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It Takes A Village to Raise Water Quality: The Effects of Residential Voluntary Taxation Mechanisms on Lake Water Quality in Orange County, Florida

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IT TAKES A VILLAGE TO RAISE WATER QUALITY: THE EFFECTS OF RESIDENTIAL VOLUNTARY TAXATION MECHANISMS ON LAKE WATER QUALITY IN ORANGE COUNTY, FLORIDA

by

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Abstract

Achieving environmental standards with efficient and cost-effective economic systems is a subject whose importance is increasing in conjunction with growing technological innovation and urbanization. This project contributes to the subject's literature by empirically examining the effects of a voluntary taxation mechanism on the water quality of designated lakes in Orange County, Florida. One of two taxing district types is voluntarily formed by lakefront or near-lakefront property owners: a Municipal Service Taxing District (MSTU), wherein participants pay an ad valorem tax based on property values, or a Municipal Service Benefit Unit (MSBU), wherein participants pay an equal flat rate tax independent of property value. The taxing districts' purpose is to allocate specific funds for water management and water quality improvement, so the fixed effects econometric analyses examine the efficacy of the mechanisms using publicly available water quality data on Trophic State Index (TSI) ratings, Secchi disk depth measurements, phosphorus levels, and nitrogen levels. The empirical results show that MSTU/MSBU taxing districts are moderately effective at reducing phosphorus and nitrogen levels and that MSTU designation is weakly superior to MSBU designation. Moreover, certain taxing district characteristics are shown to be important for mechanism effectiveness.

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1 Introduction

The quality of water is an essential commodity that forms the groundwork for many environmental and economic functions. Protecting and improving water quality involves balancing incentives and disincentives across point and nonpoint sources, a mission which has been approached in large part by the Clean Water Act of 1972. A great deal of attention has been dedicated to the abatement of nutrient runoff from agricultural nonpoint sources and rightfully so, given that they have historically been the largest producer of nonpoint source surface water pollution in the United States (EPA, 2017). However, the abatement of nutrient runoff from urban nonpoint sources represents a growing problem that also merits attention. Urban environments have become increasingly centralized bases for economic and social activity, so many benefits can be realized by preventing environmental degradation within them. The Greater Orlando area and the state of Florida as a whole are no exception; recent bouts of Red Tide and damaging algal blooms have brought the debilitating nature of degraded water back into the public eye, the latter of which are endemic to many important natural areas in the state. Expanding urban populations and urbanization can exacerbate the magnitude of the urban nonpoint pollution problem (EPA, 2017) and of problems with other environmental factors such as the cycling of water and nitrogen (Seto and Shepherd, 2009), and thus the efforts to find an economically viable solution must increase along with them.

Though not specifically tailored for environmental amenities, a popular voluntary economic instrument for achieving regional economic enhancement is the business improvement district (BID). BIDs are commercially-oriented entities that are funded by taxes based on property values, and their purpose is to strengthen the economic conditions in their respective districts (Houstoun, 2017). They are designed to be an auxiliary source of support for struggling business districts and typically work in conjunction with existing municipal services to achieve advancement goals. Currently, over 1,500 BIDs exist in North America (Houstoun, 2017), and two notable BIDs operating in Orange County are: the Downtown South Neighborhood Improvement District (DSNID) and the International Drive Business Improvement District (IDBID). Taxation mechanisms of this form and others can be applied to environmental amenities. For example, in nearby Brevard county, a half-cent of sales tax has been collected since early 2017 for the purpose of funding the restoration of the Indian River Lagoon (Spear, 2017). This sort of self-regulation represents a new approach to attaining environmental standards, as evidenced by the MSTU/MSBU program taking the structure of BIDs to the realm of environmental amenities.

The MSTU/MSBU for Lake Management Services program offered and managed by the Orange County Environmental Protection Division is a variant of the BID mechanism and one of the aforementioned solutions that has the potential to effectively manage urban nonpoint source runoff and mitigate its negative effects. The program allows for the formation of self-imposed taxing districts that establish a source of funding for lake management services. Interested property owners can form a petition for designation that is comprised of at least 15% of parcels in the affected area, which can be defined as the area surrounding a given lake. Each district is typically centered around an individual lake and requires $66\frac{2}{3}\%$ of responding proximal property owners to approve its establishment. The taxing district can take one of two forms: the Municipal Service Taxing Unit (MSTU), wherein participating property owners pay an ad valorem tax that is based on property values, or the Municipal Service Benefit Unit (MSBU), wherein participating property owners pay an equal flat rate tax independent of property value.

Revenues produced by both types of taxing districts feed into an account that is managed by the County and can only be utilized for lake management activities. In this framework, the water quality of MSTU/MSBU lakes can be defined as a club good as opposed to a prototypical public good. Assuming at least partial contiguity in the district, the participating property owners derive the benefits of any resulting water quality improvements while excluding, to a certain extent, those who do not pay the tax from said benefits. However, this setup is not totally free from the free-rider problem nor is the water quality of MSTU/MSBU lakes definitively a club good, since it is relatively impossible to completely exclude non-payers from the benefits of cleaner lake water. By paying into a taxing district fund, participating property owners are contributing to the enhancement of a public good (environmental amenity), thereby improving their own utility while positively impacting aggregate economic factors. This enhancement is achieved via several methods whose implementation varies from lake to lake: aquatic weed/plant control, aeration systems, shoreline alterations, water quality improvement, lake cleaning, and general maintenance; only weed/plant control and water quality improvement are considered in this study. Out of the 402 lakes in Orange County, 46 are MSTU lakes (whose average district age as of 2018 is approximately 33 years) and 21 are MSBU lakes (whose average district age as of 2018 is approximately 10 years).

The existing literature on water pollution abatement methods describes the motivation behind such methods, namely the valuation of water quality and the benefits that stem from pollution abatement. Direct and indirect valuation studies alike have found that individuals possess a significant willingness-to-pay for environmental amenities in general and water quality improvements in particular. The economic benefits resulting directly from this willingness-to-pay and indirectly from improved water quality are consistently estimated to be large values worthy of further consideration, ranging from recreational to property price impacts (Bin et al., 2015; Gibbs et al., 2002; Leggett and Bockstael, 2000; Nelson et al., 2015; Walsh et al., 2011; Walsh et al., 2017; Wolf and Klaiber, 2017; Morgan and Owens, 2001; Cho et al., 2011; Bockstael et al., 1989). Pay-for-performance methods appear to be particularly effective at achieving quality standards and maximizing cost-effectiveness, and the MSTU/MSBU program embodies a unique realization of such methods. However, the literature has not sufficiently evaluated the impacts of pay-for-performance or any other methods in urban settings, leaving work in urban nonpoint source pollution abatement relatively scarce in quantity and specificity.

This study contributes to the current literature by directly examining the efficacy of a unique pay-for-performance method (the MSTU/MSBU program) on levels of nutrient pollution and other water quality indicators in urban lakes. Time and entity fixed effects econometric models were used to examine the changes in water quality in MSTU/MSBU lakes versus changes in non-designated lakes so as to isolate the impacts of the MSTU/MSBU program. The water quality data measuring total phosphorus levels, total nitrogen levels, Trophic State Index (TSI) ratings, and Secchi disk depth measurements will be obtained from the Orange County Wateratlas. The results are mixed with respect to the program's overall efficacy. In general, MSTU or MSBU designation is effective at improving water quality across multiple parameters, though this effectiveness is often insignificant or diminished by more complete specifications. Additionally, MSTUs were found to be superior to MSBUs in improving water quality. Moreover, certain district-specific functions such as weed control, advisory board age, overall district age, and MSTU/MSBU specific age were found to be significantly important in improving MSTU/MSBU performance.

The next section provides a review of the relevant literature. Then, section 3 presents a basic theoretical model of consumer utility to motivate the project and the ensuing empirical analysis. Section 4 then describes the econometric models used for the analyses, with section 5 detailing the data involved. Section 6 presents and examines the results of the two empirical investigations. Finally, section 7 furnishes concluding remarks and a summation of the study and its implications.

2 Literature Review

2.1 The Valuation of Water Quality

An essential goal of environmental economics is the valuation of non-market goods such as water and air quality, stocks of wildlife such as fish and cattle, and access to natural amenities such as public lands and lakes. The abatement of lake water pollution is a particular type of non-market good: a public good. Efforts to price public goods have historically involved studies designed to elicit individuals' willingness-to-pay for a given environmental good or service, be it through direct or indirect valuation of the good or service.

