ECONOMIC VALUE OF WATER QUALITY IMPROVEMENTS IN ONTARIO

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By

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ABSTRACT

This study estimates the economic value of lake water quality changes in South Eastern region of Ontario using the hedonic price method. The research combines 58,085 house transaction data between 2005-2014 time periods and water quality (WQ) data from 494 unique lakes. I examine the effect of total phosphorus and Secchi depth (SD) on house price using a log-linear regression. Considering SD as the variable of interest, results indicate that house buyers are willing to pay a 1.9% higher price for a one-meter improvement in SD if the house is located close to the lake WQ station. The marginal willingness to pay (MWTP) for SD reaches the peak, \$7,627 per meter, for houses located within 500 meters to 750 meters distance to the lake stations. However, the price premium starts to decrease as the lake distance increases; house buyers are willing to pay 4.4% less for a marginal increase in SD if the house is located within 2,000 to 3,000 meters of the WQ stations. I assess the robustness of the results across the alternative data specification and estimate the highest level of MWTP for water quality (\$6, 142) considering houses within 3 kilometres to the lake stations. The estimated local benefits can inform the design of WQ improvement programs.

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DEDICATION

I want to dedicate my thesis to my lovely mother who passed away four years ago.

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DO……………………. Dissolved Oxygen

FE…………………….. Fixed Effect

HPI…………………… House Price Index

LSPOP……………….. Lake Simcoe Phosphorus Offsetting Program

MPAC………………… Municipal Property Assessment Corporation

MWTP………………... Marginal Willingness to Pay

OGF…………………... Ontario Geospatial Feature

SD……………………. Secchi Depth

STN…………………... Station Number

TP……………………. Total Phosphorus

WQ…………………… Water Quality

WTP………………….. Willingness to Pay

Chapter 1

Introduction

Canada is rich with freshwater bodies. The landscape includes more than 8,500 rivers and 2 million lakes, which is about 9% of its total area. These lakes and rivers provide various market benefits through their use as drinking water, commercial fisheries, irrigation water, and industrial inputs. Furthermore, freshwater bodies provide aesthetic and recreational facilities, which are largely non- market benefits. These market and non-market benefits can vary with the quality of water (Keeler et al., 2012).

The Canadian province, Ontario, contains hundreds of thousands inland lakes with fresh water that offers a high recreational value not only for the people of Ontario but also for the visitors from outside of the province. According to the Ontario Ministry of the Environment (2009), Ontario has about 250,000 inland lakes greater than a hectare in size, more than 500,000 kilometers of rivers and streams, and 5,300 kilometers of shoreline on four of the five Great Lakes. The abundance of freshwater bodies and its widespread benefits promote this region as a popular recreational destination. Lakes in this region are popular for canoeing, sailing, windsurfing, waterskiing, and other water activities that raise its appeal as a vacation destination. People from different cultures, age groups, economic status gather here for recreational purposes.

The South Eastern part of this province is popular for its freshwater lakes, lakefront properties and recreational destinations. However, the wide use of agriculture, industry, and urban purposes raise lake water quality (WQ) issues, from nutrient enrichment to the release of toxic substances (Ontario Ministry of Environment and Climate Change, 2010). Agricultural runoff, industrial discharge, toxins, sewage, chemical dumping, land use actions, and development activities from the watershed may deteriorate the WQ. Agricultural and industrial runoff may deposit excessive phosphorus, nitrogen as well as other sediments to surface water. The nutrient rich waters result an increase in algae and other plant growth. When this increased plant biomass dies and decomposes, it consumes oxygen making for low oxygen waters. A shortage of oxygen for fish and other living organisms in the water can hamper fish growth and ecosystem services (Leggett and Bockstael 2000). Too much phosphorus in lake water further increases turbidity, organic matter, unfavorable taste and odor. It reduces water quality, recreational and aesthetic benefits and also increases the risk of human health.

Lake WQ may have impacts on recreational decisions, vacation destination choice, and property purchase decisions (Young 1984; Poor, Pessagno and Paul 2007). The property purchasing decision is a trade-off between people's willingness to pay (WTP) and receiving their aggregate benefits. Any improvements or deterioration in the lake WQ may increase or reduce the aggregate benefit from water use. This may also influence the WQ improvement costs. However, managing lakes, controlling pollution, and ensuring water quality improvement is a great challenge because it demands extensive efforts. The process of lake management, e.g. phosphorus offset, is a costly venture. For example, the Lake Simcoe Phosphorus Offsetting Program (LSPOP) targets reducing the phosphorus level of the lake to improve the WQ with a view to increasing the environmental, social, and economic benefits for the stakeholders (Lake Simcoe Region Conservation Authority 2017). According to the Lake Simcoe Region Conservation Authority (2017), the phosphorus offset cost for the lake is $35,000 per kilogram, with an additional 15% fee as an administration charge. Under this circumstance, it is crucial to know how much benefits are gained from WQ improvement. However, it is a challenge to estimate the economic value of WQ improvements as the monetary value of the non market benefits is uncertain. It is tough to invest in a good or service without knowing its price. So, knowledge on the value of multi-purpose use of a recreational lake is a pre-requisite for obtaining the maximum level of benefits. Moreover, the lack of valuation information of a lake may hinder the efficient lake management process. The value of WQ may help in the analysis of the costs and benefits of WQ improvement and contribute to more effective policy development.

