An Experimental Approach to Resolving Uncertainty in Water Quality Trading Programs

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Introduction and Context

Nutrient pollution in U.S. waterways remains a problem of great concern in spite of great efforts made from point sources (PS) such as wastewater and industry since the enactment of the Clean Water Act in 1972 (Ribaudo and Horan 1999). Historically, pollution from non-point sources (NPS) such as agriculture or urban stormwater has been difficult to trace leading to difficulty in regulations; yet nonpoint sources generate the majority of nutrient pollution, largely from agricultural sources (Selman, et al. 2009). The uncertainty associated with non-point contributions to pollution has led to a situation of open access where unregulated sectors largely ignore calls for voluntary reduction in nutrient run-off seeking private gains rather than contributing to a clean/safe water supply.

In an attempt to engage NPS in reduction of nutrient flows to rivers, streams and lakes, market-based instruments encourage valuation of nature so as to provide a unit of exchange between various actors within an enviro-economic setting (Pirard and Lapeyre 2014). These market based instruments can take many forms including direct markets, tradable permits, reverse auctions, Coase arrangements, regulatory price changes (taxes and subsidies) or voluntary price signals[1]. While most of these have gotten a great deal of attention in the environmental economics literature, tradable permits are the most common market based instrument to engage non-point sources in water quality improvement as they allow for flexible pollution control between various sources within an impaired watershed (Selman, et al. 2009). Under a larger framework of cap and trade, water quality trading (WQT) is often the most politically feasible pollution control option due to its low cost in comparison to other policy designs; yet implementation in a real-world setting has been limited due to many issues identified in the literature.

[1] This generally refers to a premium that one can obtain on a market good for having an environmental characteristic.

Recently, in an attempt to mitigate nutrient pollution in the state's waterways, the Colorado Department of Public Health and Environment implemented Regulation #85. This regulation places nutrient effluent limits on point sources of pollution (wastewater treatment plants-WWTPs) with voluntary management of agricultural run-off that will lead to regulation by May 31, 2022 if "sufficient progress has not been demonstrated in agricultural nonpoint source nutrient management" (5 CCR 1002-85, Regulation #85, Adopted June 11, 2012). This regulation allows for nutrient trading between point and non-point sources. While farmers in Colorado are aware of the trading provision in the policy, uncertainty surrounding pollution flows from agriculture as well as the uncertainty regarding the probability of regulation remain as significant barriers for agriculture to become involved in pollution control in a market or via other voluntary mechanisms. Indeed, the situation in Colorado is not unique; because the largest problem in having an economically viable trading program is adequate supply and demand (King and Kuch 2003, Ribaudo and Gottlieb 2011), precise information regarding regulations and environmental quality outcomes could help bridge the gap currently observed between desired abatement from farmers and actual abatement taking place either voluntarily or through trading markets.

This study uses experimental techniques to evaluate how farmers in a water quality trading (WQT) market behave when they are able to resolve two issues of uncertainty: uncertainty regarding the benefits of WQT participation and uncertainty over future regulation. Experiments were conducted in the summer of 2016 with participants assigned the role of "farmer" (seller) or "wastewater treatment plant manager" (buyer) in a WQT market. In the base treatment, all farm credit generation requires two units of clean-up for one pollution credit and asks for additional voluntary practice implementation by farmers. In a second treatment, farmers have an opportunity to verify their true trading ratio. Preliminary results suggest that farmers will invest in ratio verification and market outcomes typically improve. A third treatment asks farmers to implement practices voluntarily to reach a threshold to avoid regulation. Results indicate that farmers are unlikely to meet voluntary thresholds to avoid regulation; moreover, market outcomes are worse as voluntarily abatement comes at an opportunity cost in the trading market. These results suggest an opportunity for regulators to increase participation and improve social outcomes by resolving uncertainty in WQT markets.

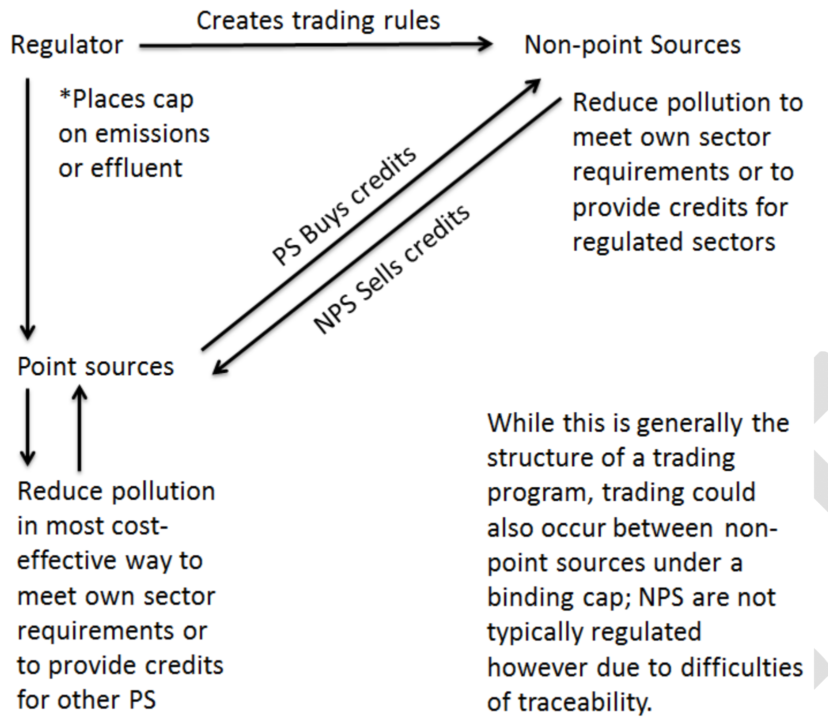
Literature Review

Water Quality Trading Literature

The EPA has supported water quality trading beginning with legislation in 1996 called the Framework for Watershed-Based Trading; that framework was updated in 2003 to provide greater guidance on how to implement a successful trading program (IEc 2008). The political impetus for this policy is that it is much more popular among the regulated sectors because it allows for flexibility in lieu of imposing fixed standards or taxes that inevitably have distributional impacts (King and Kuch 2003). Moreover, as a cap-and-trade framework, it is touted as a policy instrument that minimizes costs (Goulder 2013).

Under a cap-and-trade framework, a regulatory structure defines a maximum level of impairment or a minimum level of reduction that needs to be met in order to meet social goals. Various sources must meet this cap either through new technology adoption or by purchasing credits from a different source who reduces pollution to the level required to meet the cap. These credits can come from other PS who may be able to reduce effluent concentrations more cheaply or from NPS that implement practices approved by the regulator to reduce pollution loading to water sources. Figure 1 provides a schematic of this process. Under this framework, we know that cost-minimization is achieved because the point-source would not pay for credits to reduce pollution unless the price of the credit is less than it would cost the point source to reduce pollution.

Figure 1: Visual Representation of the Process of Water Quality Trading



This diagram was made by the author but implements information provided by (Ribaudo, Horan and Smith 1999, King and Kuch 2003 and others).

According to a 2008 EPA report, "the primary potential benefit of WQT that attracts consideration by policy makers is the potential ability to control pollutants at an overall lower cost to society" (IEc 2008, 1). Goulder (2013) contends that largely within the umbrella of the cap and trade framework, there has been gains in economic efficiency under this policy compared to a standard (command and control). Within WQT, however, the economic efficiency gains seem to be dampened by uncertainty and transaction costs (Nguyen, et al. 2013). Using an agent-based simulation model, Nguyen, et al. (2013) find that there are the most efficiency gains when there is a clearinghouse rather than bilateral negotiations. Similarly, Woodword, Kaiser and Wicks (2002) argue that the appropriate market structure matters greatly in terms of the meeting water quality goals and having successful trading programs. Four market structures are identified: exchanges, bilateral negotiations, clearinghouses and sole-source offsets. The choice of the structure must be related to the nature of the pollutant, the goals of the program, the level of uncertainty, the monitoring and enforcement requirements, and the regulatory environment (Woodward, Kaiser and Wicks 2002).