Direct approaches explicitly ask individuals how much they would be willing to pay for improvements in water quality, where payment mechanisms may take the form of increased taxes or additional bills. In fact, Nelson et al. (2015) found that people are willing to accept higher water utility bills in exchange for improved water quality, although the magnitude of the increase varies between households who actively utilize surface waters for recreational purposes and households who do not. This difference also consistently appears in indirect valuation studies centered on recreational usage (Van Houtven et al., 2007). The most direct method is of the contingent valuation or stated preference type, wherein individuals are directly interviewed to elicit their valuation of or willingness-to-pay for a given non-market commodity (Ciriacy-Wanthrup, 1947; Hanemann, 1994). Another way to directly discern individuals' valuation of water quality has appeared in the agricultural setting, where farming practices are the chief source of nonpoint source pollution. Farmers "bid" their minimum willingness-to-accept for implementing manure management practices to reduce phosphorus runoff in the first stage, which allows for the construction of a water quality improvement supply curve; the second stage involves affected residents bidding their marginal willingness-to-contribute towards the manure management practices proposed by farmers, and through this stage a demand curve for water quality improvement is constructed (Uchida et al., 2018).

Indirect valuation methods for eliciting individuals' willingness-to-pay frequently utilize a proxy variable such as recreational usage, indirect costs (travel, equipment, etc.), or property value for determining the value of water quality. These approaches are also known as revealed preference methods, wherein inferences regarding valuation of non-market goods are made based on values from real market choices made by individuals (Boyle, 2003); proxies in this framework include purchase prices, quantities purchased, and total costs. Prior work quantifying the benefits of water quality improvements in the Chesapeake Bay has utilized recreational market activity such as boating and beach use as proxies for revealed preference (Bockstael et al., 1989). This approach enables the observance of changing consumer behavior in response to changes in water quality, and the expected changes are usually positively correlated with water quality; increases in water quality are typically associated with increases in recreational activity and transportation frequency and vice versa.

Both approaches rely on the definition of use and non-use value, otherwise known as active value and passive value respectively. With respect to water quality, Schechter et al. (1998) states that use value can stem from recreational use of water bodies or admiring their cleanliness and that non-use value consists of existence and bequest motives. Plottu and Plottu (2007) clarifies existence value as the utility that individuals realize from knowing that an environmental amenity will be preserved regardless of individual use and bequest value as the utility that individuals obtain from an amenity's preservation for use by future generations.

2.2 Economic Benefits of Improved Water Quality

The achievement of improved levels of water quality imparts positive effects upon the aforementioned factors of recreational usage, tourism, and property values, among others. Bockstael et al. (1989) provides a seminal evaluation of the economic benefits of improved water quality, specifically in the Chesapeake Bay. Their findings estimate an aggregate willingness-to-pay of between $10 million and $100 million for improvements in the Bay's water quality. Later work refines similar results, directly quantifying the economic benefits from increased recreational usage of the Chesapeake Bay to be between $357 million and $1.8 billion (Morgan and Owens, 2001). Naturally, there also exists a benefit in avoiding economic loss as a result of poor water quality; Viscusi et al. (2007) estimates a total annual loss of approximately $21.8 billion based on their stated preference results for water quality valuation, while Wolf and Klaiber (2017) estimate a total capitalization loss for near-lake properties of over $51 million as a result of algal blooms in six Ohio counties.

With the latter study in mind, it becomes clear that of greater interest to this study are the economic benefits stemming from positive impacts on property values. Higher property values represent an appreciation of an asset for homeowners, which imparts a pseudo income effect since homeowners experience an increase in purchasing power (or wealth). Furthermore, homeowners have been shown to increase their consumption as a result of increased property values and the accompanying bolstering of wealth (Campbell and Cocco, 2005; Attanasio et al., 2009). Berger et al. (2015) showed that a $1,000 increase in property value is associated with a $600 increase in spending for younger homeowners. Thus increased property values can impart positive effects on local economies, extending the positive impacts of improved water quality beyond the individuals in the immediate area surrounding a given water body. In addition, areas can experience rises in desirability stemming from higher property values within it, which can attract greater economic activity.

There exists an extensive literature examining the relationship between property values and water quality, with the most consistent and widespread finding being that property values vary positively with water quality, particularly for waterfront properties. Waterfront property owners have been shown to possess a positive willingness-to-pay for reductions water pollutants such as coliform bacteria and, consequently, evidence was found showing that water quality improvements impart positive effects on waterfront property values (Leggett and Bockstael, 2000). Other specific measures of water quality such as total phosphorus, total nitrogen, and water clarity have also been directly related to property values. Gibbs et al. (2002) found that decreases in water clarity negatively affect lakefront property values in New Hampshire; a notable result is that a one-meter decrease in water clarity caused, on average, property value decreases of between 0.9% and greater than 6%. Similarly, Walsh et al. (2017) examined water clarity to determine that water quality positively affects waterfront property values in seven Chesapeake Bay counties. However, the effects of water quality on property values are not limited to the impacts of single pollutants. Bin et al. (2016) utilized temperature, pH, water visibility, salinity, and dissolved oxygen in their study of the Martin County, FL housing market, finding that water quality improvement is associated with increased property values. Their study also directly quantified improvements in water quality in estimating that a one-percentage point increase in water quality is valued at $1,754 on average between 2001 and 2010. As for the Orange County, FL housing market, Walsh et al. (2011) determined that a unit increase in Secchi depth (representing an increase in lake water clarity) is associated with a $5,500 increase in average lakefront property value. Each instance of increased property value stemming from improved water quality embodies a premium for the cleaner water.

2.3 Methods for Abating Pollution and Achieving Water Quality Standards

The improvement of water quality has positive effects from an environmental perspective, but economically, the reduction and control of poor water quality as an externality is also of importance. The externality effects can manifest in many ways across all types of pollution and misuse of natural resources. Freshwater eutrophication (the oversaturation of phosphorus and/or other nutrients in a water body) is an encompassing illustration of the negative impacts of this environmental externality and motivates its abatement. Severe algal blooms, resulting from eutrophication, can make surface waters unsightly and hazardous. The state of Florida has recently dealt with severe bouts of algal blooms, both locally in areas such as the Indian River Watershed and at a more widespread level with the widely publicized Red Tide occurrences. At the lake level, Florida has also historically faced issues with Lake Okeechobee, the state's largest freshwater lake and the eight largest such lake in the nation.

Lakes, rivers, and streams that are stricken by such conditions can experience decreased recreational use, reduced tourism to or around the water body, losses in ecosystem services and biodiversity (which can induce additional costs for prevention of further losses), increased drinking water treatment costs, and decreased property values in the surrounding area, particularly for lakefront properties (Dodds et al., 2008). The economic benefits that stem from reducing or managing such externalities is the converse of their negative impacts: increased consumer utility from recreational usage, increased property values, and increased financial injections to the affected communities. Areas with high levels of residential development and urbanization are associated with higher levels of common water pollutants such as nitrogen and phosphorus, which then leads to the degradation of water resources in those areas (Atasoy et al., 2006). Thus the motivation for mitigating externalities and their impacts is greater in highly urbanized areas given that the negative effects are of higher magnitudes.

Many methods have been developed by state, local, and federal entities for devising an economic framework and accompanying set of economic incentives for abating water quality pollution. Incentives are the essential driving force behind them all, since they facilitate the internalization of the true social and environmental costs and benefits of water quality. Without them, we encounter the problem that is endemic to the management of public and common-property resources: individuals disregarding the impacts of their actions on a given resource because their use or disuse of it does not explicitly enter their utility at the optimal time.