The purpose of this study is to estimate the value of lake WQ in Ontario using the hedonic price method. The hedonic price method is a revealed preference technique for quantifying a change in a non-market good that has a direct effect on property values. This method is widely used in the field of WQ value estimation; studies like Steinnes (1992); Michael, Boyle, & Bouchard (1996); Gibbs, Halstead, Boyle, & Huang (2002); Leggett & Bockstael (2000); Walsh, Milon, & Scrogin (2011); Clapper and Caudill (2014) have used the same method for WQ valuation. Though Ontario is a popular holiday destination for lake-based recreation, only Clapper and Caudill (2014) and Calderón-Arrieta, Caudill and Mixon (2019) have conducted WQ valuation studies using hedonic price method in this region. Both the studies consider only 253 cottages for their studies. This study estimates the lake WQ value by using a larger housing data set compared to the previous studies in the Ontario region.

This valuation study is conducted based on three specific objectives: (1) estimating the relationship between lake WQ and residential property values in Ontario; (2) investigating how the relationship changes across different WQ measures; and (3) estimating the economic benefits of lake WQ improvements. The research contributes to the robust value estimation of lake WQ with larger sample size; this may quantify how important the lake WQ is for the people of Ontario. Moreover, the estimated result may help the relevant authority in preparing recreational and aesthetic guidelines and policies for the lake users. The study comprises the following sections; chapter one starts with the background information; chapter two provides the extensive literature review on WQ valuation; chapter three and chapter four describe the study area and the detail methodological steps of the empirical model; chapter five discusses the estimated results; and finally, chapter six portrays the conclusion of the research.

Chapter 2

Literature Review

In this section, I review the literature concerning four broad categories: (1) concepts of economic valuation approaches; (2) Hedonic price method and WQ valuation studies; (3) WQ variables used in various research; and (4) estimated results of WQ valuation studies. I apply the results of this review to determine the research gap of valuation application in Canada.

2.1 Economic Valuation Approaches

Economic valuation focuses on estimating the monetary expression of both market and non-market goods and services. Marketable goods define the bundle of goods that can be traded in the market with an observable price whereas non-market goods are those which are not typically or not able to be traded in the market. For example, fishes are harvested from lakes and traded in the market; however, the scenic view of the lake is not possible to buy and sell in the traditional market. Here, fish is a marketable good; the scenic beauty is non-market good. Non-market goods have an incomplete value in the market but may have high economic value.

As environmental goods are typically non-market goods, these goods are not possible to trade in the traditional market. The total economic value of an environmental good comprises both use values and non-use or passive use values. The benefits an individual gains by using that environmental good is the use value; the value without using (e.g. for existence or future use) that good is the non-use value of the environmental good. Again, the use value of an environmental good is two-dimensional: consumptive use value (diminish the amount through consumption; for example: harvesting fish) and non-consumptive use value (not diminishing with consumption; for example scenic beauty of a lake). The use value of an environmental good can also be direct use value or indirect use value (Champ, Boyle and Brown 2014, 10-11).

People value an environmental good based on their welfare gain and loss from that good (Champ, Boyle and Brown 2014, 10). The non-market valuation approach (explores value given by the individual for non-market goods) estimates the price of environmental goods (Grafton et al. 2008, 6). The valuation is based on measuring the welfare change due to the change in that good (Grafton et al. 2008, 2). The first stage of measuring the welfare change is to formulate alternatives. Based on the alternatives, changes in the environmental good should be identified that acknowledges the impact on human welfare due to that change. The impact is quantified and finally, the environmental change is valued with proper valuation methods (Champ, Boyle and Brown 2014, 13-14).

Different methods of non-market valuation are used in a different context. According to Grafton et al. (2008, 7-9), for the valuation of an environmental good, changes in environmental characteristics needed to evaluate either based on the relationship between market goods and environmental goods or creating a hypothetical market for the environmental goods. Moreover, Freeman, Herriges and Kling (2014) discussed two approaches to measure the value of environmental goods; revealed preference method and stated preference method. Revealed preference methods deal with the actual human consumption behavior targeting utility maximization with constraints. Any change in environmental good influences the consumer behavior (demand) of a marketable good as both goods are internally linked. Revealed preference methods estimate the value (use-value) of any change in environmental quality by the price variation of related marketable goods. Hedonic methods, random utility models, travel cost methods, and ecosystem service models are different approaches of these methods (Freeman, Herriges and Kling 2014).