The reality of WQT differs greatly from theory. Various case studies have identified where there has been success in WQT and factors that inhibit successful program development.

Hoag and Hughes-Popp (1997) observe non-existent trades and summarize 6 factors influencing the success of WQT: low transaction costs, non-thin markets, heterogeneous abatement costs, low enforcement costs, certainty in trading ratios, and binding regulations (a cap). By 2003, King and Kuch still find little evidence for WQT trading due to significant market structure issues such as thin markets and unbinding regulations and institutional barriers which are relatively easier to overcome. By 2009, the picture is somewhat less grim with identification of 26 active trading programs (Selman, et al. 2009). They identify the same rationale for failure as previous studies with the additional insight that point sources (WWTPs primarily) are typically risk averse such that they would prefer to install costly upgrades that they can control rather than expose themselves to risk by making trades with other parties (either other PS or NPS).

The trading ratio, or the rate at which NPS control is converted into PS pollution control, interacts with market performance in various ways (Malik, Letson and Crutchfield 1993). Higher ratios lead to higher costs of pollution control whereas lower ratios lead to potentially lower environmental outcomes (Hoag and Hughes-Popp 1997, King and Kuch 2003). Moreover, ratios are often arbitrary and not based on scientific models leading to uncertainty over the future trading ratios (Malik, Letson and Crutchfield 1993). Resolution of uncertainty, say through a multi-attribute credit market that allows exact environmental outcomes to be known to both PS and NPS, leads to more environmentally and economically efficient outcomes (Ghosh and Shortle, Water Quality Trading when Nonpoint Pollution Loads are Stochastic 2009).

Additionally, issues of trust and uncertainty impact participation from farmers in particular. Regulatory uncertainty is rampant wherein farmers often have to meet a “baseline” amount of pollution before they can participate in trading. It is often uncertain what is required *individually* in order to meet this baseline threshold and serves to greatly increase the costs associated with abatement as NPS implement the cheapest options to meet the baseline (Ghosh, Ribaudo and Shortle 2009). This serves as a disincentive for farmers to engage in pollution control until they are actually regulated. This disincentive is exacerbated by a general sense of distrust of the government and other polluters in a watershed wherein farmers hesitate to give more information to the government in terms of pollution control potential or to other polluters lest this information be used against them (Breetz, et al. 2005).

Perhaps the rationale for the dismal view of water quality trading is due to a lack of indicators for success. Breetz et al. defines success as “the program’s ability to bring farmers to the table and implement BMPs for the purposes of trading" (Breetz, et al. 2005). Under these criteria, 10 out of 14 projects analyzed in their study were considered successful. Predictors of success followed closely what has been outlined above as inhibitors! When uncertainty is eliminated and trust is formed, farmers are able to participate in a program in at least some capacity. Selman, et al. (2009) define success as stakeholder satisfaction, trading activity, and meeting environmental goals (Selman, et al. 2009, 2) although the authors fail to identify how many of the active trading programs they would consider as successful. Regardless, WQT continues to lag compared to what theory would suggest in terms of quantity of actual trades.

Experimental Literature

While markets for pollution have been prevalent both for air quality and water quality, much of the *ex post* analyses identify numerous factors that impact the success of a particular program. In order to better identify how specific factors impact the behavior of participants and thus the market and environmental outcomes of these policy regimes, a laboratory setting can be helpful as much of the exogenous factors that have subtle influences in real-world settings can be controlled. Participants have the opportunity to participate in a market setting making money based on their relative performance while researchers can isolate characteristics that are theorized to influence human behavior as well as to test different market structures before implementing them. Generally, economic experiments have proven helpful to explore gains from trade in emissions markets as well as the impact of market design on performance (Muller and Mestelman 1998).

There have been several economic experiments conducted that relate to the design of water quality trading programs. Jones and Vossler (2014) explore how variation in upfront investment costs impacts the generation of credits. They find that when firms are required to make a binding abatement choice prior to trading, there is a large decrease in efficiency as firms tend to over-invest in abatement technology (Jones and Vossler 2014). Similarly, Suter et al. (2013) find that over-abatement by point sources occurs when participants have limited abatement potential with existing technology and are risk averse. The "lumpiness" associated with water quality improvement technology for point sources makes trading problematic as an upgrade moves the pollution to a new tier in terms of pollution levels which may exceed regulatory limits (Suter, Spraggon and Poe 2013). Additionally baseline-and-credit programs are found to be less efficient than cap-and-trade designs as well as tax/subsidy schemes when upfront investments are required (Jones and Vossler 2014). Generally, an ambient tax/subsidy is found to be the most economically efficient design, particularly when participants can cooperate (Poe, et al. 2004).

Policy design related to meeting environmental goals have also been studied with experiments. Banking of permits has opposing impacts serving to smooth out price variability but increasing problems of non-compliance and worse environmental outcomes (Cason and Gangadharan 2006). Another experiment found no evidence that enforcement may be more effective based on firm-specific characteristics (Murphy and Stranlund 2007). Furthermore, compliance has countervailing impacts. On the one hand, increased enforcement results in fewer violations and motivates firms to increase the number of permits purchased which increases the price; higher permit prices then motivate firms towards greater violations (Murphy and Stranlund 2006).

Additionally, several experiments focus on the provision of public goods—including that of environmental quality. Indeed, the parallels between asking farmers to implement practices voluntarily for pollution control and public good games are undeniable. This body of literature has generally found that public goods are difficult to provide as per the theoretical literature as people put private gain ahead of public gain (Samuelson 1954). More recent experimental literature finds that in a one-shot public good game repeated several times often leads to free-riding as predicted by theory wherein the interior Nash Equilibrium involves participants failing to provide the public good collectively (Laury and Holt 2008); nevertheless, there is evidence of a "conditional cooperator" who contributes to the public good either altruistically or because other's contributions encourage them to cooperate and provide the public good (Fischbacher, Gachter and Fehr 2001). Additionally, when participants have an opportunity to punish non-cooperators, provision of the good increases (Kroll, Cherry and Shogren 2007). Similarly, when a group is able to turn a public good into a club good through membership fees, it drastically increases provision (Bchir and Willinger 2013).

Additionally, several experiments have been conducted on threshold, or step-level, public goods wherein coordination takes place over several time periods and culminates in either provision of the public good or a situation of free-riding as in the one-shot public good game. It is often the case that there is uncertainty regarding what the threshold actually is; much of this literature comes to the conclusion that, like in one-shot public goods games, provision depends on conditional cooperation. However, some authors find that thresholds with lower expected mean levels experience greater provision than those with a higher mean (Suleiman, Budescu and Rapoport 2001). Uncertainty regarding the consequences of meeting the threshold has also been studied noting that the less uncertainty there are as to the consequences of not meeting the threshold, the more likely it is that a public good will be provided (Barrett and Dannenberg 2013).

Identification of Research Questions

This study complements the extensive body of literature just discussed in a few ways. First of all, often experiments lack context in order to control for the impact that this context might have on behavior. For example, when a user is "producing" a good for income versus engaging in "pollution control," one might expect that a participant's behavior may be influenced differently given these different contexts. The experiment described in this paper includes a great deal of context (explained in the experimental design section and appendix below) in order to determine if people do react differently in their market behavior based given this added context. If the preferred mechanism for pollution control is market based instruments, it is important to know if people behave differently regarding pollution than they would in any other market.