A classic approach to combatting externalities in general is the Pigovian tax (Pigou, 1920). Constructed as a device for correcting problems with externalities in any welfare economics situation, the Pigovian tax has been proposed extensively for use in the environmental economics arena. It is designed to correct market behavior by taxing actions that generate negative externalities, where the tax rate is equated to the marginal social cost of the externality. Segerson's ambient tax (Segerson, 1988) represents an alternative tax structure to Pigou's, wherein two components comprise the tax: a specific or per unit tax that is a function of the difference between the real pollutant level and the objective pollutant level and a fixed lump-sum tax that is levied if the real pollutant level exceeds a certain threshold (de Vries et al., 2016). Segerson's ambient tax is particularly useful in nonpoint source scenarios where individual emissions are not reliably discernable but an overall measure of total emissions is (Segerson, 1988). Another classic method is command-and-control, wherein a government agency imposes strict standards for all polluters and levies fines when those standards are violated. The command-and-control method has been compared to methods entailing economic incentives with respect to efficiency and cost-effectiveness with mixed results arising depending on the situation in which each method is applied (Harrington and Morgenstern, 2004).

Incentives based approaches rely on market actions to achieve of water quality standards or improvement. A quintessential model utilizing economic incentives is the cap-and-trade approach, which provides polluters with maximum total emissions amounts and allows for trading of such allotments between polluters (EPA, 2001). Derivatives of the cap-and-trade approach are pollution permit trading and auctions. Pollution permit trading allows polluters to trade their respective pollutant allotments in a market setting to assist in achieving the water quality standards imposed upon them (EPA, 2003). In the context of nonpoint source pollution, the trading of water pollution permits remains feasible despite the uncertainty in measuring pollutant levels and identifying their sources; trading programs for nonpoint sources must account for these uncertainties by abiding by one of the EPA's methods, such as site-specific discount factors (EPA, 2003). Auctions or conservation auctions offer a more formalized environment for market activity such as the aforementioned pollution permit trading, but with the added benefits of an extensive and efficient market structure. That is, conservation auctions allow economic agents to trade more than just pollutant allotments while also mitigating potential problems of adverse selection and suboptimal cost-effectiveness, both of which can present themselves when pricing opportunity costs associated with environmental quality improvements or the lack thereof (de Vries et al., 2016). In such auctions, landowners bid their minimum willingness-to-accept (in terms of monetary compensation) in exchange for fulfilling the terms of a given conservation contract to "buyers" such as regulatory agencies or other agents that possess an interest in environmental improvement; the buyers offer their contract to the bidder with the greatest potential environmental benefit and most cost-effective pricing.

Given the subject of this study, methods that are more citizen-driven are of particular interest. The agglomeration bonus is one such method, wherein landowners are offered payments for volunteering their lands for participation in an environmental contract if their land is near neighboring lands that are also registered for the given contract; this approach can mitigate the problem of discontinuous land coverage of a contract, and most of its applications exist in land conservation efforts (Parkhurst et al., 2002). Beyond the agglomeration bonus is the pay-for-performance method, which is a derivative of general payment for environmental services programs. Payment for environmental services programs entail voluntary transactions for environmental services between at least one buyer and at least one provider. Buyers can be actual users of the environmental service or third parties acting on behalf of service users; the former constitutes the user-financed framework while the latter constitutes the government-financed framework (Engel et al., 2008).

Pay-for-performance, like other payment for environmental services programs, reverses the payment scheme such that the beneficiaries of environmental services are subject to payments instead of pollutant producers (Talberth et al., 2015). Within the agricultural nonpoint runoff setting, Talberth et al. (2015) also shows that pay-for-performance is superior to conventional subsidization approaches both in cost-effectiveness and effectiveness in nutrient reduction; pay-for-performance yields the same nutrient reduction results as subsidization at half the cost and provides two to three times the amount of nutrient reduction for an equal level of investment. Bohlen et al. (2009) describes a pay-for-performance scheme that has been implemented in Florida by the Florida Ranchlands Environmental Services Project, wherein state agencies pay ranchers in accordance with their production of water storage and phosphorus load reduction services. One issue with payment for environmental services approaches is that transaction costs can act as a barrier to participation, as evidenced by low participation in such approaches in numerous environmental markets (Peterson et al., 2015). This problem appears in the MSTU/MSBU program; out of the 402 lakes in Orange County, only 67 are currently designated as MSTU/MSBU lakes.

3 Theoretical Framework

MSTU/MSBU taxing districts can be classified as types of pay-for-performance (PFP) mechanisms, which are a subset of payment for environmental services (PES) methods. The buyers in this setting are parcel owners and/or residents who pay into a singular and district-specific fund, and they are hereafter referred to as beneficiaries; beneficiaries are essentially paying to prevent lake water quality degradation and/or to improve lake water quality. The providers or sellers in this setting are the suppliers of various lake management services, and they are hereafter referred to as providers. Performance in this MSTU/MSBU setting can be defined as improvements in water quality or as observed completion of contracted lake management tasks; I argue that the latter concretely defines performance moreso than water quality improvements themselves. MSTU/MSBU districts differ from other PFP cases in that payments are functions of property values instead of performance; the prototypical case has payments being based directly on performance. However, I claim that property values are indirect measures of performance as previously defined, since they vary positively with the effectiveness of said performance. Thus the PFP setting holds for MSTU/MSBUs, albeit unconventionally.

Moreover, MSTU/MSBU lakes themselves are public goods whose external influence is being internalized by the voluntary taxing mechanisms. That is, MSTU/MSBU lakes are non-rival and non-excludable goods that exert positive and negative effects on surrounding consumption behavior and beneficiary utility. Certain MSTU/MSBU lakes located in residential areas capable of exercising high enough levels of exclusivity can be classified as club goods; restricted access residential communities are a prime example of a residential area that can make an MSTU/MSBU lake a club good. These lakes are non-rival but very much excludable to those who are not residents of the community and, consequently, are not MSTU/MSBU taxpayers.

The exposition in the following subsections and this study as a whole depend on the relationship between each of the four selected indicators and lake water quality. Phosphorus and nitrogen are naturally present in lakes and are important to the health of algae and other aquatic vegetation, which provide sustenance and living environments to lake wildlife (EPA, 2017). High levels of either are conducive to overgrowth of algae, but overly high phosphorus content is the chief culprit in spurring harmful algal blooms, which degrade the exterior quality of lakes and adversely impact lake wildlife by reducing oxygen levels (Minnesota Pollution Control Agency, 2008). Secchi disk depth and TSI are directly affected by nitrogen and phosphorus levels, as increased levels of either lead to decreased Secchi disk depth measurements and increased TSI ratings. Thus water quality varies positively with phosphorus, nitrogen, and TSI and negatively with Secchi disk depth.

3.1 Beneficiary Utility

For conceptual purposes, I introduce a basic model of beneficiary utility based on the total economic value of an environmental good described in Ali et al., 2014 as:

$$\text{Total Economic Value} = \text{Use Value} + \text{Non-Use Value}$$

Alternatively, use value can be defined as active value and non-use value can be defined as passive value (Shechter et al., 1998). For this model specifically, let active/use value be the set of all direct consumption benefits that beneficiaries derive from "consuming" lake water quality, e.g. appreciating the appearance of a clean lake, lessened adverse health effects related to lake water quality, or recreational lake use. Moreover, let passive/non-use value be the set of all indirect benefits that beneficiaries derive from lake water quality, e.g. property value effects or lake maintenance cost effects.[1] In the context of lake water quality, the ith beneficiary's utility is given by

[1] Note that, for the purpose of this study and exposition, this definition differs from those provided in the cited literature.

$$U_i[A_i(WQ), P_i[V(WQ)]] = A_i(WQ) + P_i[V(WQ)] \tag{1}$$

where

$WQ \equiv$ water quality

$A_i(WQ) \equiv$ active or use value for the ith beneficiary

$V(WQ) \equiv$ property value

$P_i[V(WQ)] \equiv$ passive or non-use value for the ith beneficiary

$U(\cdot)$, $A(\cdot)$, $V(\cdot)$, and $P(\cdot)$ are assumed to be continuous, twice-differentiable, and strictly increasing functions. Thus, the beneficiary's preferences are strictly monotone such that higher levels of active and passive value are always preferred to lower values. The rest of this study focuses on use value $A(WQ)$ since property value data will not be used.

