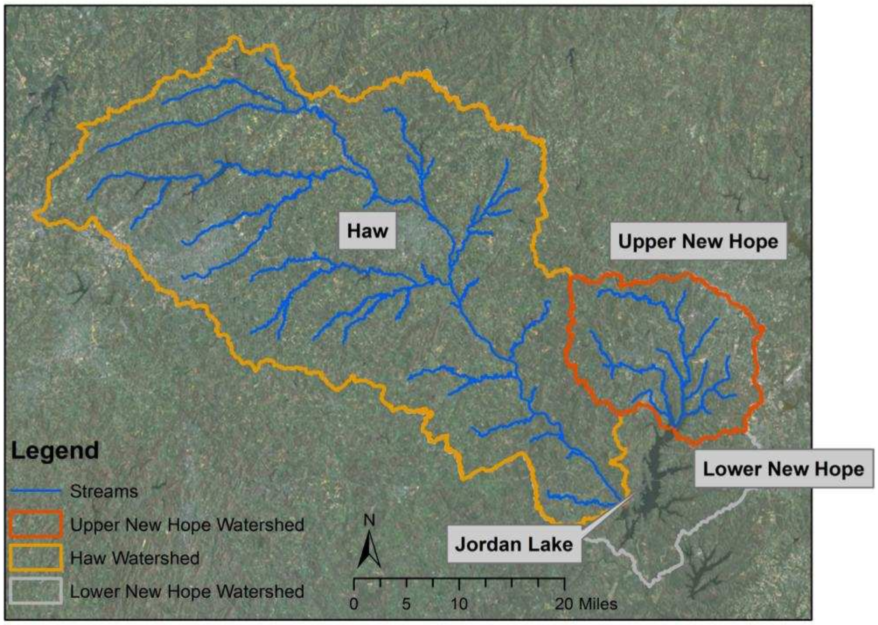

Figure 1.1. Jordan Lake Watershed

1.5. JORDAN LAKE WATER QUALITY TRADING

In the Jordan Lake watershed, TMDL (Total Maximum Daily Load) for nitrogen and phosphorus provides a cap, or driver for water quality credit trading. Under the Jordan Lake WQT rules, the agricultural community is required to meet the nutrient reductions collectively. The Jordan Lake Watershed Oversight Committee (WOC) tracks and accounts for nutrient reductions annually using Environmental Management Commission (EMC) approved tools. If the agricultural community does not meet its targeted reductions within a specified time period, then the EMC is required to mandate some form of additional implementation to occur over an additional three years before requiring full compliance. This may be individual requirements but the rule leaves latitude on this, including for the WOC to propose an alternative approach or even propose lowering expectations. Currently, agriculture in the watershed has collectively reached their N goal, so farmers are free to trade.

The Jordan Lake rules for urban areas include requirements for new development, redevelopment, and existing development. The rule establishes a minimum treatment level (TBEL), often referred to as a buyer entry point, which all new development must meet. However, the minimum treatment level does not necessarily equal the required nutrient reductions (WQBEL), with variations dictated by development intensity and resultant untreated loading. The buyer entry pollutant load, TBEL, is a minimum level of treatment that an entity must achieve before it can purchase a credit from another source. Therefore, new development seeks to install one type of BMP, such as wet pond, stormwater wetland, bioretention or sand filter, to decrease their pollution and then either buy the difference between the minimum treatment and the loading targets or oversize the BMP to meet their limit totally on site. That is, they can choose to meet any obligation after meeting their TBEL with improved technology on site or by purchasing credits.

Once a developer meets the buyer entry point loading rate (baseline), they can buy down the difference between the minimum treatment and the loading targets, if any exists, by purchasing nutrient credits from another source – in this case agriculture. Thus the Jordan Lake water quality trading rule was designed to lower implementation costs of the urban nonpoint source community. The primary conservation practice that allows urban nonpoint source credits to date in other watersheds is riparian buffer restoration, with widths ranging from 50 to 200 feet. Any non-land owner can purchase nutrient credits by buying non-forested riparian corridors and establishing forested buffers regardless of whether the agricultural community has met their nutrient TMDL reduction goal in that sub-watershed. Conversely, however, the agricultural community (e.g. an individual farmer) can only sell credits if the agricultural community has met its water quality goal in their sub-watershed.

1.6. ORGANIZATION OF DISSERTATION

A WQT program was suggested to overcome the water quality issues in Jordan Lake, NC. While this program is appealing in theory, its application in reality requires a comprehensive perspective and careful attention to detail. Lack of a holistic view about WQT programs in the literature makes it impractical to predict a priory where these programs will be feasible. In particular, wedges that will be of most importance must be identified and reduced where possible, lest the program could fail.

The three topics addressed in this dissertation are related to surface water quality. WQT will be examined from economic, social and ecological perspectives. Each topic and the resulting policy implications are relevant to stakeholders at the local and state levels. Chapters of the dissertation will be organized as three stands alone papers as below:

Chapter 2 (Economic Inquisition of WQT Programs): In this chapter, a unified WQT model will be designed, which encompasses four important wedges applied to Jordan Lake Watershed for illustration, including baseline, trading ratio, transaction cost, and trading cost. The chapter will explain how different wedges can devalue an ideal WQT program from its ideal, or text book, solution to a marginal or even infeasible market. Moreover, the impact on credit sellers and buyers' economic surplus after adding wedges will be examined. Afterwards the unified model will be applied to the Jordan Lake WQT's data. Data for the supply and demand side of the WQT model will be extracted from the Soil and Water Assessment Tool (SWAT) modeling for the Jordan Lake' water quality and urban developers' TN and TP reduction requirement, respectively.

Chapter 3 (Innovation Premium Calculation And Its Application For Jordan Lake, NC): Since the role of social aspects of WQT programs has been largely ignored in literature, I will focus on the role the innovation premium (IP) as a proxy of farmers' acceptance of a WQT program. In this research, the amount of farmers' trading cost in the Jordan Lake will be computed based on the farmers' willingness to accept (WTA) for participating in WQT program. Then the magnitude of the IP will be deduced based on the calculated trading cost. Also, the role of financial incentives to encourage farmers to participate in WQT will be investigated. To achieve these goals, a key stakeholder survey was done in person in the Jordan Lake watershed. The value of this study is demonstrating the magnitude and the effect of intangible costs on a WQT program, also illustrating how these costs might be lowered.

Chapter 4 (Is Ecosystem Service Stacking Applicable In WQT Program In Jordan Lake, NC?): In this paper, a vertical ecosystem services stacking scenario will be designed and the probability of having a successful stacking program will be investigated for Jordan Lake's WQT program.

Chapter 5 (Conclusion): The last chapter serves as a concluding "wrap-up" of the entire dissertation. My overall thoughts and lessons learned related to WQT program are presented.

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CHAPTER 2. AN ECONOMIC INQUISITION OF WATER QUALITY TRADING PROGRAMS, WITH A CASE STUDY OF JORDAN LAKE, NC

2.1. INTRODUCTION

In the United States, over half of the assessed lakes, reservoirs, and ponds were threatened or impaired for their assigned uses in 2006; this problem is mostly due to nutrients (Selman et al. 2009). Many different policies have been used in efforts to improve water quality including water quality trading (WQT). In theory, water quality can be improved at a lower cost using WQT than command and control policies such as regulation (Selman et al. 2009). Although WQT appears appealing in theory, programs that have been implemented have struggled to show any meaningful success to date (Smith, 2011; EPA, 2008).

Despite a growing list of examples in the literature evaluating different types of problems associated with WQT programs, there is not a unified model to explain when WQT will or will not work. One study, for example, might show the trading ratio is too high to make trading feasible, but does not reveal whether another hurdle would be encountered if that one was removed. Likewise, another study shows that monitoring costs are too high and has the same problem. Conceptually, the market for trading can be unified in a familiar supply-demand format like other markets, which can help clarify when and why markets work. King and Kuch (2003) for example have defined these three types of markets, as shown in Figure 2.1. If the credit supply and demand cross each other, an ideal (frictionless (Smith et al. 2012)) market may be possible, or at least a marginal market with distorted but still tradable prices can be found. If supply and demand do not cross, then a market cannot exist. Hurdles like trading ratios, monitoring costs or a list of other factors drive up transaction costs, shifting supply or demand inward, making a market less feasible or infeasible (Figure 2.1).

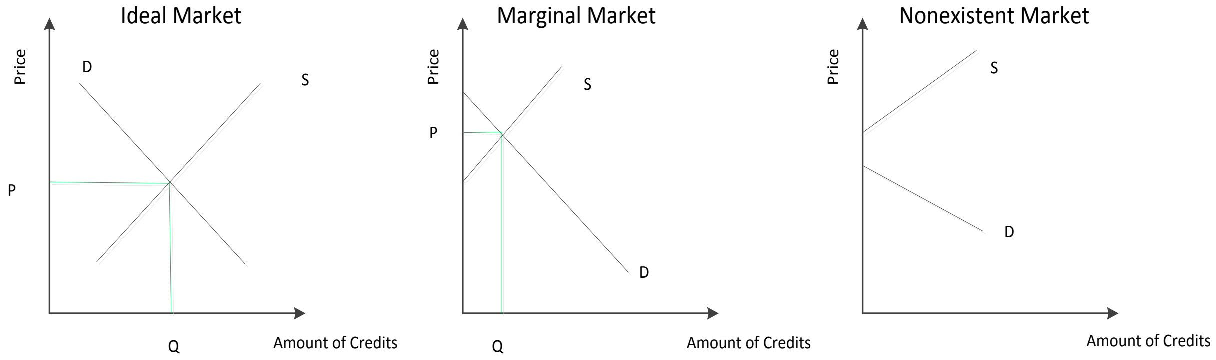

Figure 2.1.Three possible trading market

Source: King and Kuch, 2003

An ever building literature suggests that achieving an ideal WQT market is difficult and that all WQT programs have implementation hurdles that seriously impede or even preclude their success (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; Malik et al. 1993; Horan, 2001; Hennessy and Feng, 2008; Stavins, 1995). However, there is a paucity of literature that provides a way forward to make these programs successful. Most literature is focused on studying how one or two hurdles have curtailed, or most often, prevented success. I could find no study that outlines a comprehensive economic framework to study how hurdles accumulate, either independently or jointly, to increase costs to buyers and sellers, which effectively reduces supply and/or demand. Such a framework could be helpful in providing a more fundamental understanding about how the burdens of application hinder WQT programs.

The purpose of this study is to build an economic framework that can be used to unify multiple problems, as identified in the literature, into a single space that shows how hurdles, which I will refer to as wedges, affect market success. That single space is supply and demand for credits. This study contributes to the literature by providing a structured, and familiar, way to study wedges that arise when WQT programs are implemented. In this way, wedges can be anticipated and evaluated in a comprehensive way to see the combined effect on market viability before programs are implemented. If the combined effect is too great to overcome, then future failed markets might be avoided. To informally test the applicability of this framework, I applied it to an actual emerging WQT program in the Jordan Lake, North Carolina watershed.

2.2. METHODOLOGY

The first step is to identify the individual supply and demand in an ideal WQT market. The next is to extend the ideal market to account for multiple buyers and sellers. After developing the ideal, multi-trader model, four of the most important wedges discussed in the literature are applied to show how they marginalize markets through effecting supply and/or demand. These include: how a baseline is defined, transaction costs, the existence of trading costs and policies that impose trading ratios. Lastly, the impact of these wedges on the Jordan Lake WQT market is evaluated to illustrate the difficulty of overcoming multiple wedges in an actual setting.

2.2.1. THE IDEAL WATER QUALITY MARKET

2.2.1.1. INDIVIDUAL SUPPLY

To be qualified to sell the credits, nonpoint sources, such as farmers, must first accede to the baseline requirements (Ghosh et al. 2011). In order to meet the baseline and then sell the credits, farmers are required to install best management practices (BMPs). Installing BMPs generates costs for farmers including: 1) installation cost, 2) opportunity cost (lost yield), and 3) maintenance and monitoring cost. Therefore, a farmers' total cost function (TC_f) for participating in the WQT program is:

$$TC_f = TC(x) + TC_{fI}(Z) + TC_{fO}(Z) + TC_{fM}(Z) \qquad (1)$$

Where x and Z indicate ordinary inputs and inputs for installing BMPs (e.g., allocated land for BMP's installation), respectively. $TC_{fI}(Z)$, $TC_{fO}(Z)$ and $TC_{fM}(Z)$ indicate total cost of installing BMPs (e.g., labor cost, capital cost, etc.), total opportunity cost of installing BMPs, and the BMPs maintenance cost respectively. Wedges, such as transaction costs are zero in an ideal market.

Z is a function of required water pollution reduction, $Z = f(\bar{e} - e_0) = f(\Delta e)$. Where $\bar{e}$ and e_0 are the amount of pollution emission in baseline and the amount of current emitted pollution respectively. That is,

$$\begin{cases} \text{If } \bar{e} > e_0 \text{ farmers can sell credits} \\ \text{If } \bar{e} < e_0 \text{ farmers are not eligible to participate in WQT program} \end{cases}$$

Therefore, the marginal cost (MC_f) of installing the assigned BMP is then as follows:

$$MC_f = \frac{\partial TC_f}{\partial(\Delta e)} = \frac{\partial TC_{fI}}{\partial(f)} . \frac{\partial f}{\partial(\Delta e)} + \frac{\partial TC_{fO}}{\partial(f)} . \frac{\partial f}{\partial(\Delta e)} + \frac{\partial TC_{fM}}{\partial(f)} . \frac{\partial f}{\partial(\Delta e)} = Pr \qquad (2)$$

Where the Pr is the minimum price that a farmer would require to be willing to install a practice and offer a credit.

Increasingly, farmer's cooperation can be mandatory or voluntary, depending on local trading rules and their unique production situation. If farmers are not required to reduce non-point emissions, there would be no baseline and their participation would be voluntary. As shown in Figure 2.2, the voluntary supply curve is based on the MC of installing a BMP that occurs above average variable cost (AVC), or at a quantity equal to or greater than Δe1.

Introducing a baseline exposes the first wedge to consider. The benefit of developing a unified theory based on traditional market analysis (e.g., supply and demand) is immediately evident as the supply curve is bounded on the lower side by the baseline. If baseline is set above the quantity where MC is greater than or equal to AVC, then baseline sets the minimum supply. If, for example, the baseline is assigned at Δe2, supply begins at Δe2 instead of Δe1. In effect, farmers must supply Δe2 for free, which drives up the cost of credits. If the mandatory baseline is set at a level where MC is less than or equal to AVC, then the supply curve begins at Δe1.

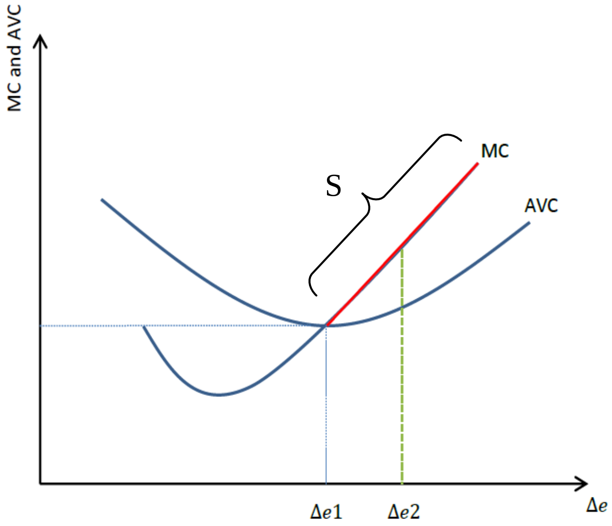

Figure 2.2. Individual credit supply curve

2.2.1.2. INDIVIDUAL DEMAND

As with supply, the ideal demand curve has no wedges. The trading ratio is given (1:1), there is no uncertainty, and transaction cost is zero. In the Jordan Lake watershed, the demand function represents the needs of urban developers, which are regulated non-point emitters. New urban developers have two options to reduce their nutrient emissions into water. They can either install waste water treatment technologies or participate in the WQT program to buy credits. If the marginal cost of participating in trading is less than the marginal cost of installing technology, developers can meet their pollution requirements at lower cost with the WQT program.

The total cost function of water pollution reduction for a new urban developer is as follows:

$$\begin{cases} TC_{uTech} = Tech\big(f(e_0 - \bar{e})\big) = Tech\big(f(\Delta e)\big) = P_{tech}.\Delta e_{tech} & \text{if technology cost per unit of reduction} < \mathrm{Pr}^* \quad (3) \\ TC_{uTrade} = Pr.t.(e_0 - \bar{e}) = Pr.t.\Delta e_{trade} & \text{if technology cost per unit of reduction} >= \mathrm{Pr}^* \quad (4) \end{cases}$$

Where, TC_{uTech} is total urban developer's waste water treatment technology cost, which is a function of the amount of emission reduction, TC_{uTrade} is the total cost of participating in the trading program for urban developers (Heberling et al. 2010), t is the trading ratio, Pr is trading price per unit of emission reduction, and $\bar{e}$ and e_0 have been defined previously. A linear relation between TC_{uTech} and Δe_{tech} is assumed for simplicity.

Therefore an urban developer can minimize his/her mitigation cost by either installing technology or participating in the WQT program, as follows:

Min $TC_u = P_{tech}.\Delta e_{tech} + Pr.t.\Delta e_{trade}$ (5)

st. $\Delta e_{tech} + \Delta e_{trade} \geq E^*$

Where E^* is the required urban developer's emission reduction. Based on this optimization, the trading demand function is:

$$\Delta e_{trade} = \frac{TC_u - P_{tech}E^*}{Pr.t - P_{tech}} \qquad (6)$$

Equation (6) shows that increasing the Pr will decrease the Δe_{trade}. Therefore, the trading demand has a downward slope. If there are one credit buyer and one credit seller participating in WQT, one equilibrium point will occur and the law of one price will apply. In the next section, I will explain that the law of one price would not apply when multiple traders participating in a WQT program.

2.2.2. A WQT MARKET WITH MULTIPLE TRADERS

Total required water pollution reduction (E^*) in a watershed plays a profound role for the water quality credit price discovery. If the E^* in the watershed is achieved with just one trade, a single price for the market will occur. However, if there are many sellers and buyers in the WQT market, there is no single price for the WQT market, which would exist in a traditional market. The amount of demanded credits and credit price are functions of marginal cost of each credit seller and E^*. For instance, in Figure 2.3, I assume two credit sellers and one credit buyer are participating in the WQT market and the required loads reduction is E^*.