Secondly, while a few experiments have looked at the trading ratio, these experiments have largely focused on the stochastic nature of pollution control and devising a permit that reflects this stochastic pollution scenario from NPS. In reality, the data needs required to devise a permit reflecting the stochastic pollution loads would likely be untenable at best and prohibitively costly to implement over multiple time periods. However, the trading ratio treatment described here involving one investment at one point in time that determines the trading ratio over several rounds, is highly implementable in the real-world and provides a starting point for analyzing whether or not NPS are willing to invest in resolving this source of uncertainty in order to improve their place in the market, even given a known down-side risk. Behavior in this treatment will serve to highlight potential impacts on the trading market when NPS have an opportunity to invest in uncertainty reducing technology.

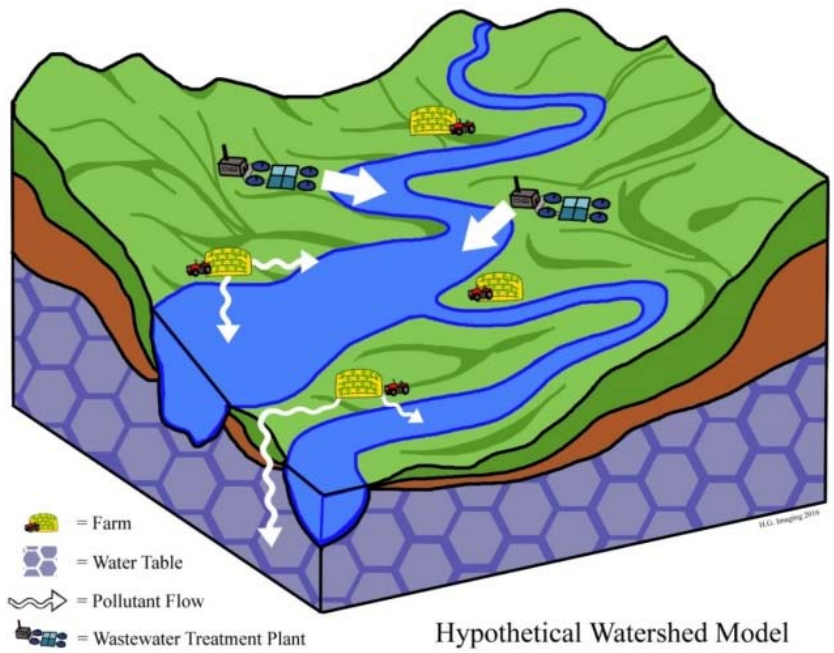
Finally, while the threshold treatment has components mirroring what has been done previously, there are a few points of novelty in this treatment. Continual voluntary pollution control by NPS in all treatments mirrors one shot public goods and has corresponding behavioral expectations. However, the implementation of the threshold public good in the threshold treatment differs from previous experiments not only in that it is based in context but also because this treatment specifically tests whether threat of a regulation is sufficient to involve NPS in pollution control when there is a known opportunity cost of their pollution control in the market. Like in the trading ratio treatment, this has a great deal of applicability in the real world as introduction of carbon markets and other pollution markets often is implemented in addition to "commitments" to reduce pollution. The combined impacts of these two mechanisms in place at the same time on behavior has important policy implications.

Experimental Design and Procedures

This experiment features a typical baseline and credit market design as the base treatment and two variations on this: a trading ratio treatment and a threshold treatment. In all treatments, participants, in a 6-person group, are first privately informed of their role: 4 are identified as farmers and 2 are identified as wastewater treatment plants (WWTPs). 33 rounds, called years, are played in total with the first 3 years as strictly practice years (non-binding) and 3 games of 10 years each played subsequently. One of the games is chosen at random at the end of the experimental session to be "binding" so as to elicit optimal behavior in all games. Expected earnings are an average of $20 based on game performance (at a 100:1 exchange rate) and each subject is also given a $5 show-up fee. In the 2-hour session, 30-45 minutes are dedicated to instructions and practice and the remainder of the time is spent in the experiment. Talking or sharing of roles or information is strictly prohibited among participants.

To add context to the experiment, participants are informed that they are all neighbors within a watershed with a goal of achieving a certain amount of pollution control (see figure 2). An example of instructions for the WWTPs participants is included as an appendix. WWTPs had the same requirement in all treatments: to reduce pollution in each time period from 8 units to 4 units either through buying credits in the market or by automatically implementing the deficient number of practices at the WWTP after the trading round. Farmers have the opportunity to clean-up as many as 4 units of pollution each; the default trading ratio for all farmers is 2:1 such that two units of clean-up is required to generate one credit to the WWTP. Farmers are the sellers of credits and WWTPs are the buyers of credits and no trading is allowed between participants in the same sector. This bilateral experimental design was chosen because under homogenous cost schedules within each sector, no inter-sectoral trading was expected and allowing trading within one's own sector might serve to unnecessarily complicate the decision making environment.

Figure 2: Fictitious Watershed Illustrating the Relationship between Sources and Pollution Contribution



The experiments were designed using the experimental software, z-tree, developed by Fischbacher (1999). In the base experiment, each year consists of the following screens:

- Information about regulation: farmers are informed that there is no regulation for their sector and WWTPs are informed that they must clean up 4 units of pollution that year either through the purchase of credits or through the implementation of practices.
- Each market round is 90 seconds with the exception of the first practice round which took place over several minutes to demonstrate the software. Figure 3 is the market screen from a WWTP perspective.
- After the market round, WWTPs are informed of how many practices that must be implemented in order to meet their regulation and farmers are asked to implement practices voluntarily. Figure 4 is the farmer's voluntary regulation screen. Voluntary practices came at a cost of the next unit of clean-up.
- After resolving the regulation, all participants are informed of round and cumulative earnings.

Figure 3: Market Screen Example for a WWTP

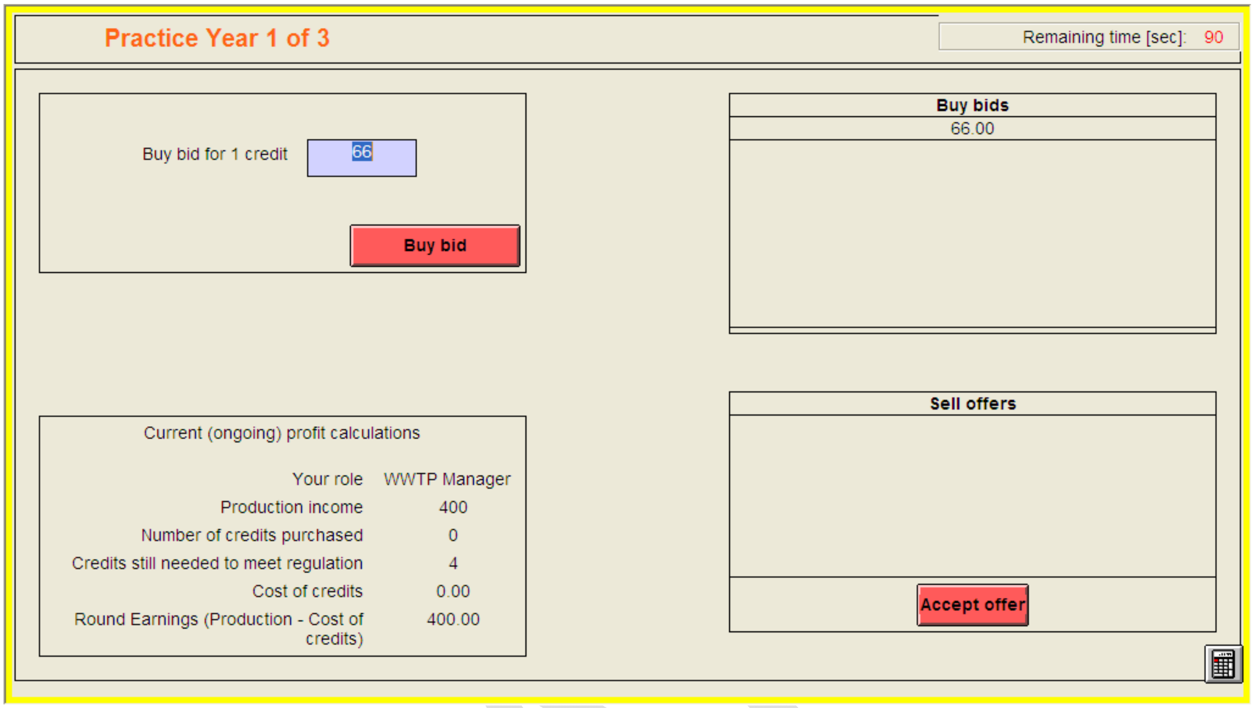
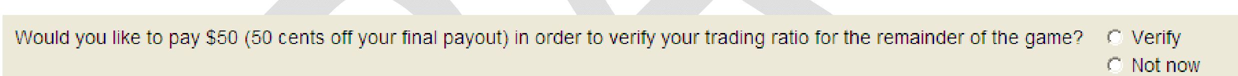