On the other hand, stated preference method is based on a hypothetical market rather than a real choice scenario. In some cases, environmental change may have no connection, or a tenuous connection, with any marketable good. For example, people may have willingness to pay to save an ecosystem service that has no use-value in the present context but may have existence value for the future. This type of value for an environmental good, where any change in the environmental quality does not affect market behavior, can be measured by the stated preference method. It is a survey-based non-market valuation technique where the value of an environmental good is assessed based on individuals' replies within a structured questionnaire. Contingent valuation, attribute-based methods, accounting for uncertainty (option prices, quasi option value) are different approaches to the stated preference method (Freeman, Herriges and Kling 2014).

2.2 Hedonic Price Method and Water Quality Valuation Studies

The valuation of WQ is not an easy task as it provides both market and non-market benefits. To estimate the non-market benefits (e.g. recreational and aesthetics benefits), the hedonic price method has been widely used in different studies like Clapper and Caudill (2014); Steinnes (1992); Gibbs et al. (2002); Leggett and Bockstael (2000); Liu, Opaluch and Uchida (2017); Walsh, Milon and Scrogin (2011); Boyle, Poor and Taylor (1999); Poor, Pessagno and Paul (2007); Michael, Boyle and Bouchard (1996, 2000); Artell (2014); Young (1984); Walsh et al. (2017); Boyle and Taylor (2001); Node, Lansford and Jones (1995); Bin and Czajkowski (2013); and Poor et al. (2001).

The hedonic price method is a revealed preference technique for quantifying any change in the environmental attribute that has a direct effect on property values (Clapper & Caudill, 2014). This method estimates the value of environmental attributes through analyzing the property value, the actual behavior of property buyers, as a function of its attributes (Walsh et al., 2017). For example, lake WQ may influence waterfront property demand, and any change in WQ may also affect the adjacent house price. Here, WQ has use values to the property buyers where improved WQ provides higher utility and raises welfare. Under this circumstance, valuing an environmental attribute (use-value) is possible by observing the market for any change in environmental quality. Clean lake water may raise the adjacent property prices and a lower water quality may decrease the willingness to pay of agents in the real estate markets. The value of any change in WQ can be estimated by hedonic price method.

To estimate the value of lake WQ, the variation in sale price on the lake-adjacent property market due to the change in the WQ are observed. Freeman (1979) argued that the method comprises two separate stages. The first stage of the hedonic technique estimated the implicit price of environmental attributes with the hedonic price equation and the second stage estimated the home buyers' demand or MWTP function with the estimated implicit price derived from the first stage of the model. The price of the house is a function of its structural, neighborhood, and environmental attributes where the marginal implicit price of a single attribute is estimated by differentiating the price function of that specific attribute. Housing markets in the different regions are diverse with their altered demand and supply structure. A home buyer maximizes his or her utility at the point where the marginal implicit price of an attribute is equal to the MWTP for an additional unit of that attribute.

Leggett and Bockstael (2000) and Walsh et al. (2017) estimated the potential benefits of WQ improvements in the Chesapeake Bay, US by using hedonic pricing methods and concluded that improvement in WQ had a significant positive impact on property prices. Leggett and Bockstael (2000) described the influence of physical characteristics of water on residential prices in the same property market (adjacent to the Bay). They estimated the benefits for a small number of affected properties and the upper bound to benefits for a widespread improvement. Walsh et al. (2017) also conducted a hedonic study with a large data set (over 225,000 property sale data within 4 km of Chesapeake Bay) in 14 counties of Maryland to explore the effect of WQ on property price in a wider area. The study found that houses nearer to the bay provide better access to the environmental amenities, e.g. recreational and aesthetic, with significant benefits of WQ improvements.

Environmental quality as well as neighborhood attributes of an adjacent property were not easy to observe in an instance for a home buyer as the quality and quantity of these attributes are measured in units and proximity (Poor et al. 2001). Poor et al. (2001); Boyle, Poor and Taylor (1999); Michael, Boyle, and Bouchard (1996); Michael, Boyle, and Bouchard (2000); and Boyle and Taylor (2001) conducted different WQ valuation studies with hedonic approaches on different lakes and ponds in Maine, US and found a significant effect of WQ on adjacent property prices. Many studies use water clarity as a measure of WQ. Boyle, Poor and Taylor (1999) estimated the effect of water clarity on four different property markets where the lake WQ values differed from market to market. A two-stage hedonic model (linear, log-linear, Cobb-Douglas) was used for the study.