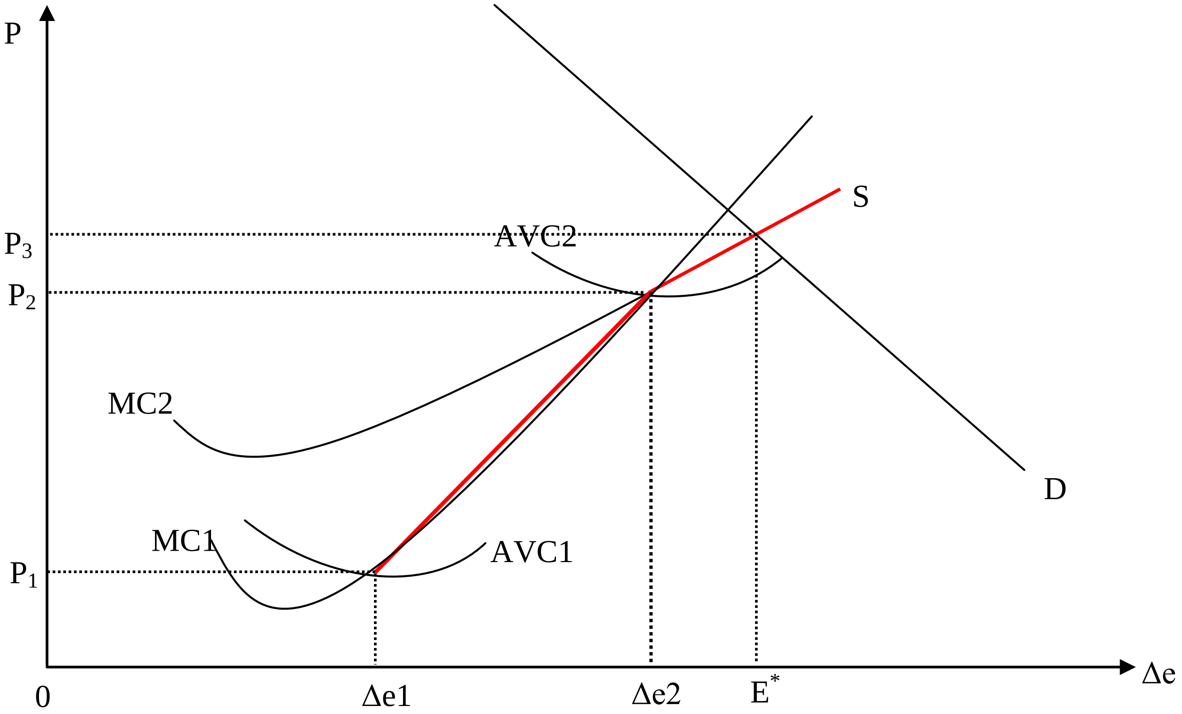

Figure 2.3. Multiple price situation

In Figure 2.3, MC1 and MC2 indicate the marginal cost for credit seller 1 and 2 respectively. Below Δe2, since the seller 1's credit is cheaper, a credit buyer would trade with him/her (MC2>MC1). While above Δe2, a credit buyer will alternate his/her trade purchases from credit seller 1 to credit seller 2 because MC2 is less than MC1. That is, the cumulative water quality credit supply or the market credit supply curve kinks at (Δe2, P_2) and depending on the amount of E^*, the WQT market would have either a single price or multiple prices for credits.

A single price for WQT market will happen when E^* occurs below Δe2. Therefore, the market price would be P_2. If E^* locates above Δe2, the urban developer will pay two different prices for the WQT credits. Below Δe2, the credit price would be P_2, and above the Δe2, for compensating E^*- Δe2, the credit buyer would pay P_3.

Figure 2.3 illustrates when two sellers and one buyer participate in a WQT program, the market supply curve kinks once. If there are more than two sellers in the market, more kinks will occur in the market supply curve. The number of kinks plus one indicates the circumstances where a demander will buy from multiple sources at multiple prices to achieve the required reduction. Likewise, this pattern might happen in the demand side of a WQT market. In the demand side of the WQT program, the market demand curve is kinked by each buyer. When there are many buyers and sellers in the WQT market, the process of price discovery would be difficult. Moreover, since each credit demander has to search for viable sellers at one time, illustrating the equilibrium graphically would be meaningless. The process of searching for one or more than one possible credit seller increases the transaction cost of the trading program. One solution to discover the credit price in a multiple trader situation is designing a suitable form of auction. An efficient auction would yield a total welfare equal to the consumer surplus (CS) and producer surplus (PS) in the total demand and supply curves, less trading costs, regardless of who trades with whom.

After defining the demand and supply curve, in the next section, wedges will be added to the model. The first assumption for adding any kind of wedge is that the individual credit supplier and demander decide to trade. Introduced wedges will be baseline, transaction cost, uncertainty trading ratio, and trading cost. A less than ideal market occurs when some wedges lead the ideal market to a marginal or non-existent one.

2.2.3. LESS THAN IDEAL MARKET (ADDING WEDGES TO THE IDEAL MARKET)

In this section the role of four important wedges, baseline, transaction cost, trading ratio, and trading cost on a WQT program is investigated.

2.2.3.1. BASELINE

Baseline conditions could have a profound influence on the feasibility of a WQT market (EPA, 2007; Ghosh et al. 2011). A baseline can affect demand, by requiring a minimum threshold of abatement before allowing credits to be purchased, or supply by applying a minimum to be achieved before credits can be sold. The baseline ($\bar{e}$) defines the amount of pollution reduction that must be achieved by farmers and urban developers before trading is allowed. Solving Equations 2 and 6 simultaneously yields the following marginal cost (MC) of trading:

$$MC_{trade} < \frac{\partial TC_{uTech}}{\partial f} . \frac{\partial f}{\partial(\Delta e)} \qquad (7)$$

Equation 7 shows that a trade will happen if the marginal cost of producing WQT credits is lower than the marginal cost of installing on site remedies, such as waste water treatment technology for urban developer. As previously shown in Figure 2.2, the baseline condition has the effect of truncating the lower end of the supply function, and effectively requiring a farmer to supply up to the baseline at their own expense. Likewise, the baseline requirement truncates the upper portion the demand function, requiring the first units of abatement to be supplied at the expense of urban developer.

2.2.3.2. TRANSACTION COST

No transaction costs were included in an ideal WQT market. But we know transaction costs exist. The transaction costs associated with a given environmental policy can be divided into two types: policy transaction costs (PT) and market transaction costs (MT). Herath and Weersink (1999) defined PT costs as a function of three arguments: monitoring cost (M), desk work and filling forms (D) and liability cost (L). Market transaction (MT) cost is a function of four arguments: information cost for the firm (I), search cost for the firm to find a trade partner (S), negotiation costs between two firms (in trading programs) or negotiation costs between firm and regulator (N), enforcing the negotiated terms (E) and other transaction costs which are not observable (O). The most discussed transactions costs in the literature are those related to market structure. For example, four commonly mentioned markets include an exchange market, bilateral negotiations, clearinghouses and sole-source offsets (Woodward and Kaiser, 2002). There is significant variability in the transaction costs associated with these different market structures (Woodward and Kaiser, 2002). Obviously, policy makers can have an impact on the success of programs by changing baseline. From a technical perspective, reducing baseline encourages trades. However, from a social perspective, reducing baseline can misalign those responsible for pollution and those who clean it up.

2.2.3.2.1. TRANSACTION COST FOR URBAN DEVELOPERS

Based on the transaction costs discussed in the literature, D, L, I, S, N, E, and O, the cost function for urban area's developer is:

$$TC_{u2} = Pr.t.(\, e_0 - \bar{e}) + A' = Pr.t.\Delta e + A' \qquad (8)$$

$$A' = \alpha'(D_u + L_u) + \beta'(I_u + S_u + N_u + E_u + O_u) \qquad (9)$$

From Equation 8, it is obvious that if urban developers are willing to cooperate with a trading program, A' (urban developer's transaction cost for participating in WQT program) will reduce demand. In this example, transaction costs are assumed to be additive, which means demand would be shifted in, but it could easily be changed to a multiplicative cost adjustment, which would rotate demand inward. α' and β' are coefficients between 0 and 1 to show the proportion of transaction costs paid by the developer. Policy makers can have an impact by working to reduce transaction costs, or to reduce α' and β'.

Although most of the work to date on transaction costs has been qualitative in nature, a few studies have attempted to directly estimate transaction costs of environmental markets or conservation programs, and can be of benefit here to make estimates. The transaction costs estimates from these few studies range between 10% and 50% of the other costs of generating credits Chesapeake Bay Commission (2012). For example Fang et al. (2005) estimated a 35% transaction cost factor for a nutrient program in the Minnesota River Basin. Moreover Chesapeake Bay Commission (2012) adopted 38% adjustment factor for calculating transaction cost. In this study, a 35% adjustment factor was assumed in the demand side of the WQT in Jordan Lake, NC.

2.2.3.3. TRADING COST FOR FARMERS

Trading cost encompasses two influential components of a WQT program including transaction costs and innovation premium (IP). I inserted these two wedges to the supply side of the WQT program as follows:

2.2.3.3.1. TRANSACTION COST FARMERS

Similar to urban developers' transaction costs, there are two types of general transaction costs for farmers, policy transaction cost and market transaction costs. These costs are the same types that the urban developer faces, but in different amounts. Therefore, the farmers' transaction cost (TrC) is:

$$TC_f = TC(x) + TC_{fI}(Z) + TC_{fO}(Z) + TC_{fM}(Z) + TrC \qquad (10)$$

$$TrC = M_f + \alpha''\left(D_f + L_f\right) + \beta''(I_f + S_f + N_f + E_f + O_f) \qquad (11)$$

Where Trc is transaction cost. $Z, TC_{fI}\,(Z), TC_{fO}\,(Z)$, and $TC_{fM}\,(Z)$ have the previous definitions. Also $Z = f(\bar{e} - e_0) = f(\Delta e)$.

Similar to α' and β' for urban areas, $\alpha''$and β'' are two important elements that policy makers can affect the success of a market.

In order to determine how supply curve changes, I will connect Trc to the amount of reduction. I define Trc as a function of reduction as shown below:

$$Trc = \eta\,.(\bar{e} - e_0) \qquad (12)$$

η is the coefficient that determines the amount of transaction cost (policy and market) per unit of reduction. Based on this definition:

$$MC_{f1} = \frac{\partial TC_f}{\partial(\Delta e)} = \frac{\partial TC_{fI}}{\partial(f)} . \frac{\partial f}{\partial(\Delta e)} + \frac{\partial TC_{fO}}{\partial(f)} . \frac{\partial f}{\partial(\Delta e)} + \frac{\partial TC_{fM}}{\partial(f)} . \frac{\partial f}{\partial(\Delta e)} + \eta = MC_f + \eta \qquad (13)$$

2.2.3.3.2. INNOVATION PREMIUM

The concept of IP is distinguished separately from transaction costs for the first time here and is meant to account for an aggregate of intangible factors (Peterson et al. 2007) that can shift water quality supply or demand to the left. Lack of social trust between the involved parties in a WQT program and unfamiliarity of the participants with program details are intangible wedges that can reduce adoption of conservation practices below the expected rates (Breetz et al. 2005; Mariola, 2011). Moreover sometimes a WQT program is too new to permit trades and the new trading rules and regulations yield uncertainties for the WQT participants (Shortle, 2013; Morgan and Woverton, 2005). Farmers' socio–cultural concerns (Breetz et al. 2005) are other types of intangible factors which yield the fact that the economic bottom line may not be enough to encourage farmer to participate in a trading program (Breetz et al. 2005).

These mentioned intangible aspects, which in this study are called IP, will lead farmers to ask for more money to participate in WQT programs to compensate for the uncertainties. These premiums lead policy makers to underestimate the cost for motivating farmers to adopt conservation practices for a WQT program.

In this study the role of IP was investigated in the supply side of the Jordan Lake WQT program. We measured the magnitude of the IP by calculating the difference between farmers' willingness to accept (WTA) for participating in WQT program and BMP's installation cost and transaction cost of cooperating with this program. In order to calculate the WTA, a survey was done in person with 90 farmers whose farms are located in the Jordan Lake watershed (see Chapter three).

$$IP = \vartheta * TC_{fI}(Z) = \vartheta * TC_{fI}(f(\Delta e)) \qquad (14)$$

ϑ is the coefficient which determines the amount of premium per unit of total cost of installing BMPs ($TC_{fI}(f(\Delta e))$).

Since the survey couldn't separate the amount of IP from the total transaction cost (TrC) of participating in this program, the magnitude of the IP and TrC were summed and called trading cost. Trading cost added to the model as follows:

$$TC_f = TC(x) + TC_{fI}(Z) + TC_{fO}(Z) + TC_{fM}(Z) + TrC + IP = TC(x) + TC_{fI}(Z) + TC_{fO}(Z) + TC_{fM}(Z) + Trading\ Cost \qquad (15)$$

2.2.3.4. UNCERTANITY AND TRADING RATIO

Trading ratios are a combination of delivery or location ratios, equivalency ratios to adjust for trading different forms of the same pollutant, and uncertainty ratios to adjust for uncertainties associated with nonpoint sources trades (US EPA, 2007). In this model, I account for the uncertainty of achieving at least α% of the pollution abatement goal based on trading ratio (Ghosh and Shortle, 2009). The trading ratio is equal to the marginal rate of substitution of emissions between two sources and ensures no net change in ambient pollution (Horan and Shortle, 2011). The stochastic nature of non-point source emission makes the success of implementing an abetment trading uncertain when nonpoint sources are involved.

Uncertainty changes the WQT model from a deterministic to a stochastic one. Chance constrained programming (CCP) (Charnes and Cooper, 1965) deals with uncertainty by specifying a confidence level (α) for uncertain constraints. CCP will be used in this paper to address the uncertainty of achieving water quality goals. The CCP method was used by Zhang and Wang (2002) to calculate the trading ratio of WQT program in Taihu Lake in China. The general view of the model shows as below:

Min Cost of Trade

s.t.

$$P\{[e_f + e_u] \leq E^*\} \geq \alpha \qquad (16)$$

P is the probability of achieving at least α% of a pollution abetment goal. e_f and e_u are farmers and urban areas' water pollution emission after participating in WQT program, respectively. $E^*$is the targeted emission. A deterministic equivalent of Equation (16) is shown in Equation (17):

$$Y = E(e_f) + z_{\propto}\left[var\left(e_f\right)\right]^{\frac{1}{2}} + E(e_u) + z_{\propto}[var(e_u)]^{\frac{1}{2}}) \qquad (17)$$

Where $z_{\propto}$ is the standard normal variable and is the one tail normal variable for α, which can be obtained from the tables in statistic texts. Y is total pollutant abatement in a specific watershed. In Equation (16), $E(e_f)$ and $E(e_u)$ represent the expected emissions from farmers and urban area respectively, and they are considered to be deterministic. The $var\left(e_f\right)$ and $var(e_u)$ are variance of farm and urban area emissions, and $z_{\propto}$is the weight attached to the variance to capture the probability of reaching to the α% of the abatement goal (Zhang and Wang, 2002). Any change in $z_{\propto}$ will change the trading ratio (t) and the slope of water quality credit demand. In my model, I assumed urban developer emission is deterministic, therefore the trading ratio based on CCP approach will be as follows;

$$t = \frac{\frac{\partial Y}{\partial e_f}}{\frac{\partial Y}{\partial e_u}} = \frac{E'(e_f)+0.5dz_{\propto}[var(e_f)]^{\frac{-1}{2}} * (var(e_f))'}{E'(e_u)} \tag{18}$$

Increasing the certainty of achieving the water quality goal increases the $z_{\propto}$ and t. Showing in Equation (18), increasing the trading ratio will tilt the credit demand curve to the left which drives up the price of credits and reduces the urban developers' willingness to participate in WQT program. In regard with the EPA (2007)'s definition of trading ratio, the SPARROW[2] coefficient was used to include the delivery or location ratios in the model (see Appendix II).

2.2.4. THE MARGINALIZED MARKET

The ideal market without wedges changes significantly when wedges are added. I have looked at only four types here, but, as shown in Figure 2.4 below, these wedges add up. Each wedge pushes supply and/or demand inward, marginalizing the market. More wedges equal more shifts and an increasingly marginalized market. For example, the ideal market is represented in Figure 2.4 by S_1 and D_1 where the wedges have not been included in the market. Beginning with the first wedge examined here, the regulator would assign a baseline for the urban developers and farmers would trade at Δe0. For simplicity, the same baseline was assigned for both farmers and developers, while in a real situation the baseline for these two groups can be different. Baseline truncates both demand and supply curves at Δe0. Basically, baseline changes the starting point of the trade from the origin to Δe0 and decreases the amount of tradable credits.

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[2] (SPAtially Referenced Regressions On Watershed attributes; Smith, et al., 1997)

The second wedge is the transaction costs. Transaction costs increase the cost of participating in WQT program for both urban developers and farmers. Thus, this wedge shifts both ideal demand and supply curves to S_2 and $D_{2,}$ respectively. Another wedge which is added to the supply side of the WQT market is IP. IP contains farmers' intangible costs for participating in a WQT program. The magnitude of this wedge shows how much the uncertainty of participating in WQT raises the credit price. Figure 2.4 depicts that the IP tilts the supply curve to the left and decreases the amount of the available credits.

The last added wedge to the model is the trading ratio. Based on Equation 18, increasing the trading ratio reduces the credit demand because urban developers require buying more than one-unit of reduction to offset one-unit of increasing in his/her emission (Horan and Shortle, 2011). The trading ratio tilts the WQT demand to the left and decreases the urban developers' willingness to participate in this program.

Figure 2.4 illustrates the role of all wedges on a WQT market simultaneously. Adding all of these wedges to the ideal market marginalizes the market and changes the conceptual equilibrium point from E1 to E2. If the magnitude of the wedges increases, the demand and supply curve might not cross each other and the market will be nonexistent.

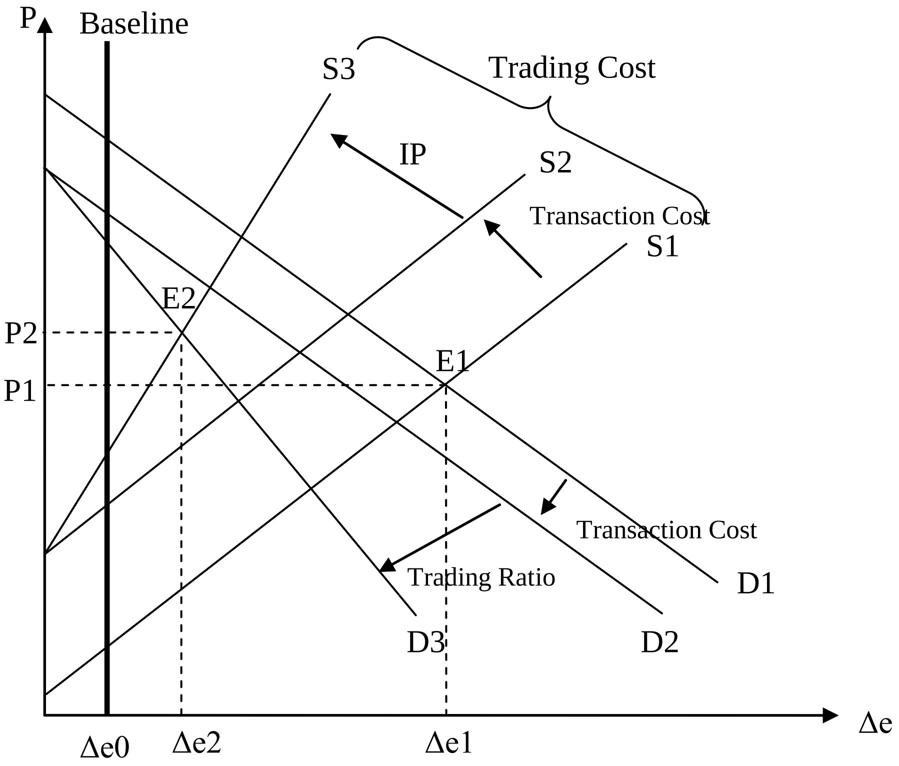

Figure 2.4. Effect of wedges on WQT market equilibrium

2.2.5. CASE STUDY: JORDAN LAKE WATERSHED PROGRAM, NORTH CAROLINA STUDY AREA

The Jordan Lake Watershed is located in the Piedmont region of North Carolina. The 4367 km^2 watershed is comprised of three subwatersheds: Haw, Upper New Hope and Lower New Hope covering 80%, 13% and 7% of the total watershed area respectively (Figure 2.5). The Jordan Lake Watershed has a land use composition of 46% forest, 21% urban/suburban and 22% agriculture, of which a large portion is pasture. Upper New Hope subwatershed is heavily urbanized and Lower New Hope subwatershed is being rapidly developed. The majority of the agricultural activities, which is dominated by pasture operations in Haw subwatershed although several urban areas also exist.