A rudimentary model of water quality in this taxing district setting is:

$$WQ(t_{MSTU}, t_{MSBU}, n) \tag{2}$$

where $t_{MSTU} \geq 0$ and $t_{MSBU} \geq 0$ are the amounts, in dollars, of money paid into an MSTU fund and MSBU fund, respectively, and n is a vector of all other factors affecting water quality WQ. Furthermore, assume that $\frac{\partial WQ}{\partial t_{MSTU}} > 0$ and $\frac{\partial WQ}{\partial t_{MSBU}} > 0$. (1) is already a function of this definition of WQ, and it is repeated in modified form here:

$$U_i[A_i(WQ(\cdot)), P_i[V(WQ(\cdot))]] = A_i(WQ(\cdot)) + P_i[V(WQ(\cdot))] \tag{3}$$

Differentiating (3) with respect to WQ yields:

$$\frac{\partial U(\cdot)}{\partial WQ} = \frac{dA(\cdot)}{dWQ} + \frac{dP(\cdot)}{dV} \cdot \frac{dV(\cdot)}{dWQ}$$

Since $A(\cdot)$ is strictly increasing (i.e. beneficiary active value is positively correlated with water quality), $\frac{dA(\cdot)}{dWQ} > 0$. As evidenced by prior research such as Walsh et al. (2011), $\frac{dV(\cdot)}{dWQ} > 0$; $\frac{dP}{dV} > 0$ by similar logic behind $\frac{dA(\cdot)}{dWQ} > 0$ (i.e. beneficiary passive value is positively correlated with water quality). Thus, $\frac{\partial U(\cdot)}{\partial WQ} > 0$.

3.2 Gainful Expenditures in Water Quality

The model of water quality given by equation (2) permits the derivation of useful results and hypotheses for contextualizing the empirical methods in the next section. The central claim is that the water quality of MSTU/MSBU lakes is superior to the water quality of non-MSTU/MSBU lakes where no tax dollars are being specifically allocated.

Proposition 1: $WQ(t_{MSTU}, t_{MSBU}, n) > WQ(0, 0, n)$

Moreover, because $A(\cdot)$, $P(\cdot)$, and $V(\cdot)$ are all strictly increasing, the following result holds:

Proposition 2: $A[WQ(t_{MSTU}, t_{MSBU}, n)] > A[WQ(0, 0, n)]$

$V[WQ(t_{MSTU}, t_{MSBU}, n)] > V[WQ(0, 0, n)]$

$P[V[WQ(t_{MSTU}, t_{MSBU}, n)]] > P[V[WQ(0, 0, n)]]$

$\therefore U[WQ(t_{MSTU}, t_{MSBU}, n)] > U[WQ(0, 0, N)]$

Thus beneficiaries stand to gain from the implementation of the MSTU/MSBU program.

These two propositions lead to the main outcome of interest for this study, namely water quality with and without MSTU/MSBU designation. Its empiric validity will determine the effectiveness of the MSTU/MSBU program, and the associated hypotheses are

H1: MSTU/MSBU lakes have higher water quality than non-MSTU/MSBU lakes (see Proposition 1).

H2: MSTU designation and MSBU designation have differing effects on changes in water quality:

$$\frac{\partial WQ}{\partial t_{MSTU}} \neq \frac{\partial WQ}{\partial t_{MSBU}}$$

4 Econometric Framework

The models for testing the hypotheses presented in the previous section have the level[2] of an indicator of water quality as the outcome variable and MSTU/MSBU designation as the principal independent variable(s). As previously postulated, my expectation is that MSTU/MSBU lakes will have higher water quality than non-MSTU/MSBU lakes and that MSTU and MSBU designation have differing effects on water quality changes over time. To empirically test these hypotheses, I develop two separate specifications in the following two sections. In constructing these specifications, I also include additional variables[3] for the district-specific functions that are relevant to lake water quality and for the age of taxing districts and their advisory boards (if an advisory board is in place).

4.1 MSTU/MSBU Lakes versus Non-MSTU/MSBU Lakes

This set of models examines the effectiveness of taxing districts of either type, thereby only testing *H1*. To account for time-invariant and entity-invariant factors between different MSTU/MSBU and non-designated lakes, the model includes time and entity fixed effects variables. Thus the complete model takes the form of a fixed effects linear regression model

$$Y_{it} = \beta_0 + \beta_1 Tax_{it} + \beta_{2,j} X_{it} + \psi_i + \theta_t + \epsilon_{it} \tag{4}$$

where Y_{it} is the annual mean level of a given indicator in lake i and time t, Tax_{it} is a dummy variable equal to one when lake i at time t is an MSTU or MSBU lake in years after district establishment, X_{it} is a vector of $j \in [1, 7]$ additional independent variables associated with

[2]A logged model with the log of annual mean level as the outcome variable will also be estimated for both specification types.

[3]The additional variables are: overall taxing district age ("Age"), a dummy for whether or not a given MSTU/MSBU lake has an advisory board ("Board"), advisory board age ("Board Age"), dummies for whether or not a given MSTU/MSBU lake has weed control ("Weed Control") and/or water quality improvement ("WQ Improvement") as explicit district purposes, and separate age variables for MSTU lakes ("MSTU Age") and MSBU lakes ("MSBU Age")respectively.

MSTU/MSBU designation, ψ_i is a lake fixed effects variable, θ_t is a time fixed effects variable, and ϵ_{it} is the model error term.

A parsimonious model will also be estimated, where Tax_{it} will be the only independent variable on the right hand side:

$$Y_{it} = \beta_0 + \beta_1 Tax_{it} + \psi_i + \theta_t + \epsilon_{it} \tag{5}$$

In both the complete and parsimonious model, Tax_{it} is the primary regressor, and thus the coefficient of interest is β_1 in both specifications, which captures the average effect of MSTU and MSBU designation on the annual mean value of the given water quality indicator. In the complete model (4), the coefficients associated with the additional independent variables will also be useful.

Following the results developed in the last section, I expect the primary regressor's coefficients of interest to be negative for the nutrient pollutant (phosphorus and nitrogen) and TSI models and positive for the Secchi depth model.

4.2 MSTU Lakes versus MSBU Lakes

This set of models examines the difference in efficacy between MSTU and MSBU designation, thereby testing both *H1* and *H2*. In these specifications, some intuition informs the notion that MSTUs will be more effective in reducing nutrient pollutant levels and increasing Secchi depth than MSBUs. This is because MSTU designation implements a varying ad valorem tax based on property value, which prohibits free-riding behavior within the taxing district by forcing each parcel owner to pay into the tax fund according to their parcel's value instead of allowing certain owners to underpay, which is a possibility with the MSBU flat tax scheme. Furthermore, MSTUs are older on average and more plentiful than MSBUs, so they have had more time to take effect in their respective lakes and more data to inform their efficacy.

Each form of the aforementioned specification will be tested using a time and entity fixed effects linear regression model with differing outcome variables depending on the specification. In general, the complete specifications will be of the form:

$$Y_{it} = \beta_0 + \beta_3 MSTU_{it} + \beta_4 MSBU_{it} + \beta_{5,k} X_{it} + \psi_i + \theta_t + \epsilon_{it} \tag{6}$$

where Y_{it} is the respective annual mean level of the given water quality indicator (phosphorus content, nitrogen content, TSI rating, or Secchi depth), $MSTU_{it}$ is a dummy variable equal to one for MSTU lakes in years after district establishment, $MSBU_{it}$ is a dummy variable equal to one for MSBU lakes in years after district establishment, X_{it} is a vector of of $k \in [1, 7]$ additional independent variables associated with MSTU/MSBU designation, ψ_i is a lake fixed effects variable, θ_t is a time fixed effects variable, and ϵ_{it} is the model error term.

As in the prior section, a parsimonious model will also be estimated where $MSTU_{it}$ and $MSBU_{it}$ are the only independent variables on the right hand side:

$$Y_{it} = \beta_0 + \beta_3 MSTU_{it} + \beta_4 MSBU_{it} + \psi_i + \theta_t + \epsilon_{it} \tag{7}$$

In both the complete and parsimonious model, $MSTU_{it}$ and $MSBU_{it}$ are the primary regressors, and thus the coefficients of interest are β_3 and β_4, which capture the average effects of MSTU or MSBU designation on measures of water quality respectively. In the complete model (6), the coefficients associated with the additional independent variables will also be of value.

Moreover, I expect that the primary regressors' coefficients of interest will be negative for the nutrient pollutant models and positive for the Secchi depth and TSI models, but also that β_3 will be larger in absolute value than β_4.