Figure 4: Farmer Voluntary Clean-up Screen

Trading Ratio Treatment

The trading ratio treatment differs from the base treatment only in that farmers have an opportunity to verify their trading ratio. Verification comes at a fixed cost of $50 in game dollars (50 cents) incurred at the end of each game. Participants are also able to verify their trading ratio in the practice game. Once a farmer verifies their trading ratio, the "true" trading ratio remains their binding trading ratio for the remainder of the game. In each group, there are two farmers with a trading ratio of 1:1, one farmer with a 2:1 trading ratio, and the last farmer has a trading ratio of 3:1. As such, there is a 50% chance of getting an improved trading ratio compared to the default (2:1), a 25% chance of staying the same, and a 25% chance of having a worse trading ratio (3:1). Farmers are asked in every year at the beginning of the year if they would like to verify their trading ratio (see figure 5) until such time as their ratio is verified. After verification of their trading ratio, they are reminded at the beginning of each year of their true trading ratio until a new game begins (in years 4, 14, and 24). This trading ratio only applies to the generation of credits such that when farmers are asked if they would like to implement practices voluntarily, they still come at the cost of each practice, regardless of true ratio (environmental impact).

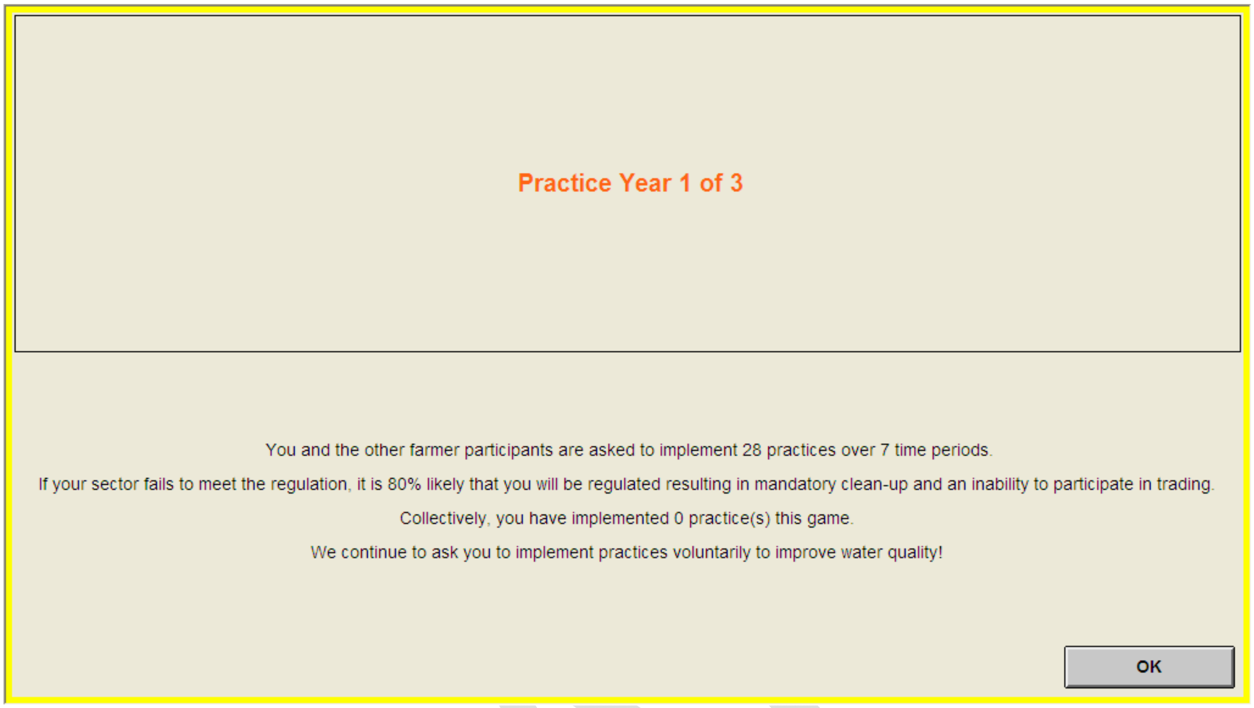
Figure 5: Screenshot of Trading Ratio Verification



Threshold Treatment

The threshold treatment differs from the base treatment in that farmers are asked to implement practices voluntarily to reduce water pollution in the system. If farmers collectively clean-up 28 practices by the end of the 7th year, they successfully avoid regulation. Failure to meet the 28 practice threshold results in an 80% chance of being regulated. Farmers are informed that this threshold would be met if each farmer implemented one practice voluntarily each round towards the threshold. Practices implemented for credits in the market do not count towards this threshold. Farmer are also informed that they will be equally as well off if all farmers contribute and meet the threshold as they would be if they did not contribute to the threshold at all (see appendix for the farmer instructions for this treatment). At the beginning of each round, farmers are informed of how many units of clean-up have been implemented collectively. Figure 6 illustrates the "regulation" screen farmers view at the beginning of each round.

Figure 6: Screenshot of Voluntary Regulation for Farmers



Experimental Parameters and Expectations

Each participant earns money each round from "production" that they can use to buy credits (WWTPs) or implement practices (WWTPs and farmers). WWTPs earn $400/year in production income and farmers earn $200 each year in production income. The marginal abatement cost (MAC) schedule for farmers follows equation 1 and the MAC function for WWTPs follows equation 2 with a as abatement. No costs were incurred if no abatement took place. The cost schedule for farmers is included in table 1 and for WWTPs in table 2. In the trading ratio treatment, farmers had the same cost schedule but they were provided a cost schedule that reflected the cost incurred for credit generation under each possible trading ratio. Table 3 shows this more detailed cost schedule.

$$MAC_{Farm} = a^3 + 10 \text{ with } TC = 0 \text{ if } a = 0 \quad (1)$$

$$MAC_{WWTP} = a^2 + 50 \text{ with } TC = 0 \text{ if } a = 0 \quad (2)$$

Table 1: Farmer Cost Schedule

Practices	Per-Unit Cost of Clean-up	# of Credits	Total Cost of Practices
1	11	--	11
2	18	1	11 + 18 = 29
3	37	--	11 + 18 + 37 = 66
4	74	2	11 + 18 + 37 + 74 = 140