Jordan Lake located at the outlet of Jordan Lake watershed was created to provide flood control, water supply, protection of water quality downstream, fish and wildlife conservation, and recreation. The lake has been declared as hyper-eutrophic since its impoundment when it was classified as Nutrient Sensitive by the Environmental Management Commission. Limits were put on wastewater discharges soon after the reservoir was constructed but there was no water quality improvement. In 2002, North Carolina Division of Water Quality (DWQ) placed the Upper New Hope arm of Jordan Lake on the 303(d) list and identified it as a segment requiring a Total Maximum Daily Load (TMDL) to meet criterion for Chlorophyll a. In its 2005 draft Cape Fear Basinwide Plan, DWQ identified the entire lake as nutrient-impaired based on chlorophyll a data, and the entire lake is currently on the 303(d) list.

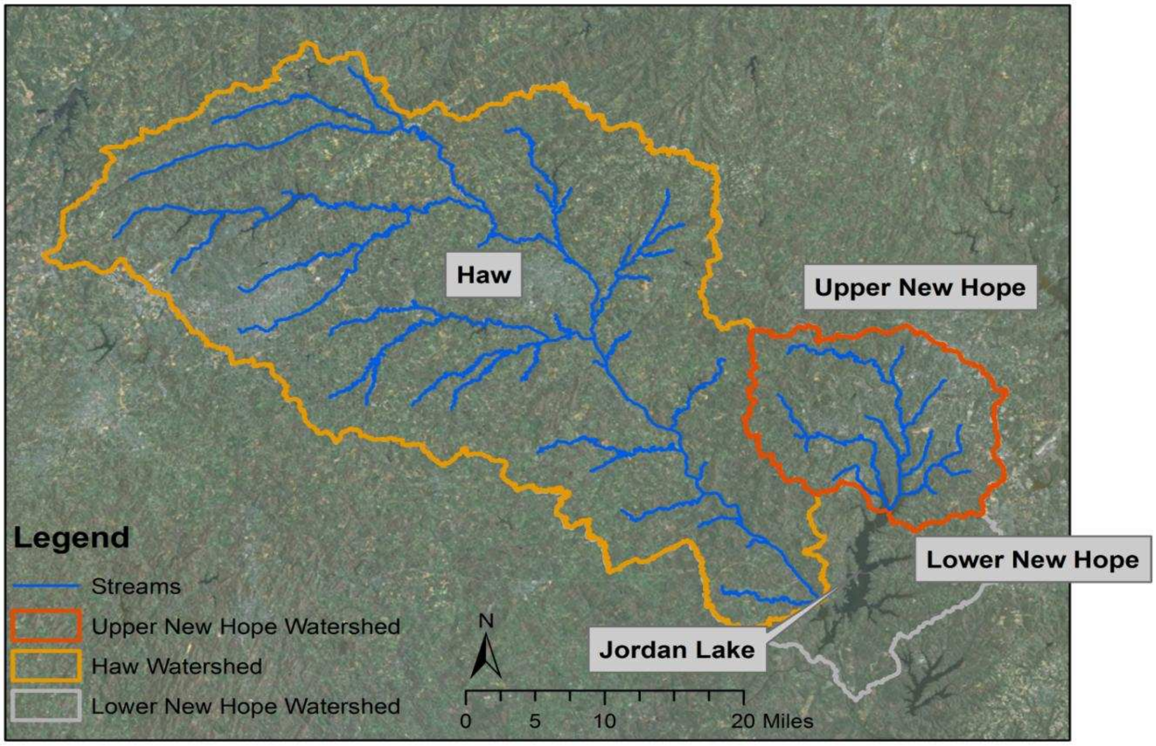

Figure 2.5. Jordan Lake Watershed

In this study, the WQT program was designed for the Haw subwatershed in Jordan Lake, NC.

2.2.5.1. AGRICULTURE IN THE HAW

Riparian buffers are land areas to preserve in permanent vegetation to reduce nutrient and sediment losses from agricultural fields, improve water quality, and provide wildlife habitat. The NC WQT program encourages farmers to adopt and maintain riparian buffers on their farms close to the streams. Several cost-related assumptions are included in the Jordan Lake's WQT model. First, based on the program's rules, the riparian buffers should be installed on the edge of fields, adjacent to a stream. 50 ft (15.24 m) is the required width. It was assumed the opportunity cost for crop and livestock farmers is equal to the amount of crop and hay that cannot be yielded due to installing the riparian buffer. To calculate the opportunity cost, 4.6% was assigned as the discount rate (NRCS, 2009). Second, it was assumed that baseline and current BMPs have been implemented on the whole field. To calculate the baseline, current BMP and riparian buffer installation cost, 2014 Environmental Quality Incentives Program (EQIP) payment rates were used (NRCS, 2014). SPARROW coefficients were used to calculate the delivery of the pollutants from edge of the fields to the lake.

The Soil and Water Assessment Tool (SWAT 2012) model is applied to the Jordan Lake watershed to predict the amount of total nitrogen (TN) and total phosphorus (TP) loads in four scenarios, including no BMPs, baseline (1997-2001), current BMP practices (2012), and TN and TP loads after installing buffer zones on the top of current BMPs.

Out of 10,835 fields located in the Haw watershed, the model was applied to the 593 fields. These 593 fields were selected based on the planning land unit (PLU) numbers and full information about their land-use, land size, and BMP type, etc. Considering the Jordan Lake rules, three interpretations of baseline could be considered. First, farmers can trade without considering the required community reduction. The rules are written in such a way as to allow this in many circumstances. Second, that the community reduction does apply, but is already met (which is the current case), and third that farmers must install riparian buffers to reduce their TN and TP below 92% and 95% of the baseline, respectively, on their own field. The amount of farmers' credit will be defined as the difference between TN (TP) load after installing a riparian border and the baseline (92% (95%) of the TN (TP)) load. According to the Jordan Lake rules, baseline is the average amount of TN (TP) between 1997 and 2001. Table 2.1 shows loadings at the edge of the 593 fields after applying different scenarios.

Table 2.1. TN and TP loads (lbs) in different scenarios for the case-study Planning Land Unit (PLU) in the Jordan Lake Watershed (edge of the fields)

	No BMP	**Baseline (1997-2001)**	**Current BMPs**	**RS and Current BMPs**	**92% baseline**	**95% baseline**
Total TN Load (lbs)	19,182	10,281	15,267	10,214	9,459	----
Total TP load (lbs)	17,100	11,552	14,642	8,524	----	10,975
Average TN (lbs/ac)	3.67	1.97	2.92	1.96	1.81	-----
Average TP (lbs/ac)	3.28	2.21	2.8	1.63	-----	2.10

2.2.5.2. NEW URBAN DEVELOPER

According to the Jordan Lake's WQT rule, new urban developers are responsible to install one of the BMPs, including bio-retention, sand filters, ponds, or wetlands, to reduce the amount of TN and TP loads to achieve the storm water management requirement. If the urban developers' load reduction is less than the total required reduction, the developer has two options. Urban developer either can oversize the BMP, which is the same as installing their own technology, or can trade with farmers for further needed reductions.

The cost of installing these BMPs including construction cost, 20 year maintenance cost, and the opportunity cost of lost production were extracted from the economics of structural stormwater BMPs report 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 cost of BMPs for the 2014. My model will utilize the TN and TP loads before and after installing BMPs for a new urban development based on the Jordan Lake Nutrient Loading Accounting Tool (NCDENR, 2007). The total storm water management requirement's threshold for urban developments in the Haw watershed for TN and TP is 3.8 and 1.43 (lbs/ac/yr), respectively. Loading from developments will vary highly across the region. Therefore, I used the results from a 43.3 acre residential and commercial development located in the city of Durham as a proxy for the region. The new urban developer's BMP installation cost is reported in Table 2.2. According to this table, a 0.7acre commercial new urban developer is required to reduce its pollution by 6.8 (lbs/ac/yr). Currently, this developer has reduced its reduction by 4.4 (lbs/ac/yr) by installing a bio-retention pond. Therefore, the developer needs to reduce its load by 2.35 additional lbs/ac/yr, either by expanding the current BMP or by trading with farmers. If he/she chooses the first option, he/she requires 1.65 lbs offset per year. The marginal cost of expanding the current BMP to reach the required reduction is 4,139 ($/lbs). Likewise, a 4acre, a 6.4acre, and a 32.2acre urban developer will spend $18,083, $163,126, and $618,238 per lbs of load reduction if they expand their current BMPs to reach the required TN reduction.

Table 2.2. New urban developers' BMP size and BMP cost based on case study in Durham County, North Carolina

Development	**Type**	**Size (ac)**	**Location**	**BMP**	**Current reduction (lbs/ac/yr)**	**Required reduction (lbs/ac/yr)**	**Total individual offset (lbs/yr)**	**TC (NPV) for current reduction ($)**	**TC (NPV) for required reduction ($)**	**MC ($/lbs)**
The Villas at Hope Valley	Residential	4.00	Durham	BRC w/IWS[3]	2.1	2.4	1.36	123,051	129,199	18,083
City Center	Commercial Building	0.70	Durham	BRC w/IWS	4.4	6.8	1.65	35,612	45,338	4,139
Hendrick South Point	Commercial Auto Mall	32.20	Durham	2 Ponds and Sand Filter	2.3	3.8	48.30	3,840,143	4,767,501	618,238
BCBS of NC	Commercial	6.40	Durham	Wetland and Sand Filter	2.2	4.9	17.28	921,651	1,362,092	163,126

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[3] Bio-retention cell with or without internal water storage

2.3. RESULTS AND DISCUSSION

2.3.1. SUPPLY SIDE OF JORDAN LAKE WQT PROGRAM

Out of 593 fields, 315 are not eligible for trades. Non eligible fields include forest lands and fields where installing riparian buffers is not possible. Two scenarios were designed and compared to investigate how efficient the Jordan Lake's baseline has been assigned. These two scenarios are 1) estimating the difference between TN's load reduction after installing riparian buffers on top of current BMPs in 2012 (R) and the baseline (B), or B→R, and 2) estimating the difference between TN's load reduction after installing riparian buffers on top of the current system and the 92%of the baseline (92%B→R). Furthermore, these scenarios can be evaluated based on the amount of TN load in either edge of field or delivery to the lake. In this study, the TN load delivery to the lake will be reported. Table 2.3 displays the designed scenarios for the baseline in this paper.

Table 2.3. Baseline scenarios (B) and riparian buffer scenarios (R) for the Jordan Lake WQT

	Edge of fields	**Delivery to lake**
Reduced over the baseline	B→R	B→R
Reduced over the 92%-baseline	92%B→R	92%B→R

The analysis of the TN load delivery to the lake after installing riparian buffers (lbs/ac), MC of TN load reduction ($/lb), average field's area (ac), and credit supply (lbs), are reported in Table 2.4. The average credit supply is 589 (lbs) and 800 (lbs) for the 92%B→R and B→R scenarios, respectively. Moreover the MC of the first pound of reduction without and with adding the trading cost in the B→R scenario is $625 and $851, while these costs rise to several million dollars for the last pound. Showing in Table 2.5, the MC of a 1 lb reduction before adding the trading cost is $756 and $625 for the 92%B→R and B→R scenarios, respectively.

Buying a 1 lb credit under the 92%B→R scenario will cost urban developers $131 more than buying the same amount of credit under B→R scenario. Regarding to Table 2.5, besides the higher MC under 92%B→R scenario, the number of participants and total credit supply in the 92%B→R scenario will be fewer. These results confirm that a baseline requirement raises the cost of credits.

On the supply side of the program, a trading cost including transaction cost and IP was added to the model. In order to calculate the trading cost, a survey was done in person with 90 farmers whose farms are located in the Jordan Lake watershed (see Chapter three). The willingness to accept (WTA) of participating in this program for livestock farmers was 3.68 times actual costs of BMP installation and 4.56 times higher for crop farmers. Trading cost was calculated based on the WTA and added to the model. After adding the trading cost to the supply side of the model in two mentioned baseline scenarios, results were determined as below (Table 2.4). The average MC after adding the trading cost for B→R and 92% B→R will increase from 145,568 ($/lb) to 191,876 ($/lb) and 156,378 ($/lb) to 204,085 ($/lb) respectively. Table 2.4 shows how wedges individually and jointly affect a WQT program. For example, adding the rigid baseline condition and trading cost at the same time to the minimum MC of the ideal WQT model will increase the price of each credit by $405 (e.g., the difference between $1,030 and $625), while adding only trading cost to the ideal scenario will raise the minimum price of each credit by $226 (e.g., the difference between $851 and $625). That is, implementing a rigid baseline or adding trading cost individually will raise the minimum credit's price by 1.2 and 1.3 times more than the ideal situation respectively. Adding these two wedges to the model simultaneously will raise the minimum price of each credit by 1.65 times.

Table 2.4. TN load reduction, MC, area and credit supply in different baseline scenarios

	Scenario	**Reduction (lb/ac)**	**MC ($/lb) before adding trading cost**	**MC ($/lb) after adding trading cost**	**Area (ac)**	**Supply (lb)**
Min	B→R	0.001	625	851	0.19	1.22
	92%B→R	0.001	756	1,030	0.19	1.01
Max	B→R	4.012	5,948,790	7,363,828	50.44	975
	92%B→R	3.74	13,864,841	17,162,869	50.44	722
Average	B→R	0.48	145,568	191,876	7.32	800
	92%B→R	0.42	156,378	204,085	7.2	589

Table 2.5. Number of fields and credits' MC in different baseline scenarios

Supply (lbs)	**Number of Fields**		**MC before adding trading cost ($/lb)**		**MC after adding trading cost ($/lb)**	
	B→R	92%B→R	B→R	92%B→R	B→R	92%B→R
1	1	1	625	756	851	1,030
10	----	----	----	----	----	----
100	6	7	1,273	1,760	1,735	2,399
722	----	238	----	13,864,841	----	17,162,869
975	278	----	5,948,790	----	7,363,827	----

Next, a trading ratio is added. Trading ratios are a combination of delivery or location ratios, equivalency ratios to adjust for trading different forms of the same pollutant, and uncertainty ratios to adjust for uncertainties associated with nonpoint sources trades (US EPA, 2007). In this study, delivery ratio and uncertainty ratio were calculated based on the SPARROW coefficient and CCP programming respectively. The uncertainty ratio was calculated based on the CCP method for TN loads of the most cost effective field, which I called Field-1.

Table 2.6 illustrates the trading ratio in different α sets for the Field-1. Evidently, when the trading ratio is bigger than one, the urban developer would pay more for one water quality credit compared to when trading ratio is not included in the model. Furthermore, in order to increase the certainty of achieving the TN emission reduction from 95% to 99% the trading ratio rises from 2.55 to 2.73. In addition, along with increasing the trading ratio, the MC of each scenario rises.

Showing in Table 2.6, in B→R scenario, the minimum MC of credits is $1,593 and 2,171 without and with trading costs at t=2.55. Setting t=2.55, changing the baseline scenario will increase the minimum MC of each credits to $1,927 and $2,626 without and with trading costs. The last column of Table 2.6 indicates the minimum TN credit supply in different scenarios. Considering Table 2.4 and 2.6, $625 and $1,593 are the minimum amount that urban developer is willing to pay before and after adding the trading ratio. That is, Field-1 will be received $968 more for each credit than he/she would gain in the ideal market.

Table 2.6. Minimum MC of credits in different trading ratio, baseline and trading cost scenarios

Probability to achieve the reduction goal	**α(95%)**	**α(97%)**	**α(99%)**	**TN Supply (lbs/ac)**
Trading ratio (t)	2.55	2.63	2.73	----
MC ($) in B→R scenario without trading cost	1,593	1,643	1,705	1.22
MC ($) in 92%B→R scenario without trading cost	1,927	1,987	2,063	1.01
MC ($) in B→R scenario with trading cost	2,171	2,239	2,324	1.22
MC ($) in 92%B→R scenario with trading cost	2,626	2,709	2,812	1.01

Table 2.6 shows how multiple wedges affect the marginal cost simultaneously. Considering Table 2.4 and 2.6, adding a rigid baseline, trading ratio (t=2.55) and the trading cost simultaneously to the ideal model will increase the minimum price of each credit from $625 to $2,626, or by more than four folds.

2.3.2. DEMAND SIDE OF JORDAN LAKE WQT PROGRAM

In this section, urban developer's credit demand will be calculated based on Table 2.2. The case study I used was divided into four sub-areas, ranging in size from 0.7 acres to 32.2 acres. The marginal cost of technology for these four sites in an ideal situation is illustrated in

Figure 2.6 and reported in Table 2.7. The table shows the total required TN reduction for the entire 43.3 acre commercial and residential area is 68.6 lbs. Moreover, by increasing the total demand for TN loads reduction, the marginal cost of expanding the BMPs increases as well. Marginal cost for the first 1.6 lbs TN reduction is $4,139 and gradually it goes up and reaches to $618,238.

Table 2.7. New urban developers' individual and total demand

Individual offset (lbs)	Total demand (lbs)	MC ($)
1.65	1.65	4,139
1.36	3.0	18,083
17.3	20.3	163,126
48.3	68.6	618,238

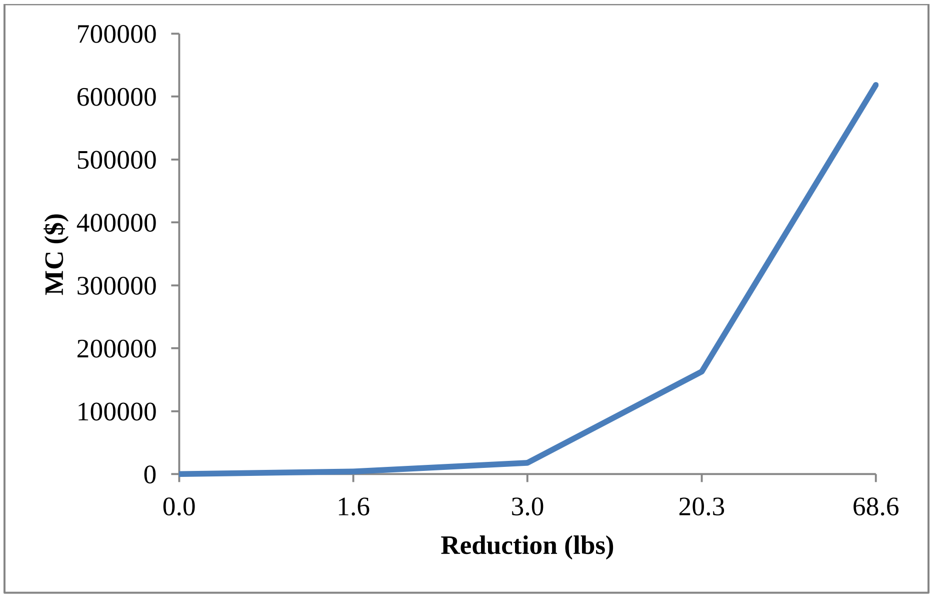

Figure 2.6. Technology cost for the new urban developers

According to the Jordan watershed model report (2014), the imperviousness (representing urban growth here) between 1999 and 2010 increased by 33,211 acre in the Haw River watershed, or by 3,019 acre per year. I assume for simplicity and lack of data that the imperviousness growth indicates the urban development growth. Therefore, the urban development in the watershed will continue to grow at 3,019 acres per year, and that all growth will have the same impact as my case study, I can assume that there would be the equivalent of 70 new developers in 2014.