5 Data

5.1 Sources

The data of interest for this study's outcome variables are water quality measures, which are defined by the following indicators: total phosphorus, total nitrogen, Trophic State Index (TSI) ratings, and Secchi depth measurements in Orange County, FL over all available years. The data for all four indicators will be obtained from the Orange County Water Atlas database. This county-level database consists of data provided by the EPA's Storage and Retrieval (STORET) data system, the USGS's National Water Information System (NWIS), the City of Winter Park, the Florida Department of Environmental Protection (FDEP), the Florida Fish and Wildlife Conservation Commission (FFWCC), Florida LAKEWATCH, Legacy Orange County, the St. Johns River Water Management District (SJRWMD) and the Orange County Environmental Protection Division. The NWIS is a data system managed by the United States Geological Survey (USGS) for the purpose of compiling and circulating water-use data from the entire country. The USGS works with local, state, and federal level agencies in the process of obtaining water-use information. STORET is an electronic data system for maintaining water quality monitoring data collected by the EPA.

In the context of phosphorus and nitrogen concentrations and TSI ratings, "higher" water quality is defined by lower concentrations of phosphorus or nitrogen and lower TSI ratings. As for Secchi depth, "higher" water quality is defined by higher measurements. As a final note for this section, though 67 distinct lakes are classified as either MSTU or MSBU, the data typically only includes 60 of them. The lakes for which there is no data are: Bellanona Grande Estates, Boot Lake, Lake Marilyn, Lake Odell, Lake Pearl-West, Lake Serene, and Little Lake Conway.

5.2 Statistical Summaries

The final datasets used in the analysis are structured as follows: 317 lakes over the sample period 1964-2018 for phosphorus (totaling 83,699 measurement observations), 314 lakes over the sample period 1967-2018 for Secchi disk depth (totaling 80,250 measurement observations), 308 lakes over the sample period 1965-2018 for nitrogen (totaling 75,668 measurement observations), and 292 lakes over the sample period 1970-2018 for TSI (totaling 59,907 measurement observations). Outliers were removed to form the final dataset according to the following ranges: 0-2000 ug/L (Jones; Hand, 2004) for phosphorus, 0-130 ft (Green et al., 1996) for Secchi disk depth, 0-20,000 ug/L (EPA) for nitrogen, and 0-100 (Lake County Wateratlas) for TSI. Finally, Table 1 contains additional descriptive information regarding the characteristic district functions specified in the previous section.

Table 1: MSTU/MSBU District Characteristics

	MSTU	MSBU
Min District Age (years)	3	1
Max District Age (years)	61	37
Average District Age (years)	43	11
Min Board Age (years)	2	4
Max Board Age (years)	61	5
Average Board Age (years)	44	4.500
% with Advisory Board	83%	10%
% with Weed Control	33%	95%
% with WQ Improvement	2%	62%

Table 5 (Appendix A) contains summary statistics for all indicators over their respective sample periods. The average phosphorus content in the samples' lakes is 41.50 ug/L, which places the average lake in the sample period in the eutrophic range for phosphorus, according to Florida LAKEWATCH. The average nitrogen content in the sample's lakes is 970.67 ug/L, which places the average lake in the sample in the eutrophic range for nitrogen, according to Florida LAKEWATCH. The average Secchi disk depth in the samples' lakes is 5.73 ft, which places the average lake in the sample in the eutrophic range of $<$6.5 ft (Green et al., 1996). Finally, the average TSI rating in the samples' lakes is roughly 47, which means that the average lake in the sample period has an adequate level of nutrients, according to the Lake County Water Atlas.

Table 6 (Appendix A) contains summary statistics for all indicators over their respective sample periods by taxing district status. On average, MSTU/MSBU lakes have lower levels of phosphorus, nitrogen, and TSI rating and higher Secchi disk depths across the sample period. Additionally, MSTU/MSBU lakes have lower maximum phosphorus content, TSI rating, and Secchi disk depth than non-MSTU/MSBU lakes.

5.3 t Tests of Annual Mean Indicator Value

The outcome variable in this study is the annual mean of each indicator (phosphorus, nitrogen, TSI, and Secchi disk depth). This value is generated by lake by averaging at the daily level, then monthly, and finally at the annual level. Using the annual mean, I present a preliminary exploration of the MSTU/MSBU program's effects on lake water quality in the following t-test tables.

Table 2: Annual Mean Indicator Value in Non-MSTU/MSBU Lakes vs MSTU/MSBU Lakes

Indicator	Non-MSTU/MSBU	MSTU/MSBU	p
Phosphorus (ug/L)	46.58	32.90	0.00***
Secchi disk depth (ft)	5.07	7.58	0.00***
TSI	49.82	39.56	0.00***
Nitrogen (ug/L)	1051.62	781.66	0.00***

*** p<0.01, ** p<0.05, * p<0.1

Table 2 contains the average annual indicator value across each indicator's sample period for non-MSTU/MSBU lakes versus MSTU/MSBU lakes. The results shown indicate that there exists a significant difference between average lake water quality in non-MSTU/MSBU lakes and average lake water quality in MSTU/MSBU lakes. Average phosphorus content, nitrogen content, and TSI ratings are lower in MSTU/MSBU lakes. Moreover, average Secchi disk depth measurement is higher in MSTU/MSBU lakes.

Table 3: Annual Mean Indicator Value in MSTU/MSBU Lakes Pre-Designation vs Post-Designation

Indicator	Pre	Post	p
Phosphorus (ug/L)	86.53	23.04	0.00***
Secchi disk depth (ft)	6.58	7.76	0.00***
TSI	48.41	38.13	0.00***
Nitrogen (ug/L)	1120.39	721.45	0.00***

*** p<0.01, ** p<0.05, * p<0.1

Table 3's results show that there exists a significant difference between average lake water quality pre-designation and post-designation for the MSTU/MSBU lakes across all indicators. Average phosphorus content, nitrogen content, and TSI ratings are substantially lower in the post-designation period. Furthermore, average Secchi disk depth is higher in the post-designation period, indicating an increase in average lake water clarity in MSTU/MSBU lakes.

Table 4: Annual Mean Indicator Value in MSTU Lakes vs MSBU Lakes

Indicator	MSBU	MSTU	p
Phosphorus (ug/L)	62.53	22.20	0.00***
Secchi disk depth (ft)	3.71	7.86	0.00***
TSI	51.83	37.79	0.00***
Nitrogen (ug/L)	1071.49	713.83	0.00***

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

To examine which type of taxing district is superior, Table 4 compares the average annual indicator value in MSTU lakes versus MSBU lakes in the years following each type's designation. The results indicate that MSTU lakes have lower average phosphorus content, nitrogen content, and TSI ratings than MSBU lakes post-designation. Additionally, MSTU lakes have higher average Secchi disk measurement than MSBU lakes. These findings suggest that the MSTU mechanism is superior to the MSBU mechanism in improving lake water quality.

6 Results

6.1 MSTU/MSBU Lakes versus Non-MSTU/MSBU Lakes

6.1.1 Phosphorus

Table 7 (Appendix B) contains regression results for equations (4) and (5) applied to phosphorus content, where "P" denotes average annual phosphorus content. Models M1 and M2 form the set of parsimonious models. Their results show that, without explicit consideration of the other district characteristics, designation as a taxing district (either MSTU or MSBU) is associated with reduced phosphorus content in lakes. This result is consistent with *H1*, meaning that taxing districts improve lake water quality on average (with respect to phosphorus levels).

The set of complete models is comprised of M3 and M4. M3's results indicate that designation as a taxing district (either MSTU or MSBU) is insignificantly associated with reduced phosphorus content in lakes; M4 shows the opposite effect, indicating that overall designation has imparted mixed effects and thus *H1* is neither confirmed nor rejected. Moreover, taxing district age ("Age") is shown to be insignificantly associated with reduced phosphorus content in both specifications. This makes intuitive sense, as greater age means that a taxing district has had more time to mature and take effect in its given lake; "older" taxing districts have had more time to impart their intended effects on their respective lakes. Additionally, M3 shows that the presence of an advisory board ("Board") is significantly associated with increased phosphorus content. This could be due to the reasons necessitating the establishment of an advisory board; taxing districts with poor performance could be more likely to form an advisory board to manage the district than taxing districts who are doing well without one, among other reasons. The coefficients of the additional district characteristics also provide interesting insight into the structural efficacy of taxing districts. Taxing districts with "weed control" specified as a characteristic district function have lower phosphorus content, while those with "water quality improvement" specified have higher phosphorus content. On a more optimistic note, the age of an advisory board has an insignificantly negative effect on phosphorus content in M4, likely for similar reasons to taxing district age. This shows that, over time, advisory boards are possibly succeeding in improving their district's performance.