Table 2: WWTP Cost Schedule

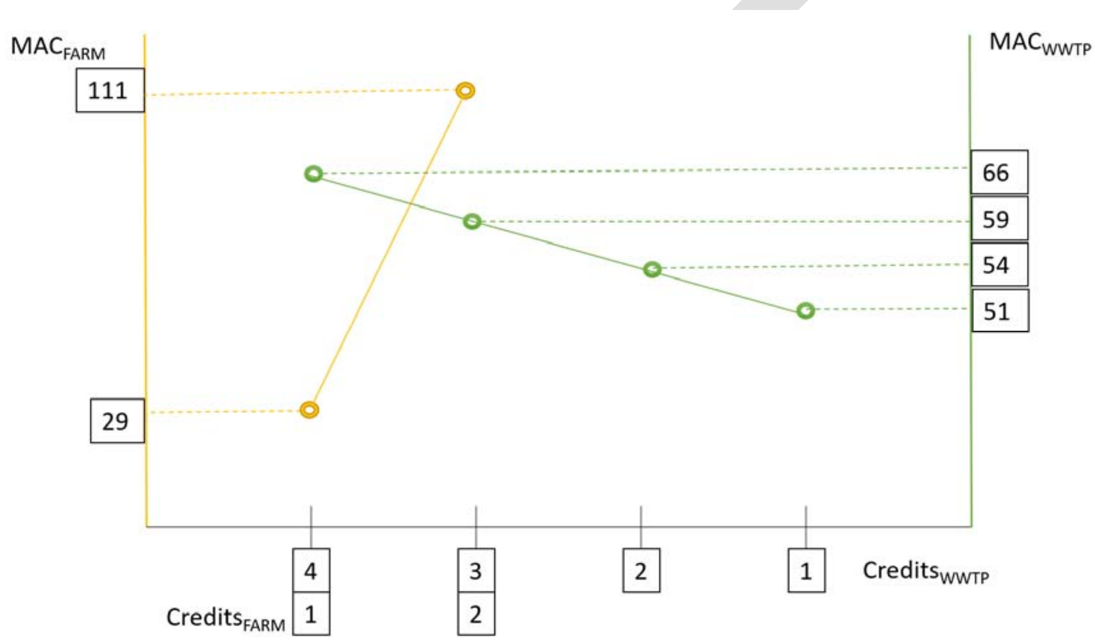
Number of Practices	Per-Unit Cost of Practices	Total Cost of Practices
1	51	51
2	54	51 + 54 = 105
3	59	51 + 54 + 59 = 164
4	66	51 + 54 + 59 + 66 = 230

Table 3: Farmer Cost Schedule under a Trading Ratio Scenario

Practices	Per-Unit Cost of Practices	Total cost of practices	Credit (1:1)	Cost per credit (1:1)	Credit (2:1)	Cost per credit (2:1)	Credit (3:1)	Cost per credit (3:1)
1	11	11	1	11	--	--	--	--
2	18	11+18 = 29	2	18	1	29	--	--
3	37	11+18+37 = 66	3	37	--	--	1	66
4	74	11+18+37+74 = 140	4	74	2	111	--	--

At a 2:1 default trading ratio and with only 4 units of pollution, farmers are constrained to only 2 credits being physically possible each year. From an economic efficiency standpoint, farmers are expected to sell one credit each during every market period. WWTPs are expected to purchase 2 credits each—2 farmers supply one credit each to each WWTP. In the base and threshold treatments, farmers are unable to profitably sell more than 1 credit as the marginal cost for the second credit for a farmer is $111 which far exceeds the maximum willingness to pay of a WWTP ($66). Even if farmers priced at average price, $70 would not be worthwhile for WWTPs as they could implement practices at a lower cost to meet the regulation. As such, market prices are expected to be between $29 and $66. Figure 7 is a graphical illustration of this theoretical outcome based on the parameters chosen. In the trading ratio treatment, it is expected that prices will be lower as the range of acceptable prices falls between $11 (the lowest willingness to accept with a 1:1 trading ratio) and $66 (still the maximum willingness to pay of a WWTP). A farmer with a 3:1 trading ratio is expected to be out of the market. Under reasonable prices, as many as 7 credits could be traded in the trading ratio treatment as farms with a 1:1 trading ratio could likely sell 3 credits each (as many as two farmers could have a 1:1 ratio), the firm with a 2:1 trading ratio would still be able to sell 1 and the 3:1 would be at the top end of the market with a willingness to accept equal to the maximum willingness to pay of the WWTP ($66).

Figure 7: A Comparison of Marginal Abatement Costs



Given the expected trading prices and volume, expected earnings in each year are approximately 200 game dollars ($2) which summed over 10 years would have expected earnings of $20 per participant. If no trading took place, farmers would earn exactly 200 game dollars per year and WWTPs would earn 170 per year. Although WWTPs may implement up to 8 units of pollution control, they are only required to reduce pollution by 4 units and as such, it is not expected that more pollution control than 4 units each would take place from WWTPs. If farmers or WWTPs over-abate, it is still impossible for a participant to go bankrupt in any year given the parameters specified.

Data Collection

In July 2016, experiments were conducted in Fort Collins, Colorado on campus at Colorado State University. Recruitment was largely within the CSU campus and thus the sample included a great deal of well-educated individuals with 74% of respondents having an undergraduate degree or higher. Not surprisingly, given the level of education of the sample, the average age of the participants with 30. Additionally, 77% of the sample was white and 84% answered that they either agreed or strongly agreed with the statement “I am an environmentalist.” While this sample is likely representative of Fort Collins, it is not necessarily representative of all of Colorado and certainly not of the U.S. overall. It would be interesting to compare results of this sample to a more diverse population, particularly that of farmers.

Most of the experimental sessions included two groups at once (12 participants) and participants were told that the person next to them might not necessarily be in their group or have the same role as they were assigned. Two sessions only had one group present (one base and one threshold). Table 4 gives some basic information regarding the data structure and outcomes. One base treatment had very high prices and would be considered a bit of an outlier in terms of expectations. A WWTP was accepting very high offers (above $66) which allowed farmers to sell more than the expected number of credits. As such, prices averaged over all groups for this treatment are in the upper range of expectations referenced in the previous section. As expected, the mean price was lower in the ratio treatment and the volume of trade is not far from expectations. In the threshold treatment, only one group was able to meet the threshold at some point in the experimental session; however, voluntary abatement over the entire experiment in this treatment far exceeded the other two treatments.

Table 4: Data Structure and Summary Outcomes

Treatment	Base	Ratio	Threshold
# of participants	30	24	30
# of groups	5	4	5
Mean price	62	50	56
Average quantity	5	6	4
Average profit	199	219	189
Voluntary abatement	40	43	179

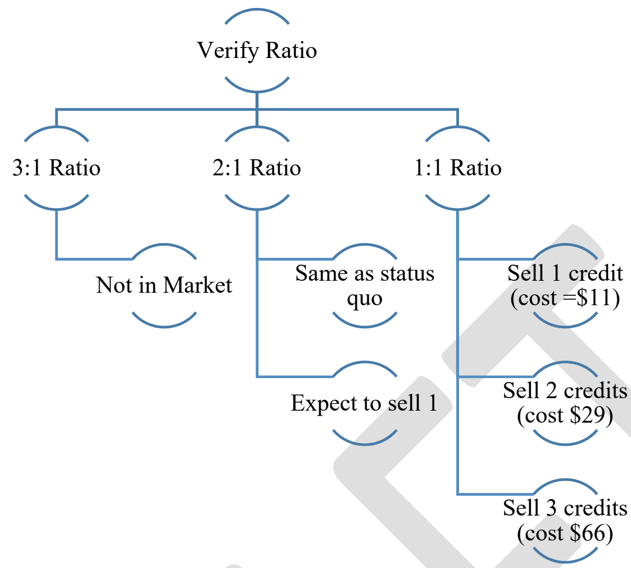
Results

The following results section is broken down by each of the four main research questions. The first conclusion is that allowing people to resolve situational uncertainty is something that people would participate in, even if there is a downside risk associated with discovery based on the fact that participants verified their ratio 94% of the time. Secondly, threat of regulation seems to be small motivation for most of the participants of the experiment as only one group out of five is able to meet the threshold. However, a third point is that there is a non-zero level of abatement occurring in all treatments which may be indicative that context does matter and people are willing to contribute to pollution control if they are informed that they are the cause and the solution to the problem. Finally, more precise trading ratios and voluntary regulations do impact market activity. When firms are allowed to trade more credits, they do just that. Similarly, when firms have a goal in mind, they do contribute to pollution control but once regulated, WWTPs are unable to benefit from a market with NPS.