Next, the transaction costs are added to the demand side of the model. Although most of the work to date on transaction costs has been qualitative in nature, a few studies have attempted to directly estimate transaction costs of environmental markets or conservation programs, and can be of benefit here to make estimates. The transaction costs estimates from these few studies range between 10% and 50% of the other costs of generating credits Chesapeake Bay Commission (2012). For example Fang et al. (2005) estimated a 35% transaction cost factor for a nutrient program in the Minnesota River Basin. Moreover Chesapeake Bay Commission (2012) adopted 38% adjustment factor for calculating transaction cost. In this study, a 35% adjustment factor was assumed in the demand side of the WQT in Jordan Lake, NC.

Figure 2.7 illustrates the water quality credit demand curve for a 0.7 acre commercial area within the 43.3 acre site. Here, I will explain the individual trade between one credit seller and one credit buyer to show the law of single price may not work in WQT program. Assume the 0.7 acre urban developer decides to trade with Field-1. At first, this urban developer needs to reach the required storm water management reduction and then reduces his/her TN load by 1.65 lbs. Under the B→R and 92%B→R scenarios, Field-1 can supply 1.22 lbs and 1.01 lbs respectively. Under both of these two scenarios the amount of supplied credit by Field-1 is not equal to the amount required for the new urban developer. Therefore, this new urban developer will investigate ways to find a farmer to compensate either 0.43 lbs or 0.64 lbs of the required TN load reduction. This process of trade indicates that there is not a single price for the WQT market. For instance, in this case the 0.7acre development area, a new urban developer would have to negotiate with two farmers with two different MC to reduce the amount of his/her required load reduction. In Figure 2.7, bargain margin defines the difference between the MC of providing 1.01 or 1.22 lbs TN load reduction from Field-1 and the marginal waste water technology cost of achieving this amount of reduction for an urban developer. The bargain margin is negotiable between credit seller and buyer and it changes in different WQT market structure. Demand curve is drawn hypothetically in Figure 2.7.

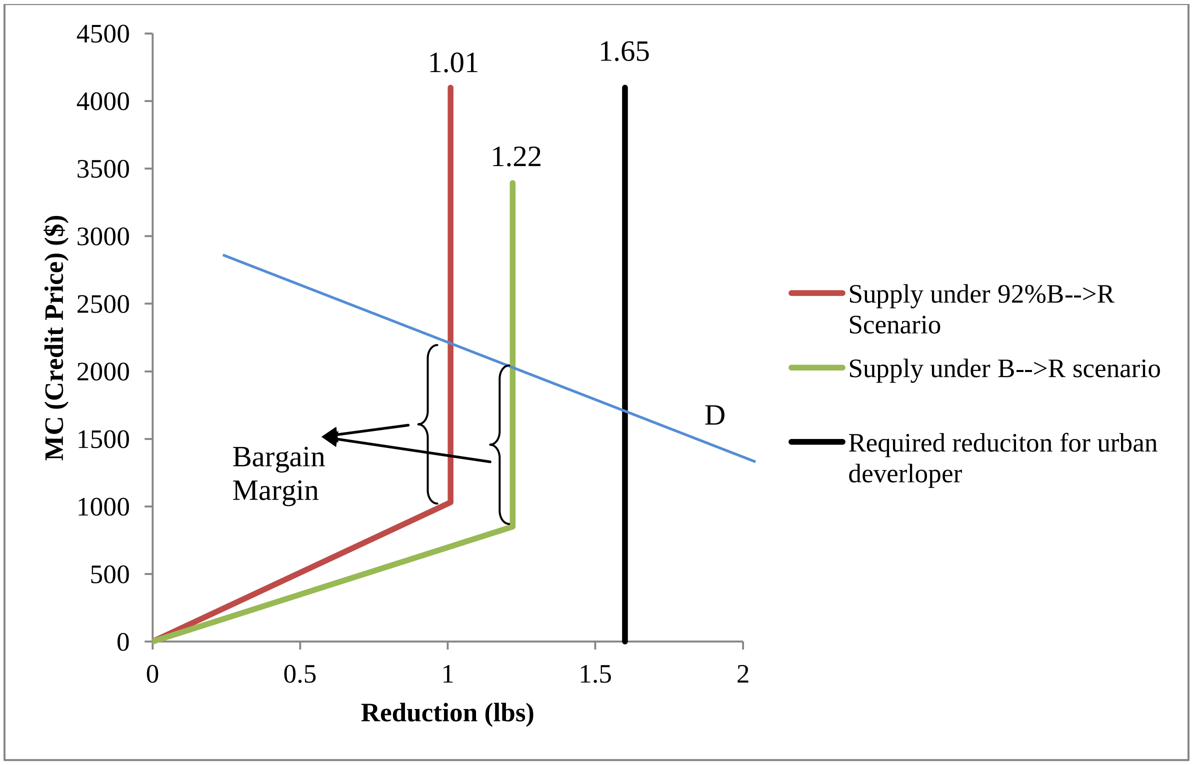

Figure 2.7. Water quality credit supply and urban developer’s TN load reduction requirement

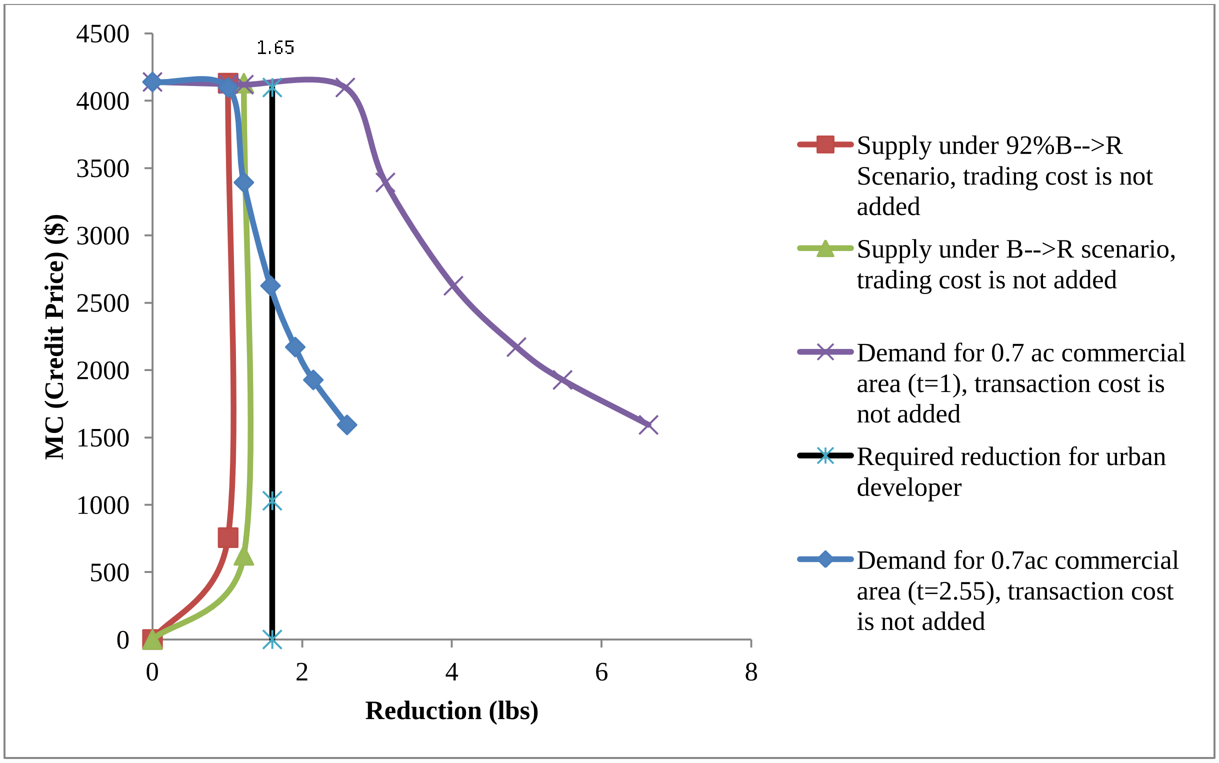

Figure 2.8. Water quality credit demand and supply in ideal market and with t=2.55

Figure 2.8 illustrates adding trading ratio to the ideal market which tilts WQT demand to the left. Showing in this graph, for instance when t=2.55, the urban developer buys 1.01 lbs of credits at $4,098, while in an ideal market paying this amount of money would have provided him/her 2.6 lbs credits at that price.

The main goal of this study is investigating the role of different wedges individually and simultaneously on a WQT program. Figures 2.9, 2.10 and 2.11 illustrate how transaction cost and trading costs can influence on the WQT program. Comparing Figure 2.8 and 2.9 indicates that adding trading cost will tilt the supply curve to the left and increase the price of each credit. In addition, Figure 2.10 illustrates when the transaction cost adds to the demand side of the model; the credit demand curve shifts down and reduces the developer's willingness to pay for WQT credits.

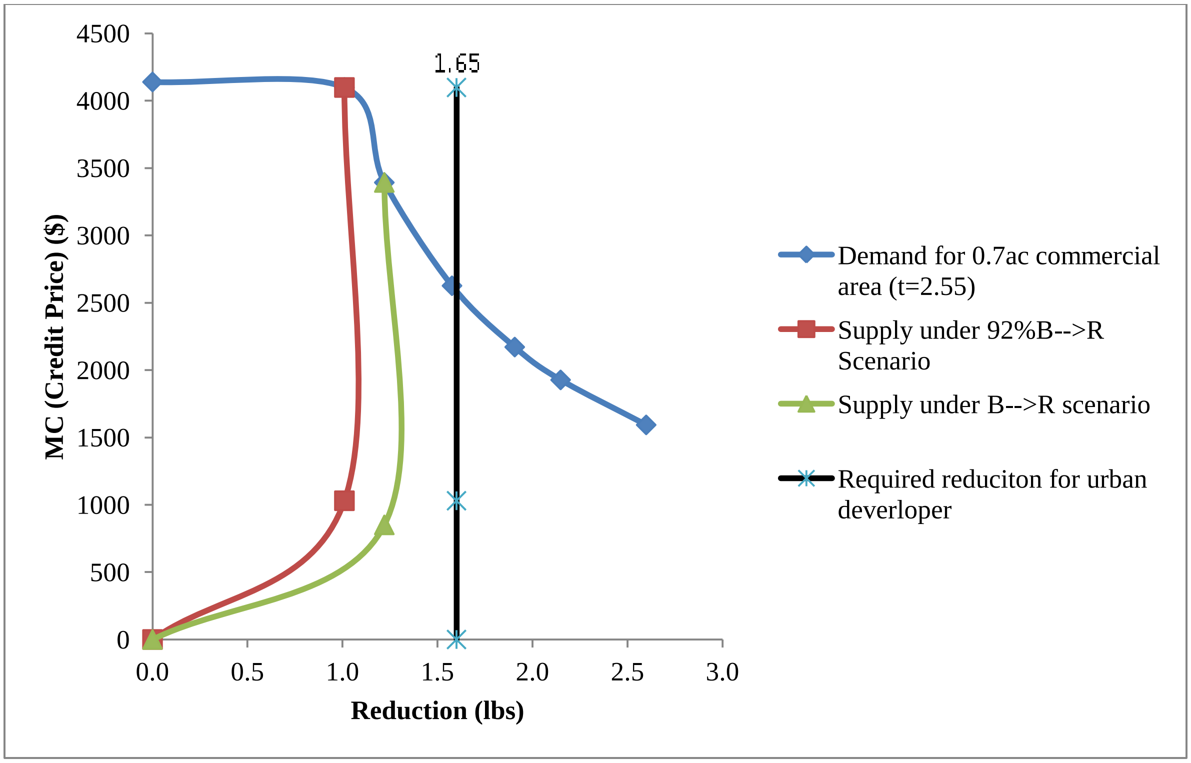

Figure 2.9. Role of baseline and trading cost on water quality trading program (t=2.55)

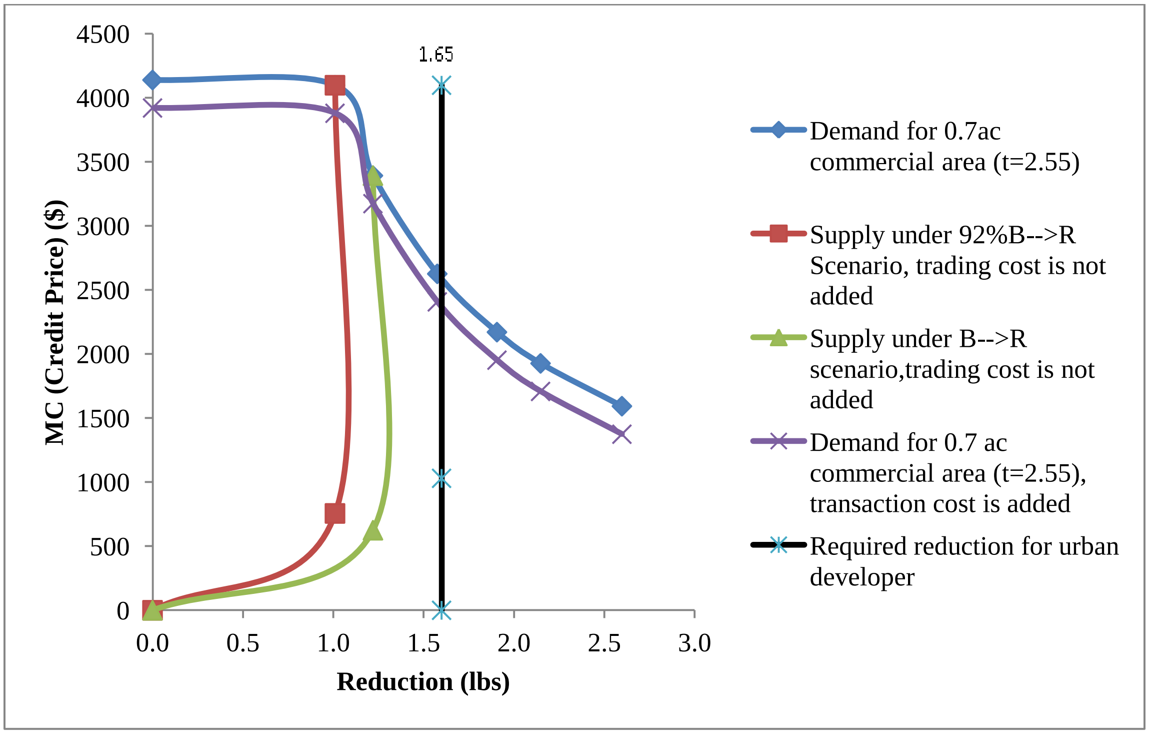

Figure 2.10. Role of urban transaction cost on WQT market (t=2.55)

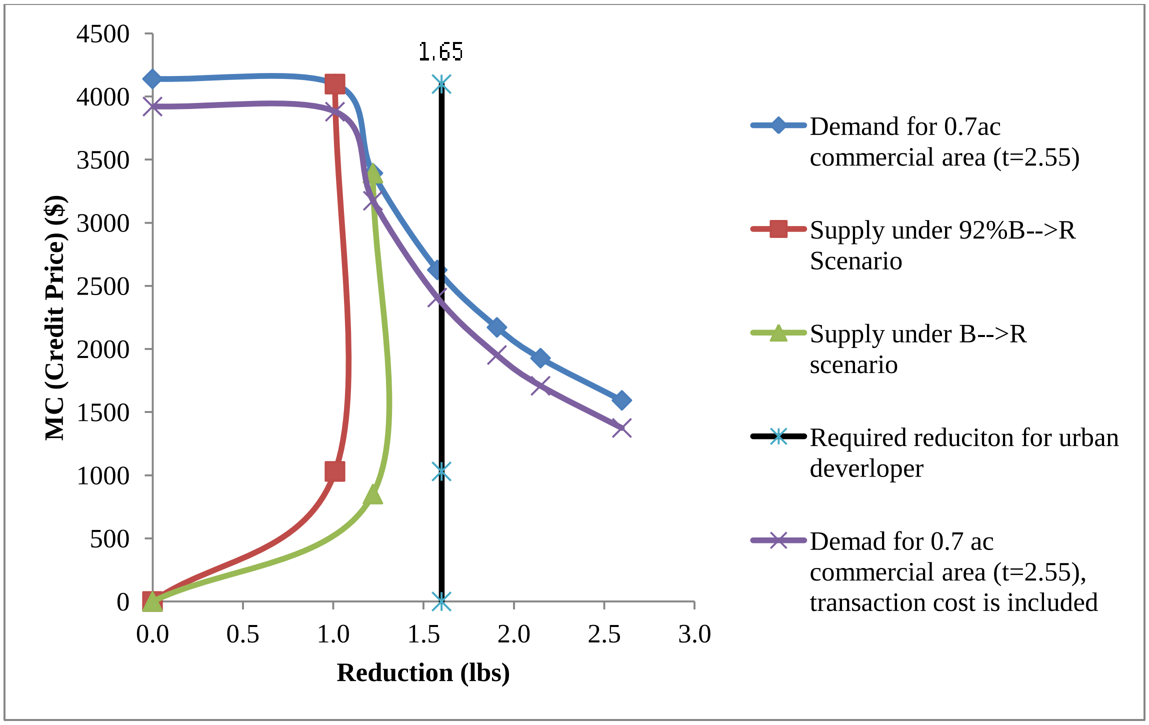

Figure 2.11. Role of transaction cost, baseline, IP on water quality program (t=2.55)

One way to determine the influence of wedges on a WQT program is by calculating their effect on the society's welfare. The indicators for a change in the society welfare are producer surplus (PS), consumer surplus (CS), which sum to society surplus (SS). Here, I assume the 0.7 acre urban developer is willing to trade with Field-1 in a bilateral market when a broker is not involved. Also I assume the Field-1's owner gains the whole bargain margin. Table 2.8 shows PS, CS and SS of different scenarios. Since the amount of credit supply is fixed either in 1.01 lbs or 1.22 lbs, and the credit suppler will receive the bargain margin, the CS will not change after adding trading ratio. The reason why CS does not change after adding a trading ratio is that adding transaction cost to the demand side of the market will shift the demand down, while the amount of reduction is fixed. Also, adding the trading cost to the model will change the break point of the supply curve, which does not affect the equilibrium point. Therefore, since the whole bargain margin will be allocated to the farmer, any change in the SS will change the PS, but the CS will remain constant. Table 2.8 illustrates the changes in CS, PS, and SS in different situations. Adding all wedges will reduce the PS and SS in all scenarios. For instance comparing the SS in ideal market and marginalized market (e.g., all wedges are added) shows a $848 and $331 reduction per trade in the two different baseline scenarios.