6.1.2 Secchi Disk Depth

Table 8 (Appendix C) contains regression results for equations (4) and (5) applied to Secchi disk depth, where "Depth" denotes average annual Secchi disk depth. In this section, Models M1 and M2 form the set of parsimonious models. Both models insignificantly show that designation as a taxing district (either MSTU or MSBU) has a negative effect on Secchi disk depth. These results contradict *H1*, indicating that, overall, taxing districts have not been effective at improving lake water quality with respect to Secchi disk depth.

Models M3 and M4 form the set of complete models for this section. In both specifications, designation as a taxing district (either MSTU or MSBU) significantly decreases Secchi disk depth. These results contradict *H1*, demonstrating that, overall, the taxing district program does not have equal effects across all water quality indicators. Additionally, taxing districts with "weed control" specified as a district function have higher Secchi disk depth on average, indicating that "weed control" is an effective or desirable district function. That is, taxing districts with "weed control" perform better than those without it, despite the overall inefficacy of taxing districts in increasing Secchi disk depth. Taxing district age, the "water quality improvement" district function, and the presence of an advisory board are all shown to insignificantly decrease Secchi disk depth, while advisory board age insignificantly increases Secchi disk depth. That is, advisory boards are likely succeeding in improving their district's performance with respect to Secchi disk depth over time despite their overall inefficacy in improving Secchi disk depth. Finally, the effects of advisory board age and "weed control" are desirable but inconclusive due to mixed levels of significance.

6.1.3 Trophic State Index (TSI)

Table 9 (Appendix D) contains regression results for equations (4) and (5) applied to Trophic State Index (TSI) ratings, where "TSI" denotes average annual TSI rating. In this section, models M1 and M2 form the set of parsimonious models. Both models significantly show that designation as a taxing district (MSTU or MSBU) increases TSI rating. This relationship contradicts *H1*, similar to the results for Secchi disk depth.

The set of complete models consists of M3 and M4. In these more robust specifications, designation as a taxing district (MSTU or MSBU) significantly increases TSI rating, which once again contradicts *H1* but is consistent with the parsimonious models' results. Thus it is more likely that, overall, the MSTU/MSBU program was not effective in reducing TSI ratings. Similar to the results in the Secchi disk depth section, both M3 and M3 show that taxing districts with "weed control" as a characteristic district function significantly (and insignificantly) decrease TSI ratings despite the overall inefficacy of taxing districts in reducing TSI ratings. This result further supports the value in incorporating "weed control" methods in lake water quality improvement efforts. That is, despite overall district ineffectiveness, having "weed control" as a district function mitigates the ineffectiveness. The "water quality improvement" function is also shown to be associated with lower TSI rating, which provides similar evidence towards mitigating district ineffectiveness.

Both models demonstrate taxing district age's negative impact on TSI rating. That is, as in prior in sections, older taxing districts perform better than younger ones, having had more time to take effect. The same conclusion can be applied to advisory board age in that districts with older advisory boards are more effective at reducing TSI rating than younger ones. Furthermore, M3 shows that having an advisory board is associated with increased TSI ratings, while M4 shows the opposite effect. M3's result is likely due again to the reasons necessitating the formation of an advisory board, such as poor performance or extremely poor initial quality conditions. On another more optimistic note, advisory board age is shown by both models to reduce TSI rating. This result shows that, given time, advisory boards are likely succeeding in their purpose of improving the taxing district's performance with respect to TSI rating despite overall district ineffectiveness.

6.1.4 Nitrogen

Table 10 (Appendix E) contains regression results for equations (4) and (5) applied to nitrogen, where "N" denotes average annual nitrogen content. M1 and M2 form the set of parsimonious models in this section. Both specifications show that designation as a taxing district (MSTU or MSBU) significantly reduces nitrogen content. This result is consistent with *H1* and shows that, without considering the interior composition of each district, taxing districts have been effective at improving lake water quality.

The set of complete models consists of M3 and M4. M3 shows that designation as a taxing district insignificantly increases nitrogen content (supporting *H1*), while M4 shows the opposite effect (contradicting *H1*). Compared to the Tax coefficients in M1 and M2, M3 and M4 show that MSTU/MSBU effectiveness may not be robustly effective. Both specifications also show that taxing district age insignificantly reduces nitrogen content for the same reasons given for prior indicator results. Another repeated result in both models is the advisory board presence significantly increasing nitrogen content. As with other indicators, this is likely due to the fact that an advisory board was necessary in the first place, either due to poor district performance or initial quality conditions. Unlike prior results however, the age of an advisory board is significantly associated with increases in nitrogen content in both models. This likely means that, unlike with TSI rating, advisory boards are not succeeding in their purpose of improving the district's performance with respect to nitrogen content over time. In M3, “weed control” is shown to significantly decrease nitrogen content. However, M4 shows the opposite effect, likely meaning that the “weed control” function is not robustly effective. The same cannot be said for “water quality improvement”, which is shown to insignificantly increase nitrogen content in M3 and M4.

6.2 MSTU Lakes versus MSBU Lakes

6.2.1 Phosphorus

Table 7 (Appendix B) contains regression results for equations (6) and (7) applied to phosphorus. Models M5 and M6 form the set of parsimonious models for this section. Both specifications show that designation as an MSTU insignificantly reduces phosphorus content, which is consistent with *H1*. However, only M5 shows that MSBU designation insignificantly reduces phosphorus content, which is also consistent with *H1*; M6 shows the opposite effect, contradicting *H1*. Moreover, the MSTU coefficients in both models are larger in absolute value than the MSBU coefficients, indicating that MSTU designation is superior to MSBU designation in reducing phosphorus content. This result is consistent with *H2* and the prior intuition hypothesizing the superiority of MSTU designation.

The set of complete models consists of M7 and M8. M7 shows that both MSTU and MSBU designation insignificantly reduce phosphorus content, while M8 shows the opposite effect for both district types. Thus M7’s results are consistent with *H1* while M8’s results contradict it, so no definitive conclusion can be reached regarding either type when considering within-district characteristics. However, the appreciable difference in coefficient magnitude between MSTU designation and MSBU designation in both models supports *H2*. Furthermore, taxing district age in these specifications is divided into two separate age variables: one for MSTUs (MSTU Age) and one for MSBUs (MSBU Age). In both models, MSTU age and MSBU age are insignificantly associated with reduced phosphorus content.

As with the overall taxing district age in the section 6.1, this result is likely indicative of MSTU and MSBU effectiveness benefiting from additional time to take effect despite their insignificant overall impact. The "weed control" function is shown to be insignificantly and significantly associated with decreased phosphorus content in M7 and M8 respectively, again providing some evidence in support of specifying it as a district function. The age of an advisory board again produces mixed results between the two models, but the presence of an advisory board is significantly and insignificantly associated with increased phosphorus content in M7 and M8 respectively. Thus it appears that advisory boards have not been successful in improving district performance overall with respect to phosphorus content.

6.2.2 Secchi Disk Depth

Table 8 (Appendix C) contains regression results for equations (6) and (7) applied to Secchi disk depth. Models M5 and M6 form the set of parsimonious models for this section. M5 and M6 shows that MSTU designation and MSBU designation insignificantly reduce Secchi disk depth, which contradicts *H1*. The difference in coefficient magnitude between MSTU designation and MSBU designation in both models supports *H2*, albeit insignificantly and without the benefit of increasing average Secchi disk depth.

The set of complete models consists of M7 and M8. In both models, MSTU and MSBU designation significantly reduce Secchi disk depth, contradicting *H1* once again. Thus, factoring in the additional within-district characteristic functions, the MSTU/MSBU program was not successful at improving lake water quality with respect to Secchi disk depth. However, the difference in coefficient magnitude between MSTU designation and MSBU designation supports *H2*, with MSBU being weakly superior in this case. Furthermore, the program did not have equal effects across all indicators.