Are People Willing to Invest in Resolving Abatement Uncertainty?

In the trading ratio treatment, farmers had an opportunity to verify their "true" trading ratio at any point throughout the game. If a farmer decides against verifying their ratio, their trading ratio remains at the default 2:1 ratio for the entirety of the game. Once verified, the revealed trading ratio is the new rate at which farmers can exchange clean-up for credits for the remainder of the game. The true trading ratio associated with each farmer is randomly re-assigned each round with at least 2 farmers always having a true 1:1 trading ratio, one with a 2:1 trading ratio and one with a 3:1 trading ratio. Figure 7 illustrates the expected impact on market activity based on trading ratio. Although farmers are not explicitly informed that they will be out of the market with a 3:1 trading ratio, it quickly becomes apparent when they attempt to sell credits in the market for a profit. Clearly having a 1:1 trading ratio is ideal as farmers can sell more credits (as many as 3 profitably).

Figure 7: Impact of Verification on Market Potential



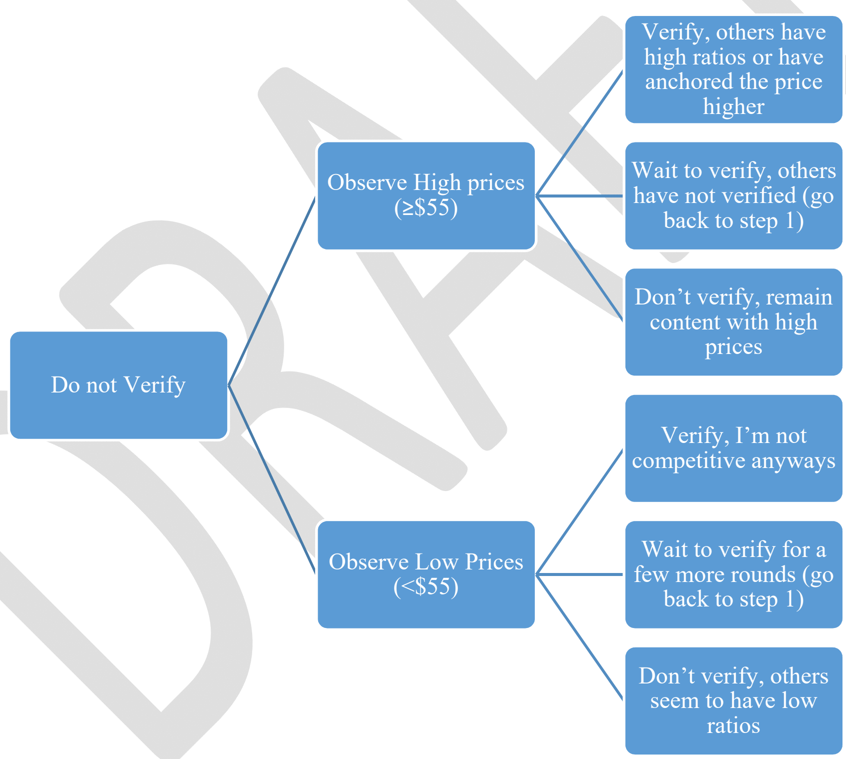
The following is an analysis of the strategic behavior of the farmer participants in this treatment. Roughly half of the farmer participants in this treatment verified their trading ratio immediately (in the first round of each game). The rationale for this behavior could be that they can immediately start benefiting from an improved (or unchanged) trading ratio and thus earn back the 50 cent investment over 10 full rounds. It could also have also been the case that participants wanted to resolve the uncertainty as quickly as possible to "get it over with." In any event, resolving this uncertainty was the slightly dominant strategy among farmer participants.

There were only 3 games wherein a participant never revealed their trading ratio (out of 48 possible). Two of the 3 instances just mentioned were the same person. Figure 8 is a map of the strategic behavior observed in the game. From an economic perspective, there are a few reasons a subject may wait at least one round before following in ratio verification. A follower[2] has an opportunity to observe the price signals from the market. No matter the price signal, all followers have the opportunity at the beginning of every year to verify their ratio. Price signals can be quite valuable information to a participant. For example, if a follower observes high prices then it might be the case that others have already verified their trading ratios and have the higher trading ratios therefore it is more likely that the follower has a potential to improve their

[2] In this case, a follower is a term used to describe a participant who waits to make a move until information is revealed.

market position. The dominant strategy (the one most taken) was to verify their ratio at the next round. If a follower observes low prices, then it may be the case that leaders[3] have revealed the improved ratios already and thus the probability of an improvement in market position is less likely. Thus, under low prices, it was the dominant strategy for followers to continue to wait, benefiting from the default 2:1 trading ratio. Even in the case of low prices, most participants eventually do verify their trading ratio. From an economic perspective, it does not cohere for participants to make this decision as expected values from verification are lower than the cost; from a psychological perspective it may be unbearable to stay in a position of uncertainty when there is an option to remove that uncertainty.

Figure 8: Strategic Behavior Regarding Following in Verification



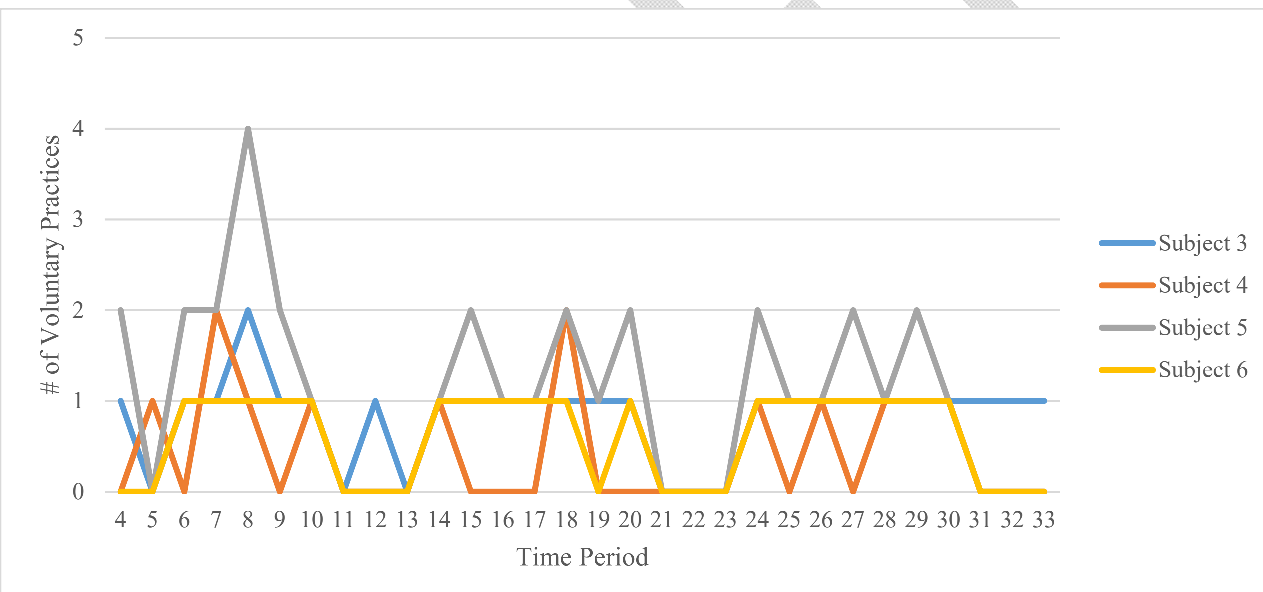
Is Avoiding Regulation a Good Motivator for Voluntary Pollution Control?