As shown in Figure 2.3, I graphically proved that in a WQT market, the law of single price may not work when the urban developers required reduction is not achieved with just one trade. As it is shown in Figure 2.7, the maximum provided reduction by Field-1 is 1.22 lbs, which is 0.43lbs below the required reduction for the urban developer (e.g., 1.65 lbs). Therefore, an urban developer will search to find another farmer to trade with. Based on my WQT model for the Jordan Lake, the second farmer will ask $899 per pound of TN reduction when the baseline scenario is B→R and $1,064 per pound of TN reduction when the baseline scenario is 92%B→R. These results determine that the WQT participants would not encounter a single price when the required reduction cannot be achieved by one trade.

Table 2.8. PS, CS and SS in ideal and less than ideal WQT market

	Ideal market		**Adding trading ratio (t=2.55)**		**Adding trading costs**		**Adding transaction costs**		**Adding all wedges**	
Scenario	B→R	92%B→R	B→R	92%B→R	B→R	92%B→R	B→R	92%B→R	B→R	92%B→R
PS	4,644	3,783	3,758	3,757	3,620	3,619	3,491	3,536	3,353	3,439
CS	12	8	455	21	455	21	455	21	455	21
SS	4,656	3,791	4,213	3,778	4,075	3,640	3,946	3,557	3,808	3,460

2.4. CONCLUSION

Cost effective conservation practices such as WQT programs might not always be the most applicable approaches. Implementing these programs requires a well-defined model that encompasses as many impediments as appropriate. In this paper, a WQT model between the most cost-effective buyer and seller was designed for Jordan Lake, NC. In addition, four wedges such as baseline, transaction cost, trading cost, and trading ratio were added to the model. The results show adding wedges simultaneously to the model will reduce the society’s welfare from between \$848 and \$331 per traded pound. Moreover, it was proved that the law of one price for credits for the entire watershed might be conceptually true but in the real market each trade will produce its own price. I designed a unified model for the Jordan Lake WQT model, but still there are some elements that I could not consider due to lack of information. We modeled the uncertainty of achieving the pollution reduction by using CCP, while there are other types of uncertainties that need to be included in the model. Adding all types of uncertainties might lead the current marginal market to a more ideal one. Moreover, since there are just two series of data to define the supply curve (e.g., TN load before and after installing BMPs), I could not differentiate between mandatory and voluntary supply. Involving more of volunteer farmers to the program will decrease the IP cost and increase the chance of having a successful program. Furthermore, the role of climate change was not investigated in the model. For instance, I have not modeled how much of the TN reduction is a result of the installed BMPs and how much of it caused by weather changes. The limitations of this study make recommendations for future areas of research related to WQT programs.

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CHAPTER 3. PRODUCER PREMIUM FOR WATER QUALTIY TRADING

3.1. INTRODUCTION

In the United States, 60% of assessed lakes, reservoirs, and ponds were threatened or impaired for their designated uses in 2006, mostly due to nutrients (Selman et al. 2009). Many different policies have been used in the US to improve water quality, including water quality trading (WQT). In theory, water quality can be improved at a lower cost using WQT than command and control policies, such as regulation (EPA, 2009). WQT is a market-based approach that facilitates the sources with high pollution cost to meet their regulatory obligations by buying pollution reductions from other sources with lower pollution reduction cost. While the idea of a WQT program is appealing, the number of successful applications has been limited (Shortle, 2013). Out of 37 WQT programs in the US in 2003, only three have actually experienced any trading activity (King and Kuch, 2003). By 2005, Morgan and Wolverton stated that out of 19 WQT programs in the USA, only four had experienced more than three trades.

If farmers are involved in a WQT program, they would be required to adopt at least one type of conservation practice (e.g. best management practices (BMPs)) to mitigate pollution. A low rate of adoption among farmers for most kinds of conservation practices is not uncommon (Hoag et al. 2012; Lichtenberg et al. 2010; Nowak et al. 1997; Marsh 1998; American Farmland Trust, 2013). For example, only 37% of the tilled areas in the US utilized some form of conservation tillage (CTIC, 1998). Therefore, a low rate of trading might be expected. However, trading is so sparse that some sort of additional limitation is implied. Several implication hurdles that impede the adoption of conservation practices in WQT programs, referred to wedges here, have been identified in the literature (Shortle and Horan, 2008; Selman et al. 2009; Shortle, 2013; Suter et al. 2011; Shortle and Ribaudo, 2012; Ghosh at al. 2011; King and Kuch, 2003; Peterson et al. 2014). Yet, an active trading market is still illusive.

Although most of the wedges discussed in the literature are tangible, Peterson et al. (2007) indicated that sometimes there are some intangible factors that increase farmers' BMP adoption cost and reduce the rate of participation. Lack of social trust between the involved parties in a WQT program and unfamiliarity of the participants with program details are examples of intangible wedges that can reduce adoption of conservation practices (Breetz et al. 2005; Mariola, 2011). Moreover, sometimes a WQT program is too new to promote trades and the new trading rules and regulations yield uncertainties for the WQT participants (Shortle, 2012 and 2013; Morgan and Woverton, 2005). Due to farmers' socio–cultural concerns (Breetz et al. 2005; USDA, 2005), which are sometimes intangible, the economic bottom line may not be enough to cause farmer participation in a trading program (Breetz et al. 2005).

Intangible wedges will lead farmers to ask for more money to participate in WQT programs. Failure to recognize and account for this "premium" will lead policy makers to underestimate the cost for motivating farmers to adopt conservation practices for a WQT program. This relatively unexplored innovation premium (IP) could be a major contributor to low adoption rates in WQT programs.

This study will investigate the existence and impact of an IP in an actual emerging WQT program in Jordan Lake, NC. In 2011, the North Carolina Department of Environment and Natural Resources (NCDENR) approved the implementation of a WQT program for Jordan Lake, NC to control excess N and P loads responsible for the lake's eutrophication. Per program rules (NCDENR, 2013), farmers participating in the WQT program may install best management practices (BMPs) (specifically riparian buffer zones) to sell as credits to new urban developments. Trading cost is simply the amount above stated BMP costs in the survey that farmers are willing to accept (WTA) to produce credits. The IP can be derived from trading cost, which is the sum of observable transaction costs and the IP. In addition, the role of financial incentives to encourage farmers to participate in the WQT will be investigated, in conjunction with trading cost. The value of this study is demonstrating the magnitude and the effect of intangible costs on a WQT program, and also illustrating how these costs might be lowered.

3.2. METHODOLOGY

Lack of the success in an ecological and environmental conservation programs is a function of several tangible and intangible wedges (Breetz et al. 2005; Granovetter, 2005; Perrot-Maitre, 2006; Peterson et al. 2007). Here, intangible factors are aggregated into the IP wedge. While the IP can have an effect on water quality credit supply or demand, I focus here on the role of IP in the supply side of the WQT program in Jordan Lake, NC.

The transaction cost and IP sum up to trading cost. As shown in Figure 3.1, the general nature of supply-side wedges is to shift the supply curve inward, driving price up and quantity supplied down. Transaction costs shift supply further, from S_1 to S_2, and the IP shifts it even more, from S_2 to S_3. The magnitude of these shifts is an empirical question, but is one that I can estimate here for the Jordan Lake program.

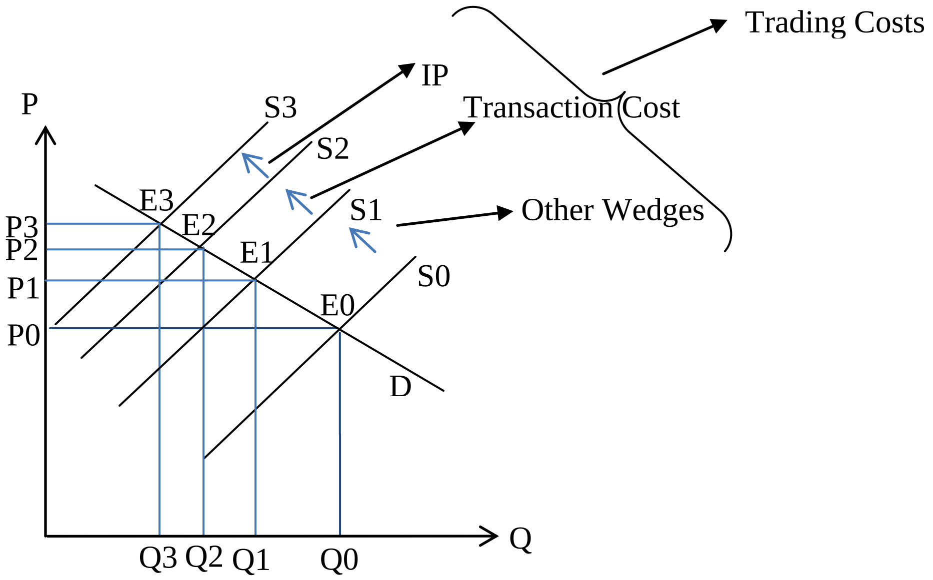

Figure 3.1. Role of innovation premium in water quality trading market

Farmers' minimum WTA to install a BMP, such as riparian buffers, is determined through an in-person survey. WTA includes direct costs to the farmers such as BMP installation cost and indirect costs including IP and transaction costs (TrC) related to installing and maintaining the BMP:

$$\text{WTA} = \text{BMP installation cost } (IC_{BMP}) + \text{BMP Opportunity cost } (OC_{BMP}) + \text{Trading cost} \quad (1)$$

$$\text{Trading cost} = TrC + IP = WTA - IC_{BMP} - OC_{BMP} \quad (2)$$

While IP cannot be directly observed, BMP installation and opportunity costs can. Therefore,

$$IP = WTA - IC_{BMP} - OC_{BMP} - TrC \quad (3)$$

I assume trading cost includes the maintenance cost. Per Jordan Lake's rules, buffer zones must be 15.24 m (50 ft) wide. Installation costs were $450 per acre ($1,110 per ha) for crops and $2,200 per acre ($5,400 per ha) for livestock farmers (NRCS, 2011). The opportunity cost for livestock farmers was assumed to equal the amount of the hay lost to land devoted to BMPs and crop farmers lost the opportunity to produce crops including corn, soybean and tobacco. Yield and price data for NC crops and hay were obtained from the USDA database (USDA, National Agricultural Statistic Services, 2012). A discount rate of 4.6 percent, and expected life of 20 years, was used to annualize the investment costs (NRCS, 2009). Finally, transaction costs were not collected, but can be inferred based on other existing studies. Although most of the work to date on transaction costs has been qualitative in nature, a few studies have attempted to directly estimate transaction costs of environmental markets or conservation programs. The transaction costs estimates from these few studies range between 10% and 50% of the other costs of generating credits Chesapeake Bay Commission (2012). For example Fang et al. (2005) estimated a 35% transaction cost factor for a nutrient program in the Minnesota River Basin. Moreover Chesapeake Bay Commission (2012) adopted 38% adjustment factor for calculating transaction cost. In this study, 35% adjustment factor was used for calculating the transaction cost in the demand side of the WQT in Jordan Lake, NC.

Data for this study were collected from a survey that was done in person with 90 farmers whose farms are located in the Jordan Lake watershed. In order to familiarize farmers with the WQT program in this watershed, a supplemental handout was provided before asking any questions. This handout clarifies that the farmers’ credits will be allocated based on the amount of their water pollution reduction after installing riparian buffers adjacent to the streams on the farms.

The contingent valuation method (CVM) was used to determine farmers’ WTA for participating in this program. CVM is based on a questionnaire that includes responses to hypothetical questions respecting the value that people put on environmental goods when actual market data is lacking (Pagiola, 1996). The most common question asked in CVM is the maximum amount that people would be willing to pay (WTP) or that they would be willing to accept (WTA) for a specific change to occur (Freeman, 1993; and Carson et al. 2001). Dupraz et al. (2003) believed that CVM is a useful method to reveal the behaviors of farmers who encounter participation in an agri-environmental scheme.

The questionnaire used a two-step approach. First, farmers were asked whether they would like to participate in a program to install a buffer zone at least 15.24 m (50 ft) wide on their farm. If they were interested in installing this type of BMP, then they were asked about the minimum amount of money that they would be willing to accept for installing the buffer on their farm. Since installing riparian buffers is a practice that farmers are unfamiliar with, the cost of buffer zone' installation was provided as shown below:

Experience shows that it would cost about $450 <u>OR</u> $2,200 (including fencing) per acre [$1,110 <u>OR</u> $5,400 (including fencing) per ha] to install permanent buffers along streams. Given that developers could pay for part, all or more than your costs with the WQT, how much would be your WTA to install riparian buffers? ______$/ ac.

This type of question is called "open-ended" CVM, which yields a continuous variable because the respondent is open to say any amount that they want. The responses were censored at zero indicating unwillingness to allow installing buffer zones.

Despite its popularity for valuing environmental amenities, CVM has been criticized for several limitations such as information bias, non-response bias and hypothetical bias (Edwards and Anderson, 1987; List and Gallet, 2001; Loomis et al. 1994; Neill et al. 1994). However, less research has been conducted regarding interviewer effects and social desirability bias (Loureiro and Lotade, 2005). People have a bias toward misrepresenting their accurate preferences because they are more concerned about how they are viewed by others (Crowne and Marlowe 1960; Fisher 1993; Leggett et al. 2003; List et al. 2004; Plant, Devine, and Brazy 2003). There are some techniques to decrease the effect of desirability bias. One of the most common ones is indirect questions. Fisher (1993) indicated that indirect questions can provide a better trace of a person’s true feelings than direct questions in cases where someone feels social pressure to behave in a certain manner. In this paper, to overcome the desirability bias, after asking farmers about whether they would accept installing buffer zones around their farm, we had two follow up questions. These follow up questions help us to understand farmers’ consistency about the amount of their WTA. These questions give the farmers who are willing to participate in this program the time to revise their answers about participation. In order to estimate the desirability bias, each farmer was asked the following question:

“In your opinion, why would other farmers be willing to accept less than their BMP installation cost?”.

Also they were asked,

“In your opinion, why would other farmers be willing to accept more than their cost of BMP installation?”.

Finally, they were asked the following question in order to elicit an indirect valuation:

“After thinking about the BMP installation a little more, are you confidant with your earlier answer that you would be willing to accept $X____to install the permanent buffers?”

The remainder of the survey asked traditional questions about demographic information on the farmer and farm such as age, education, household number, land size and land usage.

3.3. RESULTS AND DISCUSSION

The results of this study are divided into three parts: descriptive statistics, estimating the amount of farmers' willingness to participate in a WQT program, and IP and trading cost.

3.3.1. DESCRIPTIVE STATISTIC

The descriptive statistics of the variables used in the estimation process are shown in Table 3.1 and Table 3.2. Education was divided into 5 different groups: farmers who didn't go to high school (<HS), farmers who went to high school (HS) or community college (CC), farmers who have a Bachelor's degree (BA/BS) or have education higher than a Bachelor's (BA/BS<). The mean education of 3.13 indicates that on average, farmers have a degree from a community college. Farmers' age was divided into eight groups. The age group mean, (6.1), shows an average farmer age is between 60-70 years. Based on the residency variable, the sampled farmers have lived at their farms for almost 46.6 years on average. The maximum farmed land area in the sample is 728 ha (1800 acre) and the average farming area is 154 ha (380 acre).

Table 3.2 shows three types of farming include farmers who grow crops (group 1), raise livestock (group 2), and farmers who have both crops and livestock (group 3). The results indicate that 50% of the interviewed farmers primarily produce livestock and that the majority of their income comes from their agricultural activity. Almost 30% have had a failed experience in implementing a conservation practice. The percentage receiving financial assistance for implementing a conservation practice is 78%. About 82% were aware of the Jordan Lake water quality issue but did not perceive the issue is severe. Moreover, farmers believe the industry and other sectors are responsible for the Jordan Lake water quality issue. Only 2% of farmers feel that the agricultural sector is the major source of the Jordan Lake water pollution. Finally, 62% were inclined to plant trees and 71% were willing to plant vegetation in their buffer areas.

Table 3.1. Summary statistics of surveyed farmers in the Jordan lake watershed

Variable	Description	Unit	Mean	Std. Dev.	Max	Min
Education	(<HS=1, HS=2, CC=3, BA/BS=4 and BA/BS<5)		3.13	1.05	5	1
Age	(0-10=1, 10-20=2, 20-30=3,…, 70-80=8)		6.1	1.1	8	4
Residency Years in the Community		Years	46.6	17.3	75	5
Farm Size		ha	154	137.6	728	2

Table 3.2. Summary statistics of categorical variables for surveyed farmers in the Jordan lake watershed

Variable	Category	Frequency	Percentage
Type of farm	Crop	26	30
	Livestock	46	50
	Both	18	20
Agricultural income	Major income	75	83
	Not major income	14	16
	No answer	1	1
Have farmers ever experienced failure implementing a conservation practice	Yes	27	30
	No	62	69
	No answer	1	1
Technical assistance with conservation practices	Yes	70	78
	No	18	20
	No answer	2	2
Aware of the Jordan Lake pollution	Aware	74	82
	Not aware	14	16
	No answer	2	2
Perceived level of severity of water pollution	Severe	19	21
	Medium	16	18
	Weak	21	23
	Nothing	27	30
	No answer	7	8
Sector responsible for water pollution	No idea	24	27
	Agriculture	2	2
	Agriculture and other sectors	13	14
	Other sectors	51	57
Type of buffer	Buffers with tree	56	62
	Buffers with vegetation	64	71

3.3.2. WILLINGNESS TO PARTICIPATE IN WQT

Farmers' response to the participation before and after being offered any specific amount of money to cover their BMP installation cost is shown in Table 3.3. When the interviewer did not suggest any specific financial amount to farmers for covering BMP installation costs, just 26% of farmers were interested in cooperating in this program, while after offering the BMP installation cost to farmers, 92% of them would be willing to participate.

Table 3.3. Farmers' participation in water quality trading program before and after offering money to cover best management practice cost

Before Offering Money			**After Offering Money**		
Answer	Frequency	Percent	Answer	Frequency	Percent
Yes	23	27	Yes	83	92
No	26	28	No	6	7
Maybe	39	43	Maybe	-----	-----
No Answer	2	2	No Answer	1	1
Sum	90	100	Sum	90	100

A *Probit* model was used to investigate the role of payment in encouraging farmers to participate in a WQT program. A dummy variable was used to measure the farmers' response to participation before and after offering specific amounts of money to cover their BMP installation costs. The data from when no payment was offered and when a payment was specified were pooled to create the dummy variable, 0 = no payment offered, 1= payment offered. A significant coefficient for this dummy variable indicates that offering a specific amount of financial help plays a notable role in motivating farmers to participate. Results of this regression are shown in Table 3.4. Since the coefficient on the dummy variable is significant, monetary motivation clearly plays a significant role in encouraging farmers to participate, while education has a positive relation with acceptance of the WQT program, farmers' years of residency in their community have a significant negative influence on program acceptance (Table 3.4). Tendency to cooperate with this program may decrease with increasing years of residency in a community because of strong pride in their private property. Also, many farmers are not willing to allow regulators oversight of their property (Breetz et al. 2005). Farmers' strong pride about their land could be one of the reasons for having a high premium in the Jordan Lake watershed.