As for the additional characteristic functions, note that "weed control" is shown to significantly increase Secchi disk depth in both models, providing more evidence supporting it as a useful district function. "Water quality improvement" is shown to have the opposite effect, though only M8 does so significantly. The presence of an advisory board insignificantly and significantly reduces Secchi disk depth in M7 and M8 respectively, which is consistent with its undesirable impacts in prior sections. As before, taxing district age in these specifications is divided into two separate age variables for MSTU and MSBU designation respectively. MSBU age reduces Secchi disk depth in both models, though only M7 produces a significant coefficient. This reinforces the fact that MSBUs did not improve average Secchi disk depth. MSTU age insignificantly reduces Secchi disk depth in both models, which reinforces MSTUs' ineffectiveness in improving average Secchi disk depth. That is, MSTUs and MSBUs do not appear to have increased average Secchi disk depth measurements even when accounting for time to mature and take effect.

6.2.3 TSI

Table 9 (Appendix D) contains regression results for equations (6) and (7) applied to TSI ratings. Models M5 and M6 form the set of parsimonious models for this section. Both models show that MSTU designation and MSBU designation are associated with increased TSI rating, which contradicts *H1*. Despite their insignificance, both models show that MSBU designation is superior to MSTU designation; both district types increase average TSI rating, but MSBU designation increases it by less than MSTU designation. This result is consistent with *H2*, though it differs from the predominant result in prior models and indicators showing that MSTU designation is superior.

The set of complete models consists of M7 and M8. In both models, MSTU and MSBU designation significantly increase TSI rating, contradicting *H1* but supporting the parsimonious models' results. Similar to the parsimonious models, M7 and M8 again show that MSBU designation is superior to MSTU designation; both types increase TSI rating on average, but MSBU designation increases is by less. The superiority of MSBU designation is further supported in both models by MSBU age's smaller coefficient compared to MSTU age. Despite the robust result that both MSTU and MSBU designation increase TSI rating instead of decreasing it, the reductive impact of MSTU age and MSBU age indicates that there is some viability for both district types. Further supporting this indication is "weed control"'s significant negative impact on TSI rating in all but one model (that lone model still shows a negative effect however), which makes the "weed control" function even more desirable. "Water quality improvement" is also shown to reduce TSI rating in all models but one (M7). The presence of an advisory board insignificantly increases TSI rating in M3 and M7 (and insignificantly decreases it in M4 and M8), but advisory board age significantly decreases TSI rating in all four models. This demonstrates that districts with advisory boards are at least possibly working in the desirable direction of performance improvement over time.

6.2.4 Nitrogen

Table 10 (Appendix E) contains regression results for equations (6) and (7) applied to nitrogen content. Models M5 and M6 form the set of parsimonious models for this section. Both models show that MSTU and MSBU designation are associated with decreased nitrogen content, which is consistent with *H1*. Moreover, MSTU designation is again shown to be superior to MSBU designation; MSTU designation reduces nitrogen content on average by a larger amount than MSBU designation. This result is consistent with the prior intuition hypothesizing MSTU designation's superiority and the difference in coefficient magnitudes associated with this result is consistent with *H2*.

The set of complete models consists of M7 and M8. Both models show that MSTU designation is associated with reductions in nitrogen content, though only M8 produces a significant result. This result is consistent with *H1*. However, M7 and M8 produce positive effects on nitrogen content by MSBU designation, which contradicts the results from the parsimonious models and *H1*. These mixed results indicate that MSBU designation likely had both positive and negative effects on average nitrogen content to differing extents. There is some cause for optimism however, as both models indicate that MSTU and MSBU age significantly reduce nitrogen content. In fact, MSBU age is shown to be highly significant in reducing nitrogen content. This likely means that despite MSBU designation's robust ineffectiveness, the districts are at least trending in the right direction over time. As for MSTU designation, the MSTU age result supports its negative effect on nitrogen content.

M7 shows that "weed control" reduces nitrogen content, while M8 shows the opposite effect. On the other hand, "water quality improvement" is insignificantly associated with decreased nitrogen content in both models. Unfortunately, the presence of an advisory board significantly increases nitrogen content, much like it adversely affected other indicators in prior results. Compounding the undesirable effects of advisory board establishment on nitrogen content, advisory board age is shown to significantly increase nitrogen content in both M7 and M8. This indicates that advisory boards are likely not improving their district's performance (with respect to nitrogen content) over time, i.e. maturity is not aiding district performance in this case.

7 Conclusion

The objective of this project was to empirically evaluate the efficacy of the MSTU/MSBU program in improving lake water quality. To that end, four water quality indicators were studied: total phosphorus, total nitrogen, Secchi disk depth, and Trophic State Index (TSI). After constructing the theoretical motivation, time and entity fixed effects econometric models were devised for use in the analyses. These analyses produced mixed results on the effectiveness of MSTU and MSBU designation in improving lake water quality. The mixed nature of the results is mainly attributable to the inclusion of taxing district characteristic functions. When not accounting for these functions, the parsimonious analyses show that MSTU/MSBU designation overall and individually are moderately effective at improving lake water quality; taxing district effectiveness was best supported by the results from phosphorus and nitrogen specifications. When the district functions are included in the models, the complete analyses show that the MSTU/MSBU program has imparted moderately positive effects on lake water quality; the phosphorus and nitrogen specifications once again produced the most promising results. Moreover, the superiority of a district type varied across indicators and specifications.

Substantial evidence of program ineffectiveness was also found (particularly in the TSI and Secchi disk depth models), which diminishes the positive results generated by both the parsimonious and complete models across all indicators. Despite those findings, some other positive takeaways were discovered. The weed control district function was consistently found to be effective at improving lake water quality across multiple parameters (particularly with respect to Secchi disk depth). This implies that the weed control function is deserving of continued implementation in districts that already have it and of establishment in districts that do not. Other important district functions and factors that were empirically identified are: advisory board age, overall district age, and MSTU/MSBU specific age. Those results demonstrate that district and board maturity matter for the efficacy of taxing districts.

Like other PFP methods that have been studied (Talberth et al., 2015), the MSTU/MSBU program demonstrates the potential to be an effective economic tool for attaining environmental standards. This potential is shown to be contingent upon the design of the taxing district. This is due in large part to the heterogeneity in superiority between district types across multiple indicators and specifications. That is, MSTUs achieve better impacts in more specifications than MSBUs, so there is some evidence supporting MSTUs as the superior district despite the lack of robustness across specifications. Thus it appears that the MSTU ad valorem taxing mechanism is relatively superior to the MSBU flat rate taxing mechanism, so some consideration should be given to furthering MSTU implementation and/or restructuring the MSBU taxing structure. However, I also recognize that MSTUs were typically older and more plentiful than MSBUs across the sample period, so MSTU superiority is not totally attributable to its ad valorem taxing mechanism. In sum, the MSTU/MSBU funds that have been specifically allocated for use in water management practices have, to a limited and mixed extent, mildly mitigated the negative ambient impacts of urban living.

Following prior work in hedonic valuation of lake water quality (Walsh et al., 2011; Gibbs et al., 2002; Leggett and Bockstael, 2000; Wolf and Klaiber, 2017), the environmental impacts of the MSTU/MSBU program are likely twofold since they positively influence economic indicators such as property prices. Furthermore, the voluntary nature of the MSTU/MSBU taxing districts demonstrates that the incentives of private property owners line up with environmental incentives whose effects extend beyond the local setting. Moreover, the aforementioned potential superiority of the MSTU provides evidence towards the optimal taxing structure that could be utilized in PFP methods in general. A notable component not covered by this study is the hedonic valuation of the demonstrated improvements in water quality, so future research should examine the associated property price effects.In addition, more work is needed to isolate and comparatively examine the effects of each taxing structure (ad valorem and flat rate) independent of district age and quantity.