The threshold treatment asks farmers to reduce pollution as a group in order to avoid regulation. If participants are able to implement 28 voluntary practices by the end of the 7th round, they avoid regulation, otherwise they would have an 80% chance of becoming regulated. The threshold was only met in 2 out of 45 total games in this treatment. The threshold was met by the

[3] In this case, leaders refer to those that reveal their ratios in the first round without information.

same group in both instances. Figure 9 is a graph of the contributions over time of the group who was able to meet the threshold. The first game was rounds 4-13, the second game was rounds 14-23, and the third game was rounds 24-33. The second game, this group was not able to meet the threshold and they became regulated whereas they were able to meet the threshold in the first and last game, avoiding regulation. There seems to be evidence of an altruistic participant (subject 5), conditional cooperators (subjects 3 and 6) and a "fair-weather" contributor (subject 4). Interestingly, the altruist did not implement practices during the "non-regulated" time periods (11-13 and 31-33) whereas one of the conditional cooperators (subject 3) tended to contribute even during these times. It may be the case that the altruist really was not altruistic, but rather was interested in avoiding regulation but was able to motivate others to implement practices.

Figure 9 Voluntary Practices Implemented By One Group in the Threshold Treatment



Does Context Impact Behavior?

One of the research questions looked at across all treatments was whether or not the additional context impacted behavior of participants. In particular, were subjects more willing to contribute to the public good if it was implied that they were polluters who were responsible for cleaning up pollution. As evidenced by table 4.5 above, there were contributions to voluntary abatement even if there was no incentive (as was the case in the base and ratio treatments). Additionally, there were two instances where as many as 28 practices were implemented within 7 rounds (as discussed in the preceding section). However, to determine if voluntary abatement was significant, table 6 contains the results of various econometric models. Model 1 is the aggregate model in that all voluntary practices implemented in each time period are summed and regressed on treatment using cluster robust standard errors for panel data (in parentheses under the estimate). This model shows that people are implementing practices voluntarily in all treatments (as the constant is significant at the 10% level) and they are implementing more practices in the threshold treatment. There is not significantly more voluntary abatement in the ratio treatment compared to the base treatment.

Table 6: Econometric Models of Voluntary Practice Implementation

Variable	Model 1: Aggregate	Model 2: Individual	Model 3: Threshold
Constant	0.275** (0.116)	1.008 (1.007)	1.607*** (0.386)
Ratio (binary)	0.094 (0.227)	-0.251 (0.179)	--
Threshold (binary)	1.294** (0.555)	-0.010 (0.256)	--
Quantity_1 (lagged voluntary practices)	--	0.221*** (0.024)	0.163*** (0.036)
Numsell (credits)	--	-0.595*** (0.064)	-0.923*** (0.134)
Money (earnings from selling)	--	0.007*** (0.001)	0.016*** (0.002)
Period (time)	--	-0.002** (0.001)	-0.012*** (0.002)
Profit (profit in each time period)	--	-0.005*** (0.000)	-0.007*** (0.001)
Rsell (Ratio*Numsell)		0.331*** (0.040)	--
Tsell (Threshold*Numsell)		0.212*** (0.042)	--
Environmentalist (likert scale)	--	-0.072 (0.355)	0.417* (0.239)
Gender (binary, male)	--	0.692 (0.638)	0.150 (0.170)
GroupSize (12 person =1, 6 person=0)	--	--	-0.690** (0.278)
Note: ***, ** and * indicate that coefficients are significantly different from zero at the 1, 5 and 10% levels respectively.			

Model 2 uses round data for each individual participating in the experiment. It regresses number of voluntary practices implemented by each individual in each round on lagged voluntary practice implementation, market variables (time and individual variant) and demographic attributes of the individuals (time invariant). A Hausman-Taylor model was deemed appropriate for this data as a Hausman test concluded that individual effects were correlated with the error term making neither a random effects nor a fixed effects model appropriate. The coefficients on the rsell and tsell interaction terms indicate that the treatment effects do have a significant impact on voluntary contribution. The rsell ratio is likely bigger in magnitude likely due to a wealth effect (although profit is controlled for and is significant and positive which captures some of this) as more credits being sold results in more money to spend on voluntary practices[4]. It makes sense that the more credits you sell, the fewer opportunities you have to implement practices voluntarily as credits take up available units of clean-up. Additionally, it also makes sense that if an individual implements a practice in one round, they might be willing to do so again in subsequent rounds as indicated by the positive and significant coefficient on lagged quantity. Surprisingly, gender and self-identification as an environmentalist do not significantly impact a participants willingness to implement practices.

The third model tries to tease out more information about those in the threshold treatment. As the sample size for this model is smaller, it may not be as robust an analysis, however, it confirms the sign of the coefficients in model 2 and demonstrates that factors influencing behavior in the threshold treatment may not be significantly different from the other treatments. Self-identification as an environmentalist became significant in this model as was group size. The group that was able to meet the threshold was the only 6 person session of this treatment. Perhaps the accountability pressure was higher in a smaller group as participants are intimately aware of who is in their watershed and perhaps feel more responsibility to work together to avoid regulation/protect the environment. This could be evidence for the "embedded ties" structure necessary for WQT program success suggested by Breetz, et al (2005).

What Kinds of Interactions Occur Within a Market When Uncertainty is Resolved?

Introduction of a system to verify pollution flows increases WQT market activity. A few aggregate econometric models confirm that the threshold and base treatments do not differ

[4] This also could change with more data. The ratio has the least number of observations and in addition I had to drop 30 observations (1 person) from this data analysis due to a coding error in the experiment.

significantly in prices and quantity of trades in a given round whereas the ratio treatment has a higher volume of trade and lower prices compared to the other treatments. Equations 3 and 4 show these two models. Quantity traded within a given year is expected to be 4.5 credits with the trading ratio treatment having expected credits of 6.32 (significant) and the threshold treatment having expected credits of 4.18 (not significant). The expected average price was about $62 in the base and threshold treatments with a significantly lower expected price in the ratio treatment around $50.21. Profit differs in all three treatments; equation 5 suggests that one could expect to earn around $199/year in the base treatment, $218/year in the ratio treatment and $190 in the threshold treatment.

$$Average\ Quantity = 4.54 + 1.78 * Ratio - 0.36 * Threshold \quad (3)$$

$$Average\ Price = 61.74 - 11.53 * Ratio + 1.64 * Threshold \quad (4)$$

$$Average\ Profit = 199.03 + 19.79 * Ratio - 9.29 * Threshold \quad (5)$$

There is not much price or quantity volatility in the base and ratio treatments as evidenced by figures 10 and 11. However, the introduction of regulation does disrupt not only the market but also voluntary abatement in the threshold treatments. The regulation, if triggered, required 1 unit of clean-up per firm in the last three years of each game. This would be the equivalent to 4 units of abatement each year in each group. Clearly, the only times when that much abatement occurred in a given round were in the threshold treatments as shown in figure 12. This abatement, whether voluntary or in the form of a regulation, has a direct impact on trading activity as firms concentrate on pollution control without in lieu of market activity. In the ratio treatment, participation in voluntary clean-up is more affordable for those with a lower trading ratio, however that clean-up occurs at a direct opportunity cost in the market. Those with a 3:1 trading ratio have no opportunity cost in the market, but they know their contribution to pollution control is less comparatively so they may not be discouraged from contributing even one unit voluntarily.