Table 3.4. The role of offering money in accepting water quality trading program in Jordan Lake, NC

Variable	**Coefficient**	**Std. error**	***t*-test**
Constant	-1.17	0.805	-1.46
Years of Residency	-0.017	0.008	-2.12**
Education	0.27	0.14	1.96*
Type of Buffer	0.37	0.16	2.37**
Size of Farm	-0.00042	0.0004	-1.05
Experience	-0.089	0.26	-0.34
Money (dummy variable)	2.083	0.26	8.12**
Pseudo R^2	0.4		
Log likelihood	-68.78		

** Statistical significance at the 1% level   * Statistical significance at the 5% level

Next, farmers who are willing to participate in WQT program were divided into three groups: farmers who would accept less, equal to, or more money than their BMP installation cost to participate in a WQT program. Before being indirectly questioned, 3.6% of interviewed farmers' WTA was less than their BMP installation cost for participation, while 71.4% of interviewed farmers would need to be paid more than their BMP installation cost to participate in a WQT program (Table 3.5). Nearly 5% of the interviewed farmers requested either more money than was offered in interviews, or said they would not participate in the program.

Table 3.5. Willingness to accept for farmers who are willing to participate after covering their best management practices installation cost

Answer	**Frequency**	**Percent**
Less than the BMP installation cost	3	3.6
Equal to the BMP installation cost	15	17.8
More than the BMP installation cost	60	71.4
More than BMP installation cost or unwilling to participate	4	4.8
More than BMP installation cost or equal to their BMP's cost	1	1.2
No Answer	1	1.2
Sum	84	100

Farmers who raise livestock on their farms need to install fences around their farms to exclude animals from areas where grazing or trampling will cause erosion of streambanks and lowering of water quality. So participation in this program will be more costly for livestock farmers (e.g. \$5,400 per ha including fencing, or \$2,200 per acre) than for crop farmers (e.g. \$1,110 per ha or \$450 per acre). Therefore, the amount of farmers' WTA was normalized by the total cost of buffer zone installation. The advantage of normalization is that there is no difference between a crop farmer who is willing to accept \$1,110 and a livestock farmer who is willing to accept \$5,400, because both ask the full amount of their BMP installation cost. Table 3.6 shows the normalized farmers' WTA. Almost 22% of farmers would be willing to accept less than or up to their BMP installation cost to participate in this program, while 50% of them would ask more than twice the cost, and 10% would ask more than 10 times their BMP installation cost. Some farmers even expressed a WTA 23 times more than the cost of installing the BMP. Farmers' WTA is notably higher than their BMP installation cost, which indicates that trading costs are expected to be high. After questioning farmers about their WTA for installing buffers, the process of indirect questions was followed as described in Methods (above).

Table 3.6. Ratio, frequency and percentage of the amount of willingness to accept to install conservation practices for farmers who answer to willingness to accept question

Ratio	**Frequency**	**Percentage**	**Ratio**	**Frequency**	**Percentage**
0-1	3	3. 6	5	4	4.8
1	15	18.1	5-6	1	1.2
1-2	13	15.7	9-10	1	1.2
2	10	12	10	2	2.4
2-3	12	14.5	10-11	1	1.2
3	2	2.4	13-14	2	2.4
3-4	6	7.2	20	1	1.2
4	1	1.2	20<	4	4.8
4-5	5	6			

After this process, almost 11% of the interviewed farmers (10 farmers) changed their mind and requested a different amount of money for installation of conservation practices (Table 3.7). Among these 10 farmers, five changed their mind after they were faced with indirect questions and decided to quit the program. Three out of 10 decided to participate in this program after indirect questioning, two of whom said they would participate if they received more than their BMP installation cost.

Table 3.7. Farmers' decision before and after indirect question

Before Indirect Question			**After Indirect Question**	
Willing to participate	Equal to BMP cost	3	Unwilling to participate	2
			More than BMP Cost	1
	More than BMP Cost	4	Unwilling to participate	3
			Equal to BMP Cost	1
Unwilling to participate		3	More than BMP Cost	2
			Equal to BMP Cost	1
Sum		10	Sum	10

3.3.3. TRADING COST AND IP ESTIMATION

As previously stated, WQT programs have had difficulty convincing farmers to participate. As indicated by the results here, “farmers have a parallel set of socio-cultural goals and concerns” (Breetz et al. 2005, p 172) and demand to be paid for them. Table 3.8 shows the result of calculating the rate and the amount of WTA before and after the indirect questions for livestock and crop farmers individually. The amount of WTA is almost 3.8 times more than the cost of installing BMPs for livestock farmers who were offered $5,400 per ha, and it is 5 times more than the cost of installing BMP for crop farmers who were offered $1,110 per ha. *t*-tests for these two groups of farmers (livestock and crop) were used to investigate whether the WTA rate before and after indirect questions were significantly different. The *t*-test for WTA difference for farmers with crop farming was 0.002 whereas this test for farmers with livestock farming was 0.02. This illustrates that in both cases the means of WTA were not significantly different, and indirect questions did not remarkably change the amount of money farmers said they would ask for their participation.

Trading cost was estimated based on the WTA derived after indirect questions. Equation 2 shows the process of calculating the trading cost. In order to calculate the trading cost, at first, the opportunity cost was estimated. It was presumed that the field area was a square shape. Also it was assumed the buffer zones will be installed on one side of the field. These two assumptions assisted me to calculate the crop and livestock farmers’ opportunity cost. The opportunity cost indicates the loss of crops and hay’s production from that part of the fields which will be allocated to the buffer zones. The average trading cost for crop farmers is about $6,808 per ha (6 times more than their BMP installation cost) and for livestock farmers is about $10,240 per ha (2 times more than their BMP installation cost). The weighted average trading cost for the surveyed farmers is about $9,266.6 per ha. These results prove that trading costs play a profound role in WQT program. Ignoring these costs before implementing the WQT program can marginalize the market or even create a nonexistent one. If we assume 35% of the calculated trading cost belongs to the transaction cost (Fang et al. 2005), the weighted average IP would be $6,023 per ha. The IP cost for crop and livestock farmers would be $4,425 and $6,656 per ha respectively.

Table 3.8. Rate and amount of willingness to accept before and after indirect question

<table>
<tr><th colspan="4">Livestock Farming[*]</th></tr>
<tr><td>WTA rate before indirect Question</td><td>Amount of WTA before indirect Question</td><td>WTA rate after indirect Question</td><td>Amount of WTA after indirect Question</td></tr>
<tr><td>3.73</td><td>$20,275</td><td>3.68</td><td>$19,940</td></tr>
<tr><th colspan="4">Crop Farming[**]</th></tr>
<tr><td>WTA rate before indirect Question</td><td>Amount of WTA before indirect Question</td><td>WTA rate after indirect Question</td><td>Amount of WTA after indirect Question</td></tr>
<tr><td>5.38</td><td>$5,985</td><td>4.56</td><td>$5,067</td></tr>
</table>

[*] BMP Installation cost is $5,400 per ha including fencing

[**] BMP Installation cost is 1,110 per ha

Funding: this project was funded by USDA National Institute of Food and Agriculture Integrated Water Quality Grant award # 2011-05151.

3.3.4. FARMERS' REASONS FOR ASKING A WTA DIFFERENT THAN THEIR BMPS INSTALLATION COST

Indirect questions revealed possible reasons why farmer's WTA differs from the actual cost of conservation practices. When asked about the motivation of other farmers, 13% of farmers believe other farmers would accept less money than the cost of conservation practices because of their social stewardship, 14% believe because other farmers already have at least one kind of other BMPs in their farms, and other answers varied. For example, some said that other farmers are wealthy and don't need income from conservation practices, or that they don't need developers' financial help with BMP installation, that they have their children's financial support or other jobs from which they can obtain money and that they may be tired of farming, would prefer to sell their farm and don't care about conservation programs. 50% of farmers didn't answer this question.

When farmers were asked why other farmers would demand more money than their BMP installation cost, 78% of farmers didn't answer this question, 19% stated that it was because they need revenue through this program, and 2% of believe that BMPs would cost them more than the amount of money that has been offered.

3.4. CONCLUSIONS

Many water conservation programs seem attractive in theory, but the success of these programs depends on different factors such as the acceptability of the program by the involved parties. For example, if a WQT program is not familiar to credit suppliers or credit demanders, the probability of having a prosperous program will decline. One reason that these programs are marginalized as shown here is due to the innovation premium (IP). This wedge can push a WQT market to a marginal or a nonexistent state. Therefore, before applying any type of conservation program, policy makers should be aware of the acceptability of the program for all parties who are supposed to be involved. In this study, we attempted to understand the magnitude of IP in the Jordan Lake's WQT program. The results show that farmers' average WTA for participating in this program is 3.6 to 5.38 times higher than their BMP installation cost for crop and livestock producers, respectively. The high WTA indicates the trading cost in this area is high as well. Since IP is one of the main components of the trading cost, high IP produces a high trading cost. I estimated the IP cost for crop and livestock farmers at $4,425 and $6,656 per ha respectively.

The high IP in Jordan Lake, NC can be due to lack of a strong bond of trust between the involved parties (e.g. credit sellers, credit buyers, regulators, program facilitators). Trust between the involved parties helps WQT programs succeed. Building trust makes information more believable to farmers and declines the risk that farmers may perceive in participating in the trading scheme (Mariola, 2012). Lack of trust is a temporary issue and can be eliminated by policy makers if they start building a link between the involved parties before implementing the targeted policy. Jones et al. determined that "reputations have economic consequences" and "it reduces the uncertainty by providing information about the reliability and goodwill of others" (1997: 932-933). A long–run relationship between local farmers and conservation practice experience is a key to understanding which types of farmers and practices will be suitable for these types of programs (Newburn and Woodward, 2011). Shortle (2012) stated that a successful trading requires developed institutions for organizing trade that can be trusted by the program participants. Therefore, building a strong bond of trust between participants is the necessary condition to reduce the IP in all new conservation programs. The results of this study also show that offering money to farmers to cover their BMP installation cost is a motivating tool to encourage them to participate in WQT programs.

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CHAPTER 4. IMPACT OF RELATIVE DEMAND FOR ECOSYSTEM SERVICES ON STACKING ECOSYSTEM CREDITS

4.1. INTRODUCTION

Consideration of the potential markets for ecosystem services raises intriguing questions about how such markets can and should interact with each other and what the implications of multiple markets are for cost and conservation objectives. For example, suppose that farmers in a watershed install best management practices (BMPs) to improve water quality and that they are able to sell their water pollution reduction credits to urban developers. This process lowers the cost to improve water quality. However, water quality improvement doesn't function independently from other environmental and ecological services. For example, installing buffer zones, along with removing nitrogen (N) and phosphorous (P), will enhance wildlife habitats and upgrade water related recreational services. That is, farmers' conservation practice installation for the purpose of ameliorating water quality provides more than one outcome. This raises the question: should farmers who install riparian buffers to reduce nutrients be allowed to sell other ecosystem services from that single practice?

The Center for Integrative Environmental Research and World Resources Institute (2010) reported that if farmers can obtain increased revenue by selling ecosystem service improvements into multiple markets, it is more probable that they will consider participating in conservation programs. Selling ecosystem services credits along with other types of credits has been called credit stacking, bundling, coupling or integrating credits (Kenny, 2010). The concept has been also interpreted in different ways. Willamette Partnership (2010) defined stacking as the creation of different types of credits in the same geographic area, while the National Research Council

(NRC, 2001) illustrated that stacking happens when multiple ecosystem services are bundled to compensate for a single impact. Carter Ingram (2012) indicated that there are three broad categories for stacking:

- “Horizontal stacking: occurs when more than one distinct management practice is implemented on non-spatially overlapping areas of a land/sea-scape and the project developer receives a single payment for services generated/secured by each management practice.” (Carter Ingram, 2012; page 5).
- “Vertical stacking: occurs when a project participant receives multiple payments for a single management activity on spatially overlapping areas.” (Carter Ingram, 2012; page 5).
- “Temporal stacking: is similar to the vertical stacking in that the project involves only one management activity, but payments are distributed over time.” (Carter Ingram, 2012; page 6).

Given the lack of consistent terminology for credit stacking, I will adhere to the Electric Power Research Institute (EPRI, 2011) survey results about credit stacking, where 83% of the respondents agreed that the best definition is “establishing more than one credit type on spatially overlapped areas”. The EPRI’s stacking definition is similar to the explanation of vertical stacking (Fox et al. 2011). This type of stacking is also the most challenging and controversial form of stacking from a regulatory perspective.

Under certain conditions, credit stacking appears appealing for credit suppliers because they can sell more than one type of credits from a single act of conservation, which can diversify the credit suppliers’ revenue and decrease the risk of selling one type of credit (Robertson et al. 2014). The EPRI survey also showed that 70% of the survey’s respondents believed that stacking increases the financial value of the conservation projects. However, along with this attractive aspect, a concern arises about double-dipping. Double-dipping is where one unit of mitigation action is sold once, and then sold again, whereby that second buyer doesn't actually compensate for their impact (White and Penelope, 2013). Double-dipping occurred in North Carolina, when wetland and stream ecosystem services were first defined and sold as wetland credits and then a decade later, again in a separate market as water-quality improvement credits, despite a lack of additional improvements in the meantime (Program Evaluation Division, 2009; Kane, 2009). Horan et al. (2004) showed that double-dipping will increase farmers' efficiency with well-targeted payment incentives, while in non-well-targeted programs; double dipping may result in a higher income for farmers but at the expense of point sources. Woodward (2011) proved that for two complementary pollutants, if coordinated policies are not assigned, allowing double-dipping may not yield the greatest benefits for society. Although some studies support credit stacking policy (Horan et al. 2004; Woodward, 2011), stacking might not always be applicable. In the empirical world, there are few good examples of credit stacking benefits. Where and under what conditions would stacking policy lead to greater participation and more ecosystem services benefits (Olander, 2011)? The feasibility and success of credit stacking likely depends on the unique situation of each program, such as the type of ecosystem service that is expected, additionality[4], the parties who are responsible to buy and sell the ecosystem services credits, type of BMPs, the sequence of the credit allocation, program rules for each individual credit, etc.

In this paper, the potential of stacking in a program recently approved to allow water quality trading (WQT) in the Jordan Lake watershed, North Carolina is examined. An appropriate, hypothetical stacking policy is defined based on WQT program's rules and goals. In that program, farmers can install riparian buffer zones as their best management practice (BMP)

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[4] Additionality requires that a practice would not have happened in the absence of the payment.

to reduce total nitrogen (TN) load to Jordan Lake and create credits that they can then sell to urban developers. Installing riparian buffers next to streams provides or enhances multiple types of ecosystem services, such as provisioning services (e.g., fresh water), supporting services (e.g., nutrient cycling, wildlife habitat), regulating services (e.g., climate regulation), and cultural services (e.g., recreational services such as boating, fishing, and swimming) (Millennium Ecosystem Assessment, 2003). For example, forested stream buffers built to protect the stream from surface runoff nitrogen sources can also provide carbon dioxide sequestration and habitat for wildlife. Therefore, installing buffers has the potential to create credits for multiple ecosystem markets. In this study, the role of ecosystem service stacking in the Jordan Lake watershed is considered.

4.2. METHODOLOGY

I assume the regulator seeks to apply a credit stacking policy on top of the WQT market by finding another ecosystem service market that would benefit from installing a single BMP (riparian stream buffers). Figure 4.1 illustrates a situation where farmers install just one type of BMP but receive two forms of credit. Based on this figure, a farmer installs a buffer zone in his/her field. Buffers will improve the quality of water, which is beneficial for both urban developers and recreational service users. Farmers could receive a higher financial incentive to install riparian buffers if both urban developers and recreational users were willing to pay for the benefit of that BMP. This type of credit stacking occurs when two ecosystem services are complements. That is, if the firm is obligated to reduce pollutant 1, then, without any policy intervention on pollutant 2, the cost minimization choice for the given firm will result in a reduction in the emissions of pollutant 2 (Woodward, 2011).

Figure 4.2 depicts the production possibility frontier (PPF) for two complementary ecosystem services. Improving water quality (WQ) through the Jordan Lake program will improve some other ecosystem service, such as recreational services (RS). Complementary in production comes from either technical interdependencies or inputs that cannot be separately allocated between products (Romstad et al. 2000; Nilsson, 2004). It is easy to see why this strategy appears incentive compatible for credit sellers because revenue appears to be stacking up to increase financial incentives for installing just one BMP. However, this type of stacking may not be appealing to buyers because it might allow for double dipping.