Michael, Boyle, and Bouchard (1996, 2000) as well as Boyle and Taylor (2001) measured the value of WQ (implicit price of water clarity) and found a significant price effect in response to WQ improvement. Boyle and Taylor (2001) collected lakefront property sale data and attribute data on 34 Maine lakes from town-office and surveyed to explore the implicit price of water clarity. The paybacks from improved WQ influence lakeshore property values and lakefront property owners enjoyed the highest benefits from improved WQ. If other things remained the same, buyers were willing to pay more for a lakeshore property with improved WQ. Here, the value of improved WQ was estimated by the price differentials of properties with the quality changes while keeping all the other related variables constant (Michael, Boyle, and Bouchard 1996). Michael, Boyle, and Bouchard (2000) argued that buyers' perception on water quality was significantly related to the lakefront property prices. An attempt to compare the implicit price estimated based on subjective (individuals' perception) and objective (scientific measurements of environmental quality) measurement of WQ was completed by Poor et al. (2001) where they found that the objective measurement explained the property value in a better way than subjective measurement. They also applied hedonic models for both subjective and objective WQ measurement.

The economic value of lake WQ in Northern Minnesota was explored by using hedonic methods where Steinnes (1992) followed alternative specifications to avoid various methodological and empirical problems. The author was restricted to the first-stage estimation of the hedonic approach for WQ valuation. The author applied the hedonic method to determine the effects of WQ on land values. Likewise, Poor, Pessagno and Paul (2007) used the first stage of the hedonic model to estimate the implicit value of ambient WQ of Mary's river watershed in Maryland. They used the semi-log model for value estimation. An impact analysis study with the same valuation approach had been done by Liu, Opaluch and Uchida (2017) where authors tried to explore how the WQ of Narragansett Bay affected the housing price in nearby cities. The study estimated the welfare effect of WQ improvement and found a negative impact of poor WQ on house prices. The magnitude of the effect was higher for properties closest to the waterbody and vice versa.

Walsh, Milon and Scrogin (2011) explored the effect of improved WQ on both lakeshore and non-lakeshore urban property prices in Orange County, USA by using the hedonic method. They further estimated the aggregate benefits from the improvement of WQ. The research was based on three hypotheses e.g. edge effect (WQ value varies with property location e.g. waterfront and non-waterfront), proximity effect (property distance from water body) and area effect (size of the water body) and *ceteris paribus*. The study found that property price was significantly related to WQ, location of the water body and its size; property prices were high for cleaner lake water, bigger lake size, and nearness to the lake. They further concluded that the benefit to a lakefront house was much higher than to a non-lakefront house. However, ignoring the aggregate benefits (for an improvement in lake WQ) of non-lakefront properties would underestimate the total benefits.

Young (1984), Bin and Czajkowski (2013) and Gibbs et al. (2002) investigated the impact of WQ on waterfront property prices by using the hedonic price method. The effect of WQ on summer house prices in Lake Champaign, St. Albans Bay was explored by Young (1984). The author argued that the perception of house buyers regarding WQ was not dependent on the physical measurement of WQ rather focused on visible characteristics of water. Bin and Czajkowski (2013) explored the effect of WQ improvement on the waterfront property values of South Florida. The estimation was based on the technical (temperature, p^H, water visibility, salinity and DO) and non-technical (location grade) WQ measurements where any improvement in the WQ leads to a price increase for the waterfront houses. Technical WQ measurement explained the house price more efficiently than non-technical measurements. Apart from dissolved oxygen, all the other technical WQ measurement variables (visibility, pH, salinity) had a significant positive effect on waterfront property prices. Likewise, Gibbs et al. (2002) investigated the effect of WQ (water clarity) on lakefront property prices and compared the effects on two adjacent states under different property markets. They concluded that lake WQ had a significant positive effect on lakefront property prices. They used six years of property sale data and found considerable variation in water clarity effects on two different states.

Node, Lansford and Jones (1995) estimated the implicit price of recreational benefits of lake water and concluded that waterfront properties enjoyed a premium in recreational and aesthetic benefits where proximity to the lake had a significant effect on recreational and aesthetic benefits. The study found a positive relationship between water level and property price. Artell (2014) explored a similar type of association between water usage and summer house price with some weak evidence of non-linear WTP for WQ.

Clapper and Caudill (2014) estimated the value of improved lake WQ in the Canadian context. This WQ valuation study was also very close to my study, as it was conducted in Ontario and used the hedonic approach. They applied the hedonic pricing method to measure the impact of WQ on lakefront cottages' sale value in Northern Ontario. The study considered property sale price and per square foot sale price as dependent variables and cottage characteristics, water frontage, western exposure and WQ as explanatory variables. To show the relationship between property price and lake WQ, they used linear, log-linear and log-log models. The result suggested WQ significantly influenced waterfront cottage prices where improved WQ caused higher property prices. I construct a summary table (Table 2.1) compiled with previous WQ valuation studies across the U.S. and Canada. The table provides a brief idea of different hedonic studies on WQ valuation.