Figure 10: Credits Traded Over Time by Treatment

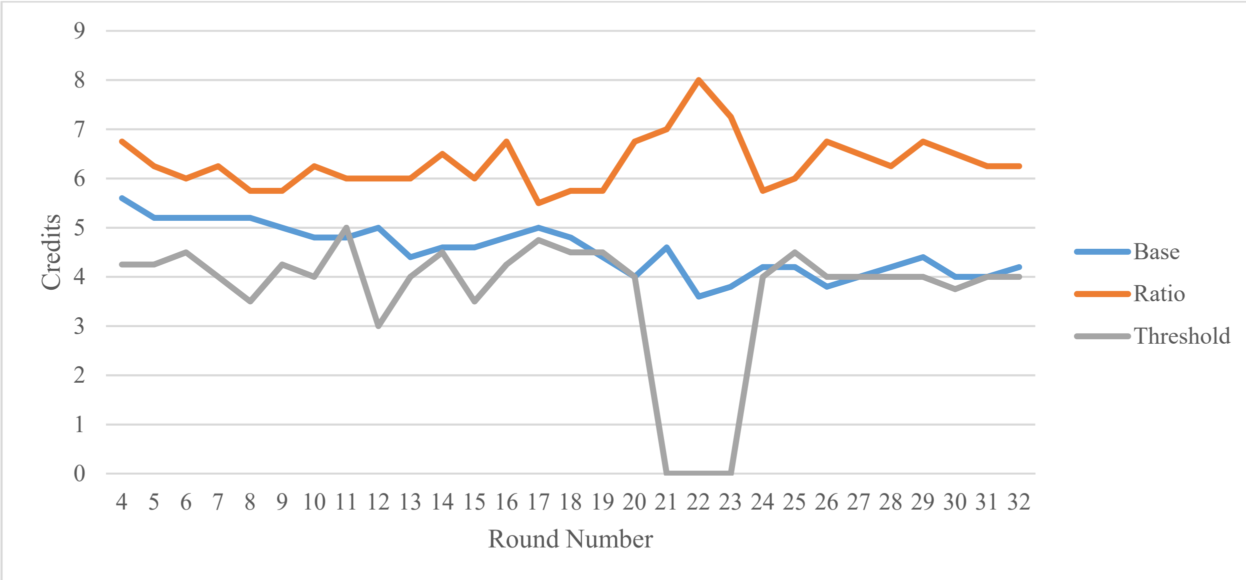


Figure 11: Average Trading Price Over Time by Treatment

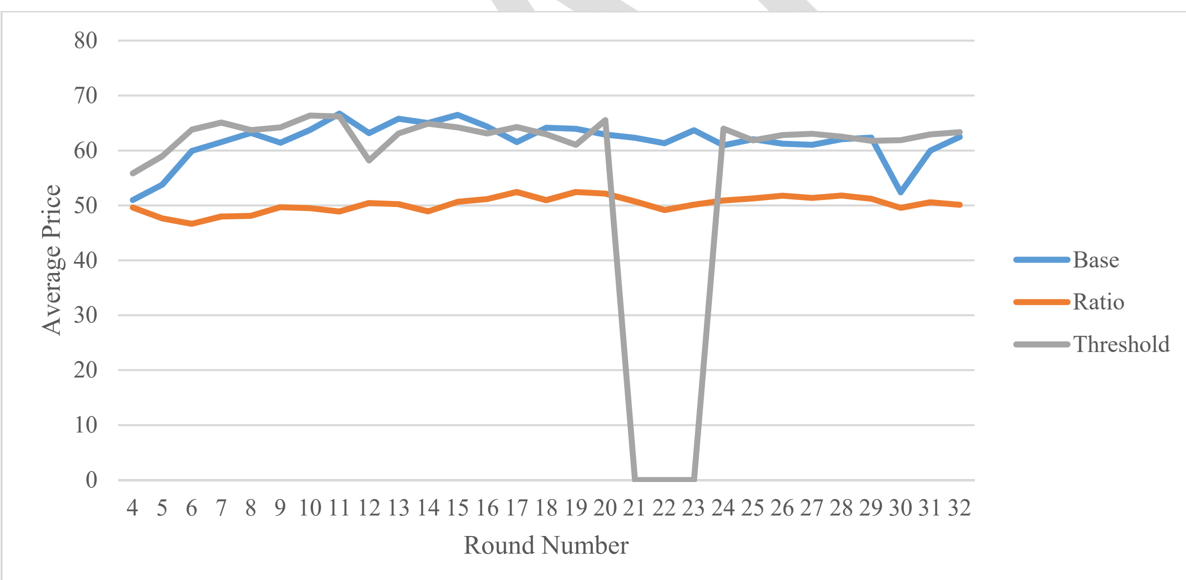
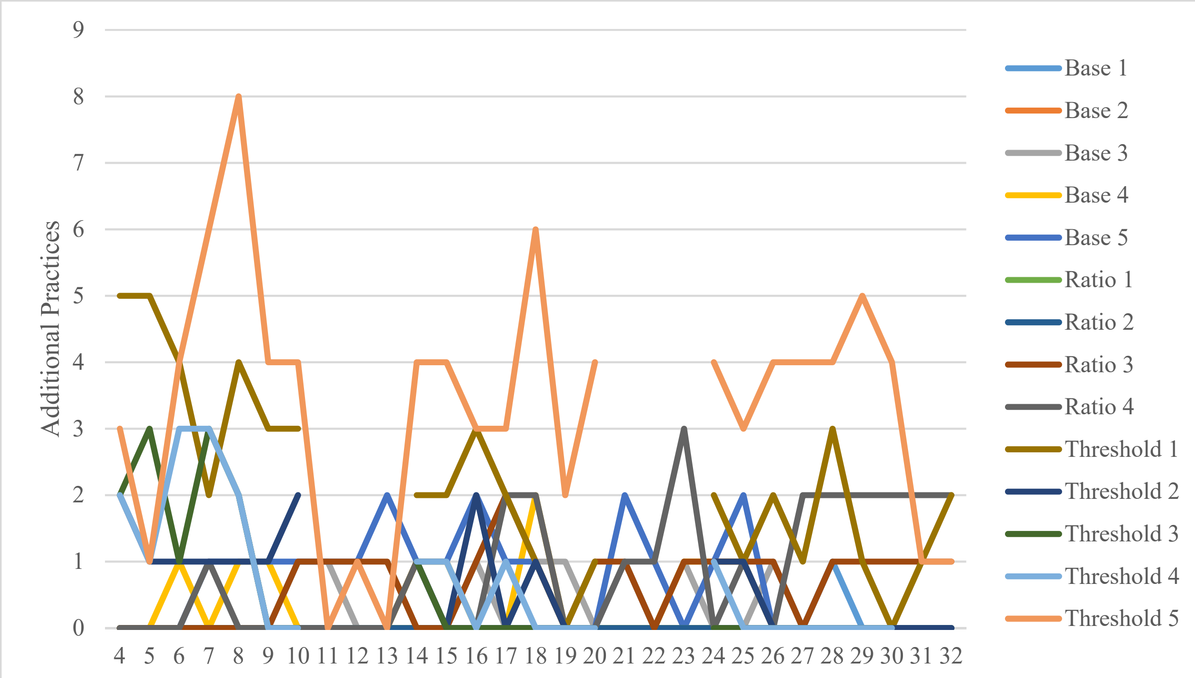


Figure 12: Additional Practices Implemented Over Time by Treatment



Discussion/Conclusion

The results indicate that if more information were available to NPS that could remove uncertainty, they will respond positively. An over-whelming majority of the time in the ratio treatment, participants verified their trading ratio, even under negative price signals. This indicates that even if firms had a pre-conceived believe about their own ability to reduce pollution, they might still want to resolve the uncertainty at some point if given the option. Additionally, welfare for farmers and WWTPs increased under this scenario as more trades were able to occur at favorable prices.

People are willing to reduce pollution voluntarily at an economic cost. Even in the ratio treatment wherein voluntary abatement had a very high opportunity cost in the market, voluntary abatement took place. At least one group was motivated by a threat of regulation in the threshold treatment indicating that if a group were given a credible threat and were responsible to each other, pollution control may be able to take place by NPS. Additionally, it might be helpful to talk frankly about who is contributing to pollution and how all sources of pollution within a watershed can contribute to beneficial water quality.

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