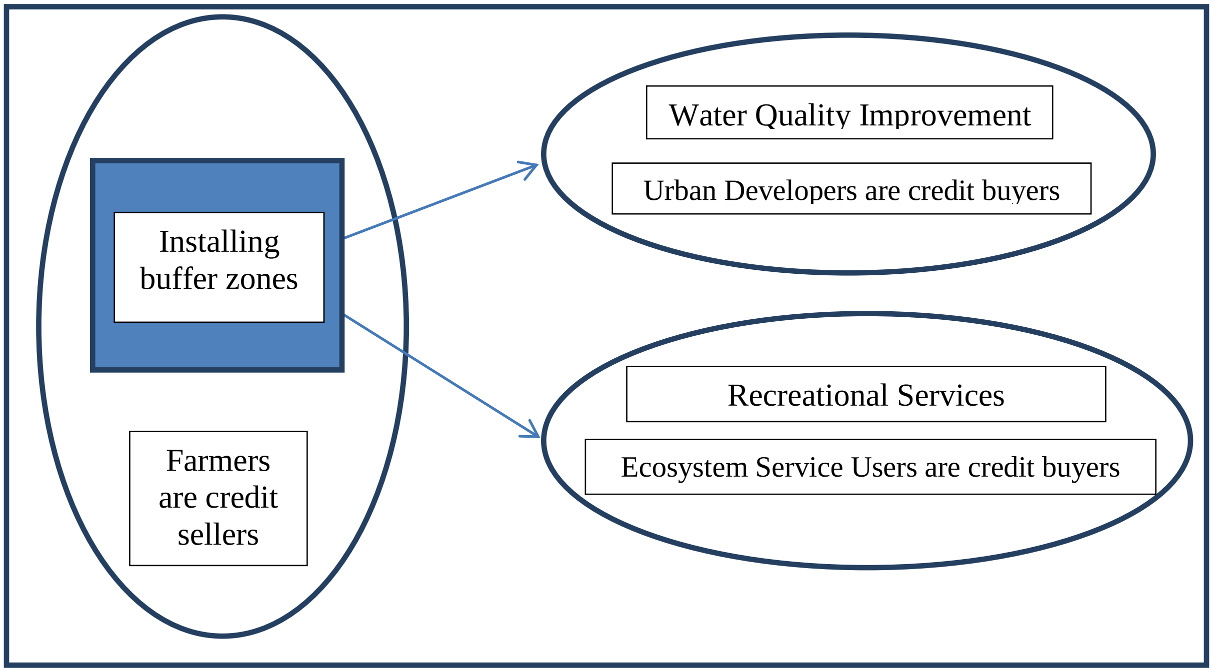

Figure 4.1. Vertical stacking scenario

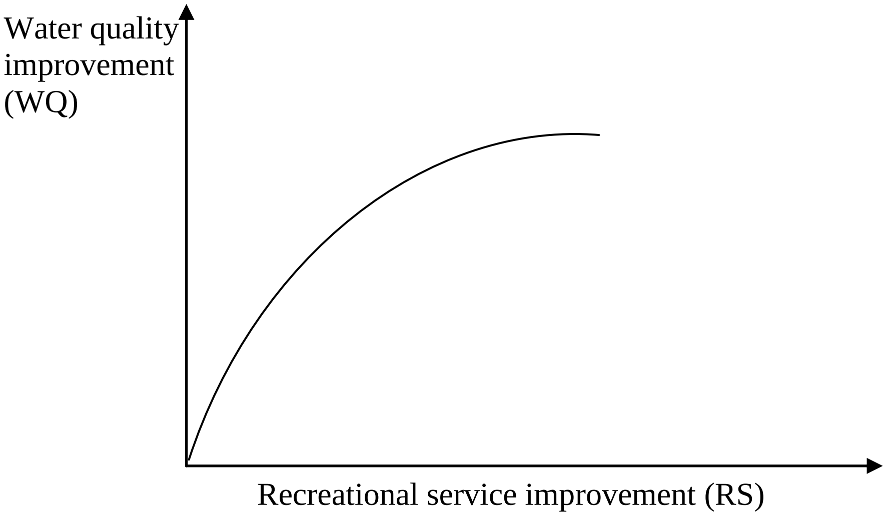

Figure 4.2. Production possibility frontier for complementary (complementary in production)

Equation (1) shows a farmer's profit function (π) based on the credit stacking scenario. A farmer can maximize his/her profit by selling crops, primary credits and the secondary ecosystem service credits, as follows:

$$\pi = P_Y Y\big(f(x)\big) + P_N \Delta e_N\big(g(Z)\big) + P_P \Delta e_P\big(g(Z)\big) - r_x x - r_z Z \qquad (1)$$

Where x and Z indicate traditional crop production inputs and the inputs required for installing BMPs, respectively. The first term ($P_Y Y\big(f(x)\big)$) is crop revenue, the second term ($P_N \Delta e_N\big(g(Z)\big)$) and the third term ($\Delta e_P\big(g(Z)\big)$) are the TN and TP reduction credit revenues. P_Y, P_N, and P_P are crop, and TN and TP credit prices, respectively. $Y\big(f(x)\big)$, $\Delta e_N\big(g(Z)\big)$, and $\Delta e_P\big(g(Z)\big)$ are crop production, and the amount of TN and TP reduction credits, respectively. The product of $r_x x$ indicates the total cost of crop production and $r_z Z$ encompasses the installation and the opportunity cost of implementing the single BMP for improving two ecosystem services. Profit, π, is a convex and continuous function of P_Y, P_N, P_P, r_x, and r_z. It is evident why stacking strategy appears incentive compatible for credit sellers; revenue appears to be stacking up to increase financial incentives for installing just one BMP. However, this type of stacking may not be appealing to buyers because it might allow for double dipping, as I show below. It also may not be relevant when demand for the second service is insufficient to add any additional incentives for conservation.

The effectiveness of credit stacking policy depends on the relative demand of the primary and secondary ecosystem services. I compare relative positions of primary and secondary ecosystem services demand curves through manipulating the relative slopes (ɣ) and intercepts (ɣ′) of these services. Then, I measure the impacts of ɣ and ɣ′ on the price discovery and the provision of each ecosystem service. The decision to allow for or participate in a stacking program can then be made based on the knowledge of whether there is sufficient incentives to offer from the secondary service and if there will be double dipping, allowing decision makers to assure that every dollar spent is stimulating additional value.

Price discovery for different stacking scenarios is illustrated in Figure 4.3a, 4.3b, and 4.3c. D_N is the demand for TN as the primary service, and D_P is the demand for TP as the secondary service, which has the lower intercept. Likewise, MR_N and MR_P are the marginal revenue for primary and secondary ecosystem services, respectively. The thick line, MR_T, is the total or vertically summed marginal revenue for TN and TP. MC is the marginal cost of the single BMP that produces the complementary products of TN and TP. Figure 4.3a demonstrates a scenario where stacking provides an incentive for farmers to adopt BMPs. whereas, figure 4.3b represents a case where the willingness to pay for the secondary ecosystem service is not enough to offer any additional incentive for credit producers to adopt more BMPs. Figure 4.3c depicts double dipping; farmers are paid more but do not change their BMP production. This simply displays that it is the relative position between primary and secondary demand that determines if stacking will be effective. A closer examination and an empirical example using our case study are provided below.

In Figure 4.3a, optimal credit supply occurs where $MR_T=MC$, which is Δe_T credits. The buyer of the primary ecosystem service pays P_N and the secondary ecosystem service buyer pays P_P for Δe_T credits. The total revenue (TR) of the credit seller from the stacking policy would be $(P_N*\Delta e_T) + (P_P*\Delta e_T)$. Without a stacking policy the farmer would have produced Δe_0 for a price of P_0. With stacking, the producer received a bonus of $P_P*\Delta e_T$. The credit producer is better off and supplies more conservation. This is a feasible market.

In Figure 4.3b, the total demand and individual demand for TN, $D_{N,}$ cross the MC curve in the same place. Therefore, the additional demand from the secondary ecosystem service provides no additional incentive for the farmer to offer more credits than are already provided by the primary service. This illustrates a case where a secondary service is not valuable enough to create a stacking program. In fact, the secondary service has all of its demand satisfied for free from the primary service. This is a passive market where the secondary service demanders are better off spending their budgets somewhere other than the stacking program.

Finally in Figure 4.3c, the relative position of the two demands leads to double dipping. In Panel C, the point where $MR_P=0$ occurs is below Δe_T and the point where $D_P= 0$ occurs at a quantity above Δe_T. In this case, the quantity of credit supplied is the same for total demand and primary demand, but producers are not providing any additional credits. Therefore, they are getting additional revenue equal to $(P_P*\Delta e_T)$ from buyers but the buyers are receiving nothing in return.

The conditions, which lead to the three different types of stacking outcomes shown in Figure 4.3, are determined from the relative demands. To better understand when these conditions occur, I changed the relative demands through a ratio of the demand intercept and slope. For simplicity, if the demand function for the TN and TP are linear and defined as $P_N = a_N + b_N \Delta e_N$ and $P_P = a_P + b_P \Delta e_P$ respectively, then a_N, a_P, b_N, and b_P are the TN demand function intercept, TP demand function intercept, TN demand slope, and TP demand slope. P_N and P_P define the price of TN and TP. The marginal revenue (MR) of TN and TP is then $MR_N = a_N + 2b_N \Delta e_N$ and $MR_P = a_P + 2b_P \Delta e_P$ where $b_N < 0$ and $b_P < 0$. Let γ be a slope changer such that $b_P = \gamma b_N$. Increasing the slope of TP demand by one unit will increase the slope relative to TN demand by γ unit. Also, let γ' be an intercept shifter such that $a_P = \gamma' a_N$. Changing γ' will shift the TP demand curve upward or downward relative to demand for TN. Finally, a reduction in the TN load will decrease the TP load, since they are complements, as follows: $\Delta e_P = \beta \Delta e_N$ and $0<\beta<1$. β is the coefficient linking Δe_N and Δe_P. The optimum amount of BMP adoption is found by setting $MC=MR_{\mathrm{T}}$ as follows:

$$MC = MR_T \rightarrow MR_T = a_N + 2b_N \Delta e_N + \gamma' a_N + (2\gamma b_N)\beta \Delta e_N \rightarrow \Delta e_N = \Delta e_T = \frac{MC^* - (1+\gamma')a_N}{2b_N(1+\gamma\beta)} \tag{2}$$

MC^* defines MC at the equilibrium point. Based on Equation (2), increasing the γ', which indicates the role of relative demand intercept on the stacking policy, will increase the Δe_{T}. Therefore, the chance of stacking will increase as well. Alternatively, if γ rises, Δe_{T} and the effectiveness of stacking decrease. Where the $MR_P = 0$, labeled Δe_{MRP} in Figure 4.3, plays a profound role on which of the three stacking scenarios will exist. Equation 3 shows that if $\Delta e_{\mathrm{T}} > \Delta e_{MRP}$ and $\Delta e_{DP} > \Delta e_{\mathrm{T}}$, as shown in panel B, double-dipping occurs.

$$MR_P = 0 \quad \rightarrow \quad a_P + 2b_P \Delta e_P = a_P + 2\gamma b_N \Delta e_P = 0 \quad \rightarrow \quad 0e_{MRP} = \frac{-a_P}{2\gamma b_N} \tag{3}$$

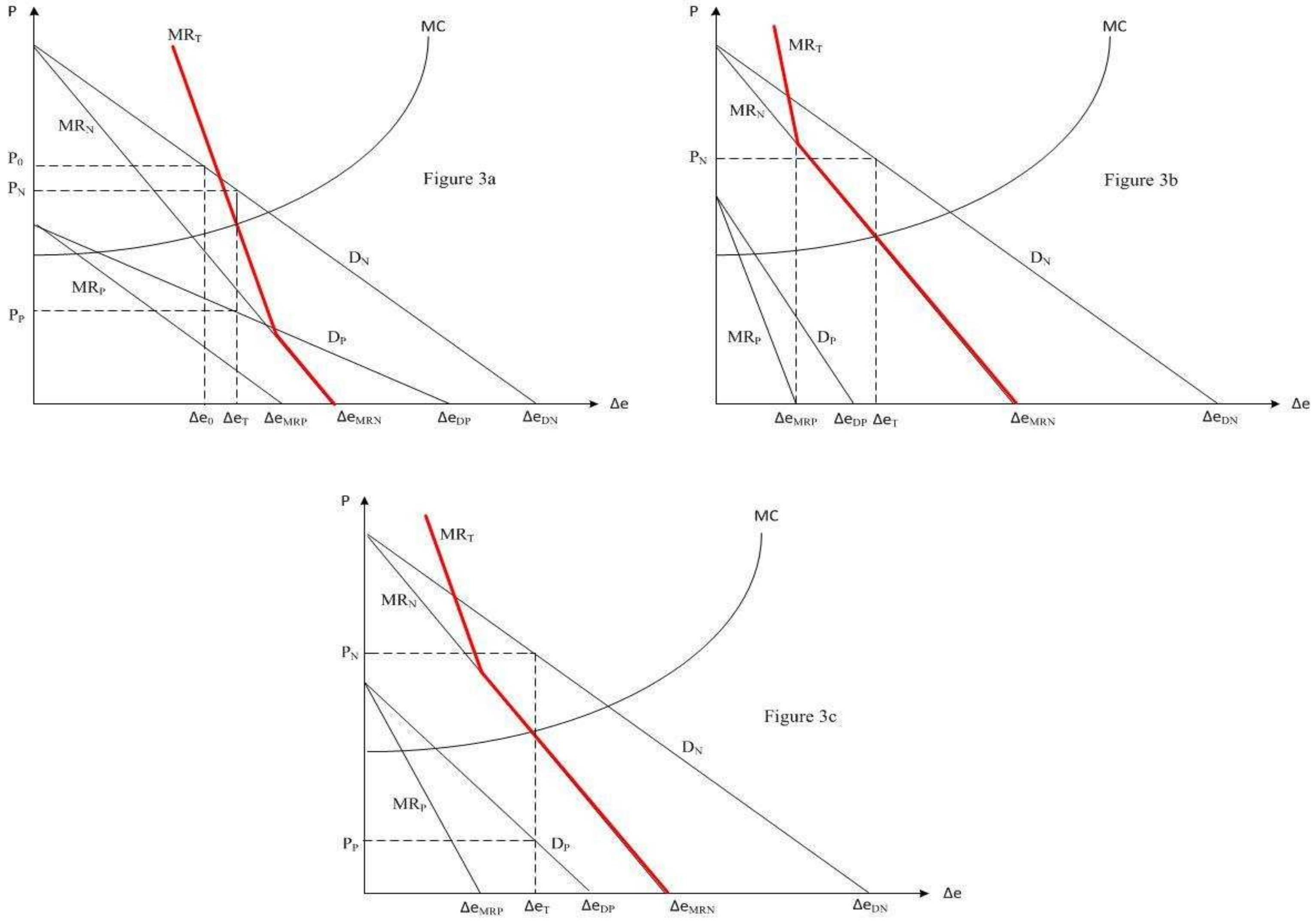

Figure 4.3 a) Stacking scenario that encourages BMP adoption, b) stacking scenario where the additional incentive is insufficient for greater BMP adoption, and c) stacking scenario where farmers receive additional compensation but do not increase BMPs

4.3. RESULTS AND DISCUSSION

The generalized model above can be applied to a case study in the Haw sub-watershed of the Jordan Lake, NC watershed to investigate the functionality of a stacking program. Figure 4-4 shows estimated supply and demand curves for the TN reduction after installing riparian buffers on feasible fields in the watershed. According to the Jordan Lake rules, all sources of nutrient pollution (wastewater treatment plants, and urban and agricultural nonpoint source pollution must reduce their nutrient loads. Developers building new urban areas have two options for nutrient reduction: 1) all nutrient reductions through stormwater BMPs or, 2) reduce a standard amount of nutrients (less than required) and then obtain the additional nutrients by participating in the WQT program and buying nutrient credits. If the marginal cost of participating in trading is less than the marginal cost of oversizing stormwater BMPs, developers can meet their pollution requirements at a lower cost with the WQT program. Therefore an urban developer can minimize his/her mitigation cost by either larger stormwater BMPs or participating in the WQT program. A complete description about how supply and demand are calculated is beyond the scope here but can be found in.

To estimate demand, I minimized the urban developer cost of reducing the TN loads, allowing them to choose between upgrading their current plants to control loads or to buy credits to meet reduction standards. I estimated the cost of oversizing (upgrading) conservation measures in urban developments based upon the actual costs to upgrade a 43 acre urban development with mixed residential and commercial use in the watershed. The credit demand function is the outcome of a line which connects two points. These points are where the credit buyer is indifferent between buying credits or upgrading his/her current technology and where he/she allocates all of his/her budget to purchase credits to meet the TN load reduction target in

Jordan Lake. There is no demand when upgrading the plant costs less than buying credits. Based on detailed calculations in chapter 2, TN credit demand is a linear function: $P_N = 4{,}319), TNe_N$ - where P_N is price of TN load reduction credits. Therefore, MR_N will be a linear function of TN load reduction: $MR_N = 4{,}319 + 2\ a\ lineae_N$.

To estimate the supply curve, TN credits were estimated for each agricultural field based on data for 593 planning land units (PLUs) for which BMP data were available in the Haw sub-watershed; there were 3,752 feasible fields[5] in the Haw sub-watershed. Edge of field pollution was simulated for each of the 593 fields in the PLU before and after installation of riparian buffers using the Soil and Water Assessment Tool (SWAT, 2012). Delivery ratios were applied based on SPAtially Referenced Regressions on Watershed (SPARROW) coefficients (Smith et al. 1997) to estimate delivery to Jordan Lake. USDA environmental quality incentive program (EQIP)'s payment rates for 2014 were then combined with these delivery rates to calculate the MC of BMP adoption for each field (NRCS, 2014). The amount of TN and TP load reduction after installing riparian buffers and cost per pound delivered were identified for every field. The supply curve is built by vertically summing load reduction from each field, starting with the lowest cost field first. I assumed MC would equal the price of credits, $P_{N,}$ and regressed the MC of provided TN credit on Δe_N. The result of the regression, as illustrated in Figure 4.4, shows an exponential relationship between price of the credit and the amount of TN reduction: $P_N = 837.8 rexp\ (0.0036 * \Delta e_N)$ with R^2=0.98.

To estimate demand, I assume for simplicity and lack of data that growth in urban development will continue at the same rate as it has in the past. In addition, I assume that the demand from each developer is the same as it was for the 43acre development for which I have

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[5] Feasible fields include fields adjacent to streams of orders 1-5

data. According to the Jordan watershed model report (2014), the imperviousness (representing urban growth) between 1999 and 2010 increased by 33,211 acre in the Haw River watershed, or by 3,019 acre per year. Based on the ratio of size between the PLU and CLU, I estimate demand will be the same as 11, 43 acre developments per year.

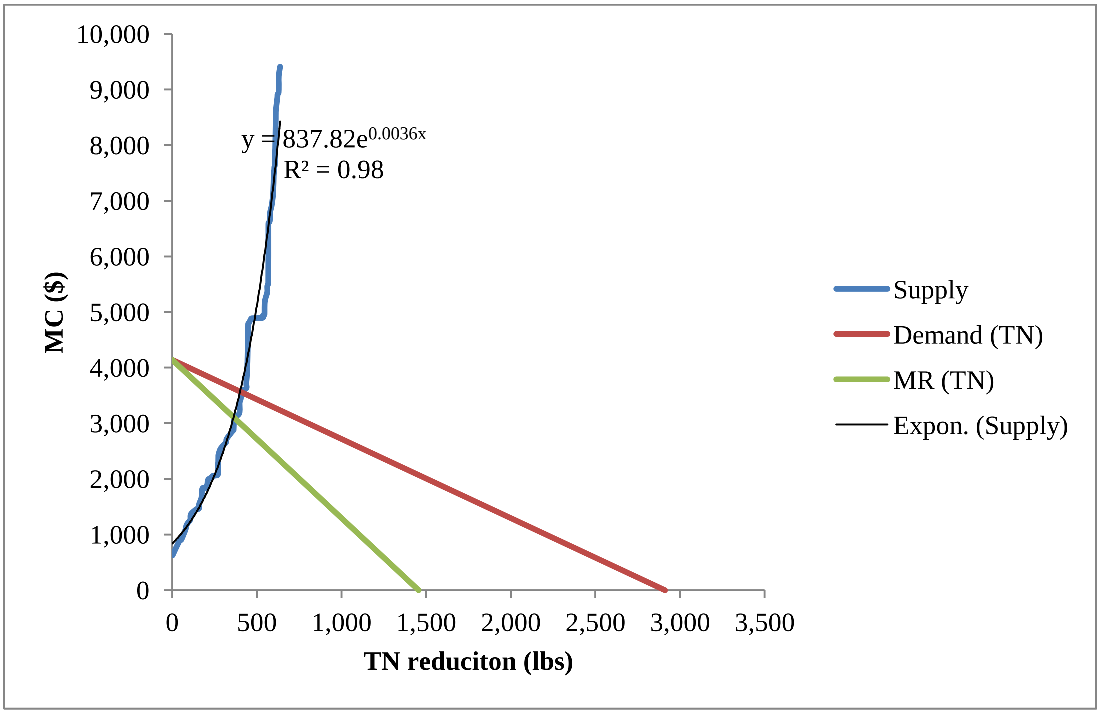

Figure 4.4. Cumulative supply and demand curves for the TN in Haw River sub-watershed, Jordan Lake, NC

The supply and demand curves in Figure 4.4 are estimated for actual conditions and trading rules for TN in the Haw watershed. A hypothetical demand curve was also constructed for TP then manipulated in a structured way by shifting the slope and intercept to determine the circumstances where a stacking program would be effective. The slope of the TP demand curve was initially set equal to the slope of the empirical TN demand, -1.4, where the slope ratio (slopes of TP/TN), γ, is set equal to 1. The intercept ratio, γ', defines how far the secondary demand is below primary demand and would be equal to 1 if both demand curves had the same intercept.