A Summary statistics

Table 5: Summary statistics for all indicators

Indicator	Mean	Std. Dev.	Min	Max
Phosphorus (ug/L)	41.50	72.74	0	2,000
Secchi disk depth (ft)	5.73	4.01	0	111.55
Nitrogen (ug/L)	970.67	943.80	0	20,000
TSI	47.06	14.61	1	100

Table 6: Summary statistics for all indicators by taxing district status

Indicator		Mean	Std. Dev.	Min	Max
Phosphorus (ug/L)	Non-MSTU/MSBU	46.20	73.10	0	2,000
	MSTU/MSBU	30.52	70.70	0	1,880
Secchi disk depth (ft)	Non-MSTU/MSBU	5.07	3.570	0	111.55
	MSTU/MSBU	7.58	4.56	0	72.18
Nitrogen (ug/L)	Non-MSTU/MSBU	1,051.20	1,030.01	0	20,000
	MSTU/MSBU	781.19	662.75	0	20,000
TSI	Non-MSTU/MSBU	49.81	13.99	1	100
	MSTU/MSBU	39.56	13.57	2	96

B Fixed effects regression results for phosphorus

Table 7: Fixed effects regression results for phosphorus

VARIABLES	M1 P	M2 ln(P)	M3 P	M4 ln(P)	M5 P	M6 ln(P)	M7 P	M8 ln(P)
Age			-1.343	-0.005				
			(1.638)	(0.009)				
Board			57.965*	0.020			57.967*	0.047
			(31.353)	(0.165)			(31.923)	(0.165)
Board Age			2.068	-0.001			2.092	-0.003
			(1.600)	(0.009)			(1.561)	(0.009)
Weed Control			-26.860	-0.433			-26.038	-0.418*
			(38.157)	(0.266)			(39.375)	(0.253)
WQ Improvement			45.002	0.175			53.356	-0.027
			(45.352)	(0.245)			(49.540)	(0.253)
Tax	-27.369	-0.037	-19.146	0.339				
	(28.945)	(0.125)	(36.485)	(0.263)				
MSTU					-30.380	-0.131	-17.072	0.262
					(41.469)	(0.161)	(40.147)	(0.268)
MSBU					-21.141	0.157	-19.927	0.582**
					(22.878)	(0.165)	(45.000)	(0.284)
MSTU Age							-1.378	-0.003
							(1.588)	(0.009)
MSBU Age							-3.924	-0.007
							(2.550)	(0.015)
Constant	241.368***	6.082***	229.612***	6.056***	241.844***	6.096***	229.378***	6.063***
	(6.143)	(0.026)	(4.761)	(0.038)	(8.029)	(0.031)	(5.047)	(0.037)
Observations	6,752	6,747	6,752	6,747	6,752	6,747	6,752	6,747
R^2	0.288	0.423	0.297	0.425	0.289	0.424	0.297	0.426
Number of lakes	317	317	317	317	317	317	317	317

Robust standard errors, clustered by lake, in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

C Fixed effects regression results for Secchi disk depth

Table 8: Fixed effects regression results for Secchi disk depth

	M1	M2	M3	M4	M5	M6	M7	M8
VARIABLES	Depth	ln(Depth)	Depth	ln(Depth)	Depth	ln(Depth)	Depth	ln(Depth)
Age			-0.026	-0.005				
			(0.018)	(0.003)				
Board			-0.591	-0.138*			-0.589	-0.134*
			(0.539)	(0.072)			(0.557)	(0.075)
Board Age			0.033	0.006			0.033	0.006
			(0.026)	(0.004)			(0.027)	(0.005)
Weed Control			3.278***	0.505***			3.315***	0.512***
			(1.132)	(0.133)			(1.146)	(0.133)
WQ Improvement			-0.749	-0.172**			-0.601	-0.181*
			(0.457)	(0.087)			(0.630)	(0.098)
Tax	-0.333	-0.050	-2.764**	-0.389***				
	(0.325)	(0.053)	(1.094)	(0.129)				
MSTU					-0.262	-0.044	-2.729**	-0.396***
					(0.445)	(0.072)	(1.155)	(0.138)
MSBU					-0.458	-0.062	-2.693**	-0.350**
					(0.307)	(0.057)	(1.168)	(0.153)
MSTU Age							-0.026	-0.005
							(0.019)	(0.004)
MSBU Age							-0.097*	-0.013
							(0.053)	(0.012)
Constant	7.254***	1.888***	7.928***	2.011***	7.308***	1.893***	7.988***	2.015***
	(0.244)	(0.041)	(0.372)	(0.068)	(0.333)	(0.055)	(0.360)	(0.068)
Observations	6,533	6,531	6,533	6,531	6,533	6,531	6,533	6,531
R^2	0.040	0.067	0.045	0.072	0.040	0.067	0.045	0.072
Number of lakes	314	314	314	314	314	314	314	314

Robust standard errors, clustered by lake, in parentheses
*** p<0.01, ** p<0.05, * p<0.1

D Fixed effects regression results for TSI

Table 9: Fixed effects regression results for TSI

	M1	M2	M3	M4	M5	M6	M7	M8
VARIABLES	TSI	ln(TSI)	TSI	ln(TSI)	TSI	ln(TSI)	TSI	ln(TSI)
Age			-0.073	-0.002				
			(0.074)	(0.001)				
Board			0.697	-0.008			0.731	-0.006
			(1.314)	(0.043)			(1.284)	(0.043)
Board Age			-0.177*	-0.005**			-0.177*	-0.005**
			(0.097)	(0.002)			(0.101)	(0.002)
Weed Control			-2.743*	-0.022			-5.413***	-0.080***
			(1.501)	(0.034)			(1.079)	(0.027)
WQ Improvement			-2.535	-0.076			0.125	-0.019
			(2.717)	(0.055)			(2.650)	(0.054)
Tax	2.710*	0.065**	6.391***	0.121***				
	(1.422)	(0.029)	(0.780)	(0.018)				
MSTU					4.492***	0.114***	9.633***	0.191***
					(1.478)	(0.028)	(1.685)	(0.037)
MSBU					1.632	0.036	6.547***	0.132***
					(1.986)	(0.040)	(0.993)	(0.021)
MSTU Age							-0.073	-0.001
							(0.078)	(0.002)
MSBU Age							-0.112	-0.004
							(0.177)	(0.004)
Constant	72.476***	4.266***	71.280***	4.247***	72.536***	4.267***	70.945***	4.240***
	(8.213)	(0.156)	(7.616)	(0.138)	(8.170)	(0.155)	(7.577)	(0.138)
Observations	4,786	4,786	4,762	4,762	4,786	4,786	4,762	4,762
R^2	0.192	0.155	0.201	0.167	0.192	0.156	0.201	0.168
Number of lakes	292	292	290	290	292	292	290	290

Robust standard errors, clustered by lake, in parentheses
*** p<0.01, ** p<0.05, * p<0.1

E Fixed effects regression results for nitrogen

Table 10: Fixed effects regression results for nitrogen

VARIABLES	M1 N	M2 ln(N)	M3 N	M4 ln(N)	M5 N	M6 ln(N)	M7 N	M8 ln(N)
Age			-9.200	-0.006				
			(6.842)	(0.004)				
Board			291.588**	0.166*			334.281***	0.189**
			(121.377)	(0.086)			(118.250)	(0.086)
Board Age			15.580**	0.010**			13.438**	0.009**
			(6.574)	(0.005)			(6.121)	(0.004)
Weed Control			-319.106*	0.019			-259.467	0.051
			(173.778)	(0.113)			(189.257)	(0.117)
WQ Improvement			109.660	0.001			-140.840	-0.144
			(231.864)	(0.134)			(402.323)	(0.227)
Tax	-250.593**	-0.122*	31.842	-0.126				
	(120.850)	(0.070)	(149.527)	(0.101)				
MSTU					-298.632*	-0.139	-89.070	-0.195*
					(179.400)	(0.104)	(175.794)	(0.109)
MSBU					-173.397	-0.094	452.937	0.102
					(130.900)	(0.071)	(369.111)	(0.218)
MSTU Age							-7.000	-0.004
							(6.359)	(0.004)
MSBU Age							-57.387***	-0.029**
							(19.121)	(0.014)
Constant	1,136.589***	6.919***	1,030.552***	6.879***	1,144.619***	6.922***	1,044.256***	6.887***
	(24.410)	(0.014)	(22.783)	(0.016)	(33.405)	(0.020)	(27.751)	(0.019)
Observations	6,266	6,265	6,266	6,265	6,266	6,265	6,266	6,265
R^2	0.139	0.142	0.150	0.150	0.139	0.142	0.152	0.151
Number of lakea	308	308	308	308	308	308	308	308

Robust standard errors, clustered by lake, in parentheses

*** p<0.01, ** p<0.05, * p<0.1

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