Table 2.1. Summary of Hedonic Studies for WQ Valuation

Author	Location	Year of Data	Number of observations	WQ variables	Effect
Clapper and Caudill (2014)	North Ontario	2010	253 cottages	SD	Significant Positive effect (2% more WTP for 1 foot water clarity)
Steinnes (1992)	Northern Minnesota, US	N/A	N/A	The percentage littoral (shallow water), amount of suspended organic material in water, and WSCD (the number of feet below the surface a Secchi disc reading can be observed)	Definite effect
Gibbs et al. (2002)	New Hampshire	1990-1995	447 lakefront house sale data	Water clarity-Secchi disc	Significant Positive effect (1 meter decrease in water clarity can decrease the property value from 0.9% to over 6% on avg.)
Leggett and Bockstael (2000)	Chesapeake Bay, US	1993-1997	1183 transactions	Fecal coliform counts in the year of sale	Improvement in WQ has Significant Positive effect on property value
Liu, Opaluch and Uchida (2017)	Narragansett Bay, Rhode Island, US	1992-2013	40,433 transactions	Concentration of chlorophyll (in micrograms per liter)	Price premium for closer houses, poor WQ reduce house price
Walsh, Milon and Scrogin (2011)	Orange county (Orlando, Florida)	1996-2004	1,496 lake-front and 53,216 non-lake front properties	SD	Significant positive effect
Boyle, Poor and Taylor (1999)	Maine, US	1990-1995	N/A	SD in summer	Significant positive effect
Poor, Pessagno and Paul (2007)	St. Mary's county, Southern Maryland	1999-2003	1,377 property sales data (2% waterfront property)	Dissolved inorganic nitrogen (DIN), total suspended solids (TSS)	Significant effect for DIN
Artell (2014)	Finland	2004	1,806 transactions	WQ index (scientific measures, turbidity, water clarity)	Water usability has positive effect on property price
Michael, Boyle and Bouchard (1996)	Maine lakes, US	1990-1994	52 samples	SD reading, difference between minimum WQ in sale year and 10 years' avg.	Significant effect
Michael, Boyle and Bouchard (2000)	Maine lakes, US	1990-1994	N/A	Current water clarity (minimum water clarity in sold year, minimum water clarity in previous year of sold year), historical water clarity avg. of min summer water clarity for 10 years, water clarity-SD	Significant effect
Young (1984)	Lake Champaign, US	1976-1981	N/A	A rating of WQ by local officials, ranging from 1 to 10.	Significant effect
Walsh et al. (2017)	Chesapeake Bay, US	1996-2008	229513 single family	Light attenuation (inverse of water clarity)	Significant benefits, positive effect
Poor et al. (2001)	Maine lakes, US	1990-1995	348 mailed survey	SD	Significant effect
Boyle and Taylor (2001)	Maine lakes and ponds, US	1990-1995	300 mailed survey	SD	Significant effect
Bin and Czajkowski (2013)	Martin County, South Florida	2000-2004	510 waterfront properties	Non-technical: WQ "location grade", Technical: water visibility, DO, P^H, salinity	Significant effect

2.3 Water Quality Variables Used in Different Studies

Lake WQ is measured using many different metrics. According to Leggett and Bockstael (2000), lake WQ mostly depends on the level of phosphorus, nitrogen, and dissolved oxygen concentration in the water body. Higher concentration of these materials not only caused algal blooms but also hampered fish growth and damaged the ecosystem. It reduced the water clarity thus deteriorated the WQ. The growth of green plants might lower the recreational and aesthetic benefits (Gibbs et al., 2002). Michael, Boyle and Bouchard (1996) argued that increased nutrient in water lead to eutrophication that promoted plant growth; the plants removed oxygen from the water and suffocated aquatic animals. The growth of harmful algal blooms reduced water clarity and threatened human health and ecosystems. The concepts of eutrophication, total phosphorus (TP) and Secchi depth are discussed in detail in section 3.2 (Water Quality Variables) of the next chapter (Chapter Four).

The Lake Assessment Report by Cataraqui Region Conservation Authority (2017) discussed that the lake health in the Cataraqui Region (in Ontario) was reliant on multiple factors where the nutrient level (e.g. phosphorus, nitrogen, and carbon) had key effects on the quality of lake water. The authority also considered water temperature, dissolved oxygen, chloride, and acidity level in the water body. The normal level of nutrients could produce a healthy and sustainable lake with higher benefits. However, a higher concentration of nutrients could increase algal growth, reduce water clarity, decrease the level of oxygen, and hamper ecosystem services and food web connections. Health Canada (2012) considered biological and chemical hazards for WQ guidelines, focusing on recreational purposes. They also incorporated clarity, turbidity, and color of the water as parameters for aesthetic purposes.