The impact of γ'on the stacking strategy is shown in Table 4.1. For simplicity, β is set equal to 1, where β is a complementarity factor that determines how much TN and TP are reduced in relation to each other through the single riparian buffer BMP. As shown in Table 4.1, if the TP intercept is small compared to TN, stacking is not effective. A payment does not alter the producer’s income or conservation decision. If the γ' is between 0.1 and 0.3, producers would accept a payment but not change the amount of conservation they apply; the reduction of loads remains at 364 lbs and double-dipping occurs. Farmers in the watershed would receive between \$112,995 and \$265,889 more for credits sold, essentially for doing nothing. For any γ' above 0.3, the stacking strategy will work. Farmers would receive from \$265,889 and \$1,754,483 more income from the two payment sources and increase their conservation efforts accordingly. Figure 4.5 visualizes this relationship more clearly. By increasing the relative intercept of TN and TP beyond 0.3, the chance of credit stacking increases as well.

Table 4.1. Role of the relative intercept of TP compared to TN demand (where ɣ′ = the ratio of TP/TN)

ɣ'	**Equilibrium TN reduction (lbs)**	**TR (N credits) ($)**	**TR(P credits) ($)**	**TC ($)**	**Net Return ($)**	**Stacking Efficiency**
0.1	364	1,317,610	----	862,254	455,356	No
0.2	364	1,317,610	112,995	862,254	568,351	Double-dipping
0.3	376	1,355,274	265,889	901,161	720,002	Yes
0.5	421	1,490,615	619,303	1,059,507	1,050,411	Yes
0.7	461	1,607,274	1,034,266	1,225,570	1,415,970	Yes
0.9	498	1,708,643	1,502,520	1,397,820	1,813,343	Yes
1	515	1,754,483	1,754,483	1,485,959	2,023,007	Yes

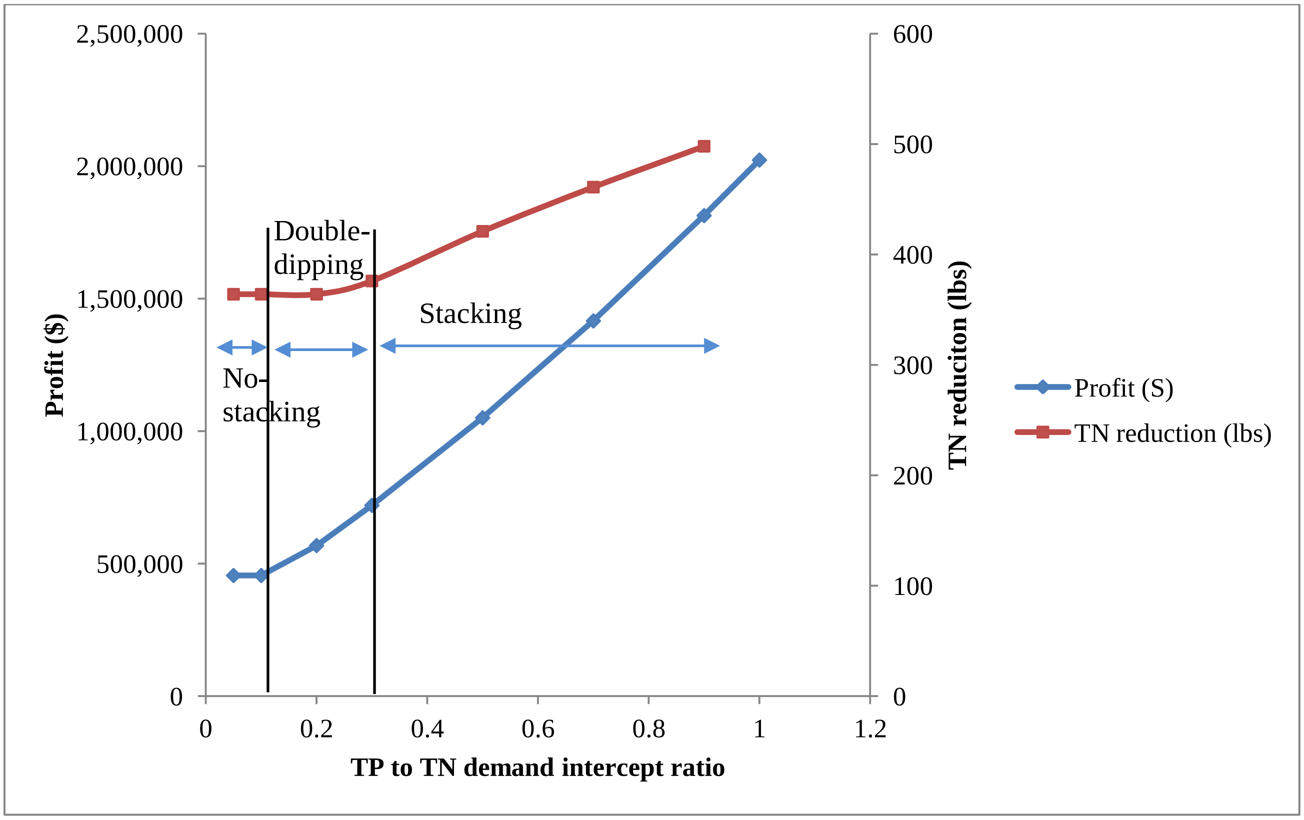

Figure 4.5. Role of relative position of TP to TN demand (ɣ′)

Next I evaluate changing relative slopes. In this case, I start by setting the TP demand intercept equal to the TN's demand intercept ($ɣ'$=1). Stacking was not effective when the slope of TP demand was 8 times steeper than TN demand. Buyers would not be willing to pay for what they already receive for free in this region. Double dipping occurs somewhere in the range where the slope for TP demand is between three and eight times that of the TN demand. Farmers are getting paid more but not adding to their conservation practices. Stacking would be incentive compatible if the relative slope of TP demand is equal to or less than three of the TN demand's.

Figure 4.6 visualizes the role of ɣ on ecosystem service stacking policy in Jordan Lake, NC. This figure shows that when the ɣ decreases, the profitability of the stacking policy increases. For instance, when the TP credit demand is three times steeper than TN credit demand, the willingness to pay for the secondary ecosystem service is not enough to offer any additional incentive for credit sellers to adopt more BMPs.

Table 4.2. Role of TN and TP ratio (ɣ) on the stacking strategy

ɣ	Equilibrium TN reduction (lbs)	TR(N credit) ($)	TR(P credit) ($)	TC($)	Profit($)	Stacking Efficiency
1	515	1,754,483	1,754,483	1,485,959	2,023,007	Yes
2	459	1,600,283	1,300,764	1,214,721	1,686,326	Yes
3	408	1,451,832	978,693	1,010,701	1,419,824	Yes
5	364	1,317,610	564,976	862,254	1,020,332	Double-dipping
8	364	1,317,610	----	862,254	455,356	No
10	364	1,317,610	----	862,254	455,356	No

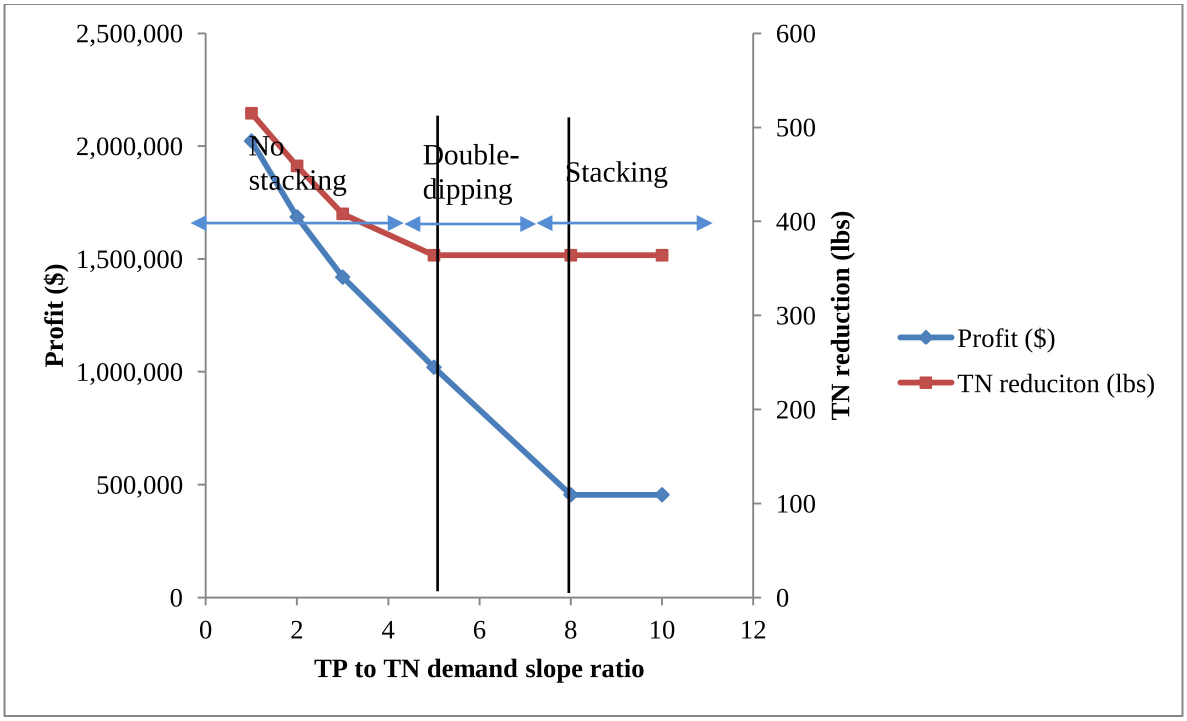

Figure 4.6. Role of relative position of TP to TN demand (ɣ)

4.3.1. VIABILITY OF CREDIT STACKING

While there has been debate about if, when, and where vertical stacking can work, the mathematical model and empirical example demonstrate that the relative demand definitely matters. A high relative demand for a second ecosystem service can provide needed extra incentives to producers to increase their conservation efforts. But buyers of a second ecosystem service are best left to ignore situations where their demand would be relatively low compared to the service with a higher demand because they will gain nothing from offering additional payments. A relative demand that is neither high or low can result in the worst outcome for efficiency by promoting double dipping, where farmers are paid more but do not change their conservation behavior. The examples examined here are based on an assumption that the conservation measure provides a one-to-one reduction in both ecosystem services and that demand curves do not cross. However, this just increases the need to support our major finding that research about relative demand can avoid wasted efforts in ecosystem stacking programs by finding those situations where it can work.

Finally, this example is relatively simple compared to actual settings. Other issues will arise. For example, measuring the relative position of ecosystem service demands relies on the accuracy of the hydrological modeling. According to our analysis, small changes in intercept and slope can change the value of a stacking program. Monitoring ecosystem services functions is another challenge because it is time consuming and expensive. Also, some ecosystem functions might be negatively correlated to those being corrected, which creates leakage (Narloch et al. 2011; United Nations, 2014). For example, installing riparian buffers in one location might improve bird habitat, but these birds might attack and eat a neighbor’s crops. Credit stacking might motivate farmers to allocate a bigger portion of their lands to conservation practices and decrease the supply of crops, increasing prices and decreasing their availability for consumers. Finally, there may be regulatory requirements for one or more of the ecosystems being considered, which does not allow for them to be considered independently over their full range. For example, regulations for TN might require levels of conservation that already provide more of a second ecosystem service than its value in its own market.

4.4. CONCLUSIONS

Credit stacking is a complicated and sometimes contradictory concept. It can motivate parties to participate in conservation practices because stacking diversifies the sources of revenues and decreases the risk of cooperating with a program. However, as shown here, ineffectiveness and double dipping are concerns, depending on the relative demand of the two ecosystem services. There are few if any real-world examples to review (Olander, 2011), but I was able to apply a realistic and measurable ecosystem service stacking program to the emerging WQT program in Jordan Lake watershed, NC. Based on this analysis, the slope and intercept ratio between two ecosystem service demand curves play profound roles on ecosystem service stacking strategies. In passive markets, where secondary ecosystem services have relatively low demand compared to the primary service, only primary services would be of interest to buyers, as the secondary service will be provided in excess of its value with no action required. Services with intermediate relative demand need to avoid double dipping. However, a relatively high demand can increase conservation and enhance farmer welfare as well. The contribution of this work is to show that researching relative demand can avoid wasted efforts and money by identifying if the situation under consideration is suitable for stacking.

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CHAPTER 5. CONCLUSION

Water quality trading (WQT) programs have the potential to be a cost-effective way of reducing pollution, but they may not be the most socially palatable or economically feasible approach. The success of WQT programs depends on many factors, which may not be initially considered during the program implementation. In this study, I identified some major contributors to the lack of WQT programs' success in general, and more specifically to a case study in the Jordan Lake watershed, North Carolina: (1) farmers are suspicious of regulatory programs, including the WQT program; (2) the high transaction cost of the WQT program may marginalize the market; (3) a high WQT baseline can truncate the supply and demand at a point that causes an infeasible WQT program; and (4) uncertainty has the potential to overwhelm the benefits of WQT program.

This research raises a number of questions with respect to WQT programs. The central question is: what BMP is "right" or "wrong" for nutrient load reduction? This question is challenging. I identified several issues that must be overcome to find success. One of these issues is the practice chosen for conservation, or best management practice (BMP). Farmers in the Jordan Lake watershed must install buffer zones to reduce TN and TP loads as a prerequisite for their participation in the WQT program. Selecting an appropriate BMP is an intricate process depending on the field soil type, slope, location, etc. installing buffer zones might reduce pollutant loads in some fields and not others. The limitation in Jordan Lake of allowing only one BMP, buffer zones, excludes some fields where nutrient loads could be reduced by an alternative BMP other than a buffer zone. Selecting the best BMP for each field may require comprehensive research, which would not be a cost effective approach; therefore, generalizing the requirement of buffer zones to all fields may be reasonable.

Another issue is the trading ratio? Almost all WQT programs currently utilize a fixed trading ratio. Assigning a fixed trading ratio for the entire Jordan Lake region is a cost saving solution. Alternately, it might not be the best plan because it can over- or underestimate the cost of credits for credit buyers. For instance, when the assigned trading ratio for a field is two and the actual trading ratio is one, buying credits from this particular field by following the assigned trading ratio will cost the credit buyer twice as much as it should actually cost.

Location is another concern. Programs put where there are few farms, for example, will not be able to generate a viable program. There is simply not enough supply. The Jordan Lake watershed might not be an appropriate place for implementing a WQT program, because it has relatively large urban growth and a relatively small farmland base. I calculate that agricultural supply of credits in the Haw River basin, which is a subset of the Jordan Lake watershed, is just under 7,000 pounds, but that demand will be approximately 5,000 pounds every year. In addition, only a fraction of these farm credits are at prices that urban developers can afford.

What is “fair” or “not”? Whom should be paid for nutrient load reductions? In the Jordan Lake watershed, some farmers are good land stewards who already contribute their time and financial resources to reducing their pollutants loads. Based on Jordan Lake’s WQT program policies, these farmers would not receive any source of credits until they install riparian buffers. That is, the benchmark of trading for both good stewards and other farmers is the same regardless of the history of fields in terms of other types of conservation practices.

As described in Chapter 3, installing buffer strips is a significant and long-term decision and paying the farmers a little money for BMP installment will not likely influence farmers’ opinions about participation in the WQT program. Taking profitable cropland out of production for the benefit of society (e.g., water quality or wildlife habitat improvement) sounds appealing in theory, but in reality, it might not be feasible for the majority of farmers. If society desires benefits of BMPs such as buffer strips, society should bear the actual cost of BMPs, which will be higher than what society expects.

With regard to Chapter 4, there is potential to apply a stacking policy in the Jordan Lake watershed if WQT programs and other ecosystem services markets are designed well. Lack of accuracy in designing these markets can lead an incentive policy for farmers to an inefficient one for urban developers. Investing in much research in the WQT program and its linkage with ecosystem services policies is highly recommended.

Overall, while the WQT program in Jordan Lake watershed, NC, shows some potential, it does not appear to be applicable soon. 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.

APPENDIX I: JORDAN LAKE TMDL SUMMARY

Jordan Lake Nitrogen TMDL Summary

Lake Arm	**Existing Point Source TN[1] (lb/yr)**	**Existing Nonpoint Source TN[1,2] (lb/yr)**	**Reduction (percent)**	**Point Source TN Target (lb/yr)**	**Nonpoint Source TN Target[2] (lb/yr)**	**Point Source TN Reduction (lb/yr)**	**Nonpoint Source TN Reduciton[2] (lb/yr)**
Upper New Hope	517,048	469,139	35	336,081	304,940	180,967	164,198
Lower New Hope	8,138	213,791	0	8,138	213,791	0	0
Haw River	972,964	1,817,253	8	895,127	1,671,873	77,837	145,380

[1] Based on 1997 to 2001 loads
[2] Nonpoint source loads include agriculture, urban stormwater, and runoff from other land
All loads are delivered loads to lake

Jordan Lake Phosphorus TMDL Summary

Lake Arm	**Existing Point Source TN[1] (lb/yr)**	**Existing Nonpoint Source TN[1,2] (lb/yr)**	**Reduction (percent)**	**Point Source TP Target (lb/yr)**	**Nonpoint Source TP Target[2] (lb/yr)**	**Point Source TP Reduction (lb/yr)**	**Nonpoint Source TP Reduciton[2] (lb/yr)**
Upper New Hope	24,324	62,921	5	23,108	59,775	1,216	3,146
Lower New Hope	566	26,008	0	566	26,008	0	0
Haw River	111,580	266,989	5	106,001	253,640	5,579	13,349

[1] Based on 1997 to 2001 loads

[2] Nonpoint source loads include agriculture, urban stormwater, and runoff from other land

All loads are delivered loads to lake

APPENDIX II: SPARROW (SPAtially Referenced Regressions On Watershed attributes)

SPARROW (SPAtially Referenced Regressions On Watershed attributes) is a watershed modeling technique for relating water quality measurements made at a network of monitoring stations to attributes of the watersheds such as contaminant sources and environmental factors that affect rates of delivery to streams and in-stream processing. The core of the model consists of a nonlinear regression equation describing the non-conservative transport of contaminants from point and non-point sources on land to rivers and through the stream and river network.

USGS scientists developed SPARROW (Smith et al. 1997) to (a) utilize monitoring data and watershed information to better explain the factors that affect water quality, (b) examine the statistical significance of contaminant sources, environmental factors, and transport processes in explaining predicted contaminant loads, and (c) provide a statistical basis for estimating stream loads in unmonitored locations.

The model estimates contaminant concentrations, fluxes (or “mass,” which is the product of concentration and streamflow), and yields in streams (mass of nutrients entering a stream per acre of land), and evaluates the contributions of selected contaminant sources and watershed properties that control transport throughout large river networks. It empirically estimates the origin and fate of contaminants in streams and receiving bodies, and quantifies uncertainties in these estimates based on coefficient error and unexplained variability in the observed data.