Water clarity is a key indicator that guides WQ measurement. SD reading is a commonly used approach to estimate the water clarity level. Government of Ontario (2019) explained that higher SD reading indicated clearer water and vice versa. Many studies e.g. Steinnes (1992); Michael, Boyle and Bouchard (1996); Gibbs et al. (2002); Walsh, Milon and Scrogin (2011); Clapper and Caudill (2014); Boyle, Poor and Taylor (1999); Poor et al. (2001) etc. adopted the SD approach to measure WQ. Walsh, Milon and Scrogin (2011) used SD reading as a WQ measurement tool as it is widely used in previous studies and easy to apply. They considered the yearly mean value of SD reading at the closest lake.

Several studies also used other WQ measurement tools instead of using SD. Walsh et al. (2017) used a light attenuation coefficient, inverse to the water clarity measurement as higher light attenuation means less clear water, as a WQ measurement tool for their study. Poor, Pessagno and Paul (2007) applied the total suspended solids and dissolved inorganic nitrogen as WQ variables. While Young (1984) measured WQ by a ‘one to ten’ scale. Here, ten represented excellent WQ and one showed the worst case. For technical measurement of WQ, Bin and Czajkowski (2013) considered water visibility, P^H, salinity and dissolved oxygen whereas location grade was applied for non-technical measurement of WQ. Technical measurement explained the house price more efficiently than nontechnical measurement. Leggett and Bockstael (2000) applied fecal coliform count as a WQ measurement tool.

2.4 Estimated Results of WQ Valuation Studies

For estimating the implicit price of WQ improvements, different studies have followed different approaches. Results vary with the spatial, temporal and housing market characteristics. Clapper and Caudill (2014) used the hedonic method to calculate the willingness to pay (WTP) of property owners which were approximately 2% higher for a unit increase (1-foot increase in SD) in WQ. Gibbs et al. (2002) also followed the same valuation approach and got similar type of relationship between WQ and house price. The result showed that an average price fall of 0.9% to over 6% due to a 1-meter decrease in the WQ.

It is clear that WQ improvement increases house price however the value of WQ is not equal for all lakes located in different regions. Michael, Boyle, & Bouchard (1996) estimated the implicit price of WQ improvements (1 meter increase in clarity) which varied from $11 per foot of lake frontage to $200 per foot of lake frontage for different lakes. Furthermore, they found that those who owned lakefront properties enjoyed the highest benefits from improved WQ. If other things remained the same, buyers were willing to pay more for a lakeshore property with improved WQ. Boyle, Poor and Taylor (1999) estimated the mean value of WQ (one meter increase in water clarity) ranged from $2,337 to $ 12,938 under different property markets. The estimated marginal benefits for WQ improvements were $2,748 (for semi-log) and $2,684 (Cobb-Douglas).

Different studies estimated different values for WQ through using different WQ measurement tools. Walsh et al. (2017) in their hedonic study found a positive water clarity effect on waterfront property prices for ten of the fourteen counties (seven counties are statistically significant) of Maryland in the Chesapeake Bay region. The estimated result showed that a 10% reduction in water clarity decreases the waterfront property prices by $2,576 to $26,497. Poor, Pessagno and Paul (2007) explored the marginal implicit price of two WQ variables: dissolved inorganic nitrogen and total suspended solids by hedonic price method. The result showed that the marginal implicit price of dissolved inorganic nitrogen was much higher than the marginal implicit price of total suspended solids. A marginal increase in total suspended solids reduced the mean house price by $1086. Similarly, a unit more dissolved inorganic nitrogen in the watershed decreased the house price by $17,642 as any increase in dissolved inorganic nitrogen contributed to eutrophication. Young (1984) in his research on Saint Albans Bay in Northern Vermont found that the price of a house located to a degraded WQ was almost 20% ($4,500 on an average) lower than a lakefront house positioned to a larger and cleaner lake. Bin and Czajkowski (2013) further investigated the value of WQ on coastal waterfront properties of South Florida and estimated the implicit price of WQ improvement in between $7,531 and $43,158. Node, Lansford and Jones (1995) conducted a hedonic study on adjacent houses to Highland Lakes on Central Texas and found that proximity to the lake is the most influential element to estimate the recreational and aesthetic benefits. They estimated a positive significant relationship between lake water level and house prices; higher water level increases the recreational and aesthetic value of lake water. Here, the marginal recreational and aesthetic benefits of lake water were about $110 to $136 per acre-foot of water.

In this section, I review several hedonic studies which deal with the lake WQ valuation in different locations. The common finding is improved lake WQ raises the house price. However, the value of lake WQ varies with place, time, housing market and WQ measurement approach. The location of the house (lakefront or non-lakefront) as well as the distance of the lake have great influence on house price. Purchasers' WTP (price premium) for a waterfront house increases with the better WQ. However, the price premium of a house far from the lake may not increase as much as a lakefront house. In this context, my study focuses on estimating the value of lake WQ improvement in Ontario by using the hedonic price method and data on nearby residential property prices. This research may address the research gap in the field of WQ improvement valuation in Ontario as well as Canada. It may also help the relevant authority analyze the cost and benefits of WQ improvement. Furthermore, the research may contribute to update the lake management policies and prepare recreational and aesthetic guidelines for the lake users.

Chapter 3

Study Area and Data

3.1 Study Area

The study area is located in Southern Ontario. Southern Ontario is bordered by three of the five Great Lakes (Huron, Erie, and Ontario). A large number of lakes, an abundance of fresh water resources as well as many rural houses make this an ideal location for a hedonic analysis. The area is adjacent to two cities, Peterborough (mid-size city) and Orillia (small city), which are part of Central Ontario. Belleville is another neighboring city situated in the south-eastern part of the research area. Huntsville and Bracebridge are two towns from the Muskoka Region of Central Ontario. I obtained the municipal shapefiles from the Government of Ontario website. The blue colored portion, in Figure 3.1, of the southern part of Ontario, is my study area that contains around 500 lakes. The specified location is a polygon (area- 36289.928 sq. km) in shape constructed by keeping the cities (e.g. Peterborough, Orillia) just outside of its boundary to reduce any large deviation in the neighborhood amenities.

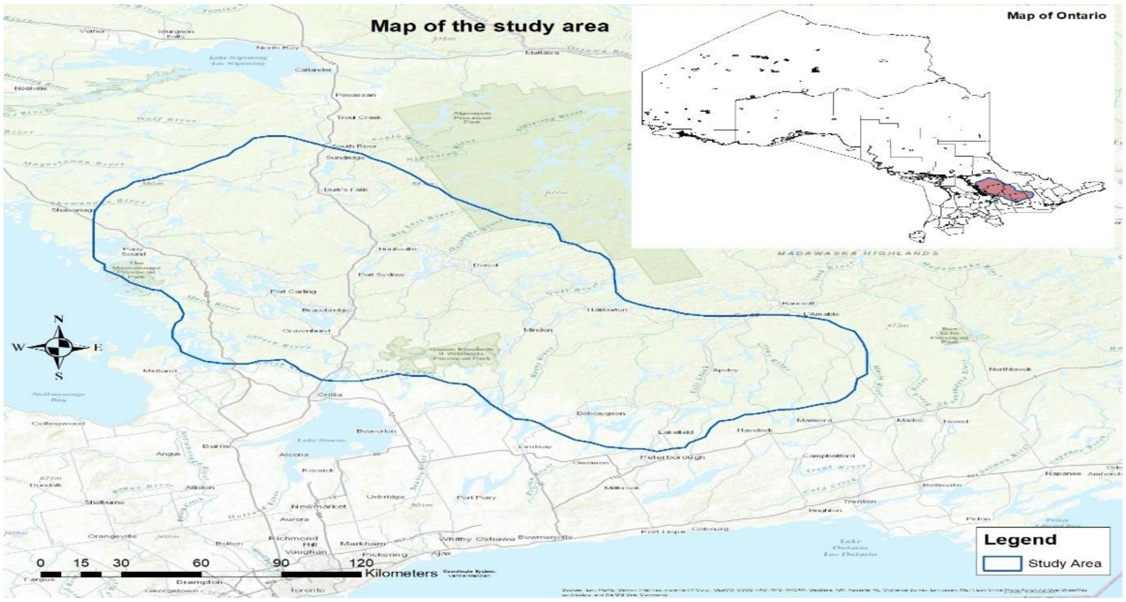

Figure 3.1. Map of Study Area

3.2 Water Quality Variables

Physical, chemical and biological characteristics of water are the determinants of WQ (Ontario Ministry of Environment and Climate Change 2010). The physical appearance of water like color, taste, odor and turbidity; concentration of chemicals including phosphorus, chloride, fluoride, pesticides and metals e.g. mercury, lead, cadmium; and the presence of biological attributes like bacteria, viruses, algae, zooplankton, plants and animals etc. thus defines the quality of a waterbody. However, to measure the WQ, no best indicator may characterize WQ on its own. In previous studies, WQ has been measured in different ways, for example, SD reading (Clapper and Caudill (2014); Gibbs et al. (2002); Walsh, Milon and Scrogin (2011); Boyle, Poor and Taylor (1999); Michael, Boyle and Bouchard (1996); Poor et al. (2001); Boyle and Taylor (2001)), dissolved oxygen level (Bin and Czajkowski (2013)), total phosphorus level, fecal coliform (Leggett and Bockstael (2000)), total suspended solids (Poor, Pessagno and Paul (2007)), concentration of chlorophyll (Liu, Opaluch and Uchida (2017)), dissolved inorganic nitrogen (Poor, Pessagno and Paul (2007)), pH (Bin and Czajkowski (2013)), etc. SD reading is widely used in several studies for WQ measurement. For this hedonic study, I use the two WQ variables SD reading and TP level.

Phosphorus is a relatively scarce naturally occurring element in surface and ground water that influences the growth of green plants (Ontario Ministry of Environment and Climate Change 2010). It is a key source of nutrients for aquatic ecosystems, concentrated in different forms in the water body. All these forms of phosphorus in water is measured in a collective indicator TP (Ontario Ministry of the Environment 2009; Georgian Bay Biosphere Reserve n.d.). The average concentration of TP is measured in micrograms per liter (μg/L).

Phosphorus is not poisonous for human and animal health until it is concentrated at an excessive level in the lake water (Ontario Ministry of the Environment 2009). As the substance contributes to the food web for aquatic plants and animals, the presence of phosphorus in a lake contributes to a productive aquatic system. However, excessive concentration of phosphorus may hamper the normal ecosystem services in the water body. An excessive level of phosphorus, characterized by 'nutrient enrichment' or 'eutrophication', enhances the growth of algae and green plants. Due to this nutrient enrichment, the oxygen concentration level in water changes; the shortage of oxygen causes harm to the living organisms and decrease biodiversity in water. Moreover, eutrophication also increases animal and plant biomass, turbidity, organic matter, unfavorable taste and odor along with the risk of human health and aquatic life. It further reduces the quality of water as well as recreational and aesthetic benefits (Ontario Ministry of Environment and Climate Change 2010).

Generally, the TP concentration in freshwater is low in the mountainous zones and high in the lowland zones. As the snowmelt from rivers and streams carries nutrients to lakes, the presence of phosphorus in lake water is typically high in the spring. However, people of Ontario have been working on reducing TP concentration in surface water since the 1970s (Georgian Bay Biosphere Reserve n.d.). The government provides specific guidelines to control the excessive concentration of TP in fresh water bodies. To reduce the phosphorus concentration in waterbodies, the provincial government regulates phosphorus use in laundry detergents, sewage treatments, as well as agriculture (by providing alternative nutrient management plans) and industries (Ontario Ministry of Environment and Climate Change 2010). According to the phosphorus guideline framework, the concentration level should not exceed the trigger range and any increase over 50% of the base level should require further assessment and management decisions (Canadian Council of Ministers of the Environment 2004). The term trigger range means the standard or desired concentration level of phosphorus in a lake and any value that exceeds the upper limit of the trigger range is treated as a potential threat for the environment.

The range of TP concentration for the natural water body lies between <1 µg/L (ultra-oligotrophic water) to >200 µg/L (eutrophic water). Wetzel (2001) cited in the Canadian Council of Ministers of the Environment (2004) argued that the range of TP in most of the uncontaminated water bodies stays between 10 µg/L - 50 µg/L. The range varies with types of water body, ecosystem, location and WQ. The trigger ranges for TP in Canadian lakes and rivers are <4 µg/L (Ultra-oligotrophic), 4 µg/L -10 µg/L (Oligotrophic), 10 µg/L -20 µg/L (Mesotrophic), 20 µg/L -35 µg/L (Meso-eutrophic), 35 µg/L -100 µg/L (Eutrophic) and >100 µg/L (Hyper-eutrophic). The Ontario Ministry of Environment and Climate Change (2010) specified the TP level of 20 µg/L for lakes and 30 µg/L for rivers and streams for reducing excessive plant growth. Moreover, the average TP concentration for the ice-free period should not cross 20 µg/L for controlling algae growth and 10 µg/L for ensuring the aesthetic benefits (Canadian Council of Ministers of the Environment 2006). As Mesotrophic lakes contain medium-level nutrients and provide a great source of fishing facilities (RMB Environmental Laboratories 2020), I consider the TP trigger range as 10 µg/L -20 µg/L for the study.

Another WQ variable for the study is a SD reading. A SD is a metal disk, 8 inches (20 cm) in diameter and painted black and white, with a cord attached to the center. The cord has a black mark at one-foot intervals and a red mark at six-inch intervals. To measure the water clarity, the rope is lowered down to the lake water until the disk is no longer visible (Government of Ontario 2019). Once it is lowered into the water, the SD reading will be the length of the rope at the point where it becomes invisible. Here, SD reading is estimated (in Figure 3.2) by subtracting the water distance (distance from the observer to water) from the total distance (distance from the observer to the point where the disk is disappeared). It helps to measure the water clarity of the lake where high reading denotes cleaner water and lower reading means turbid water. The typical SD value for Canadian lakes lies between 1-8 meters (Water Rangers 2015-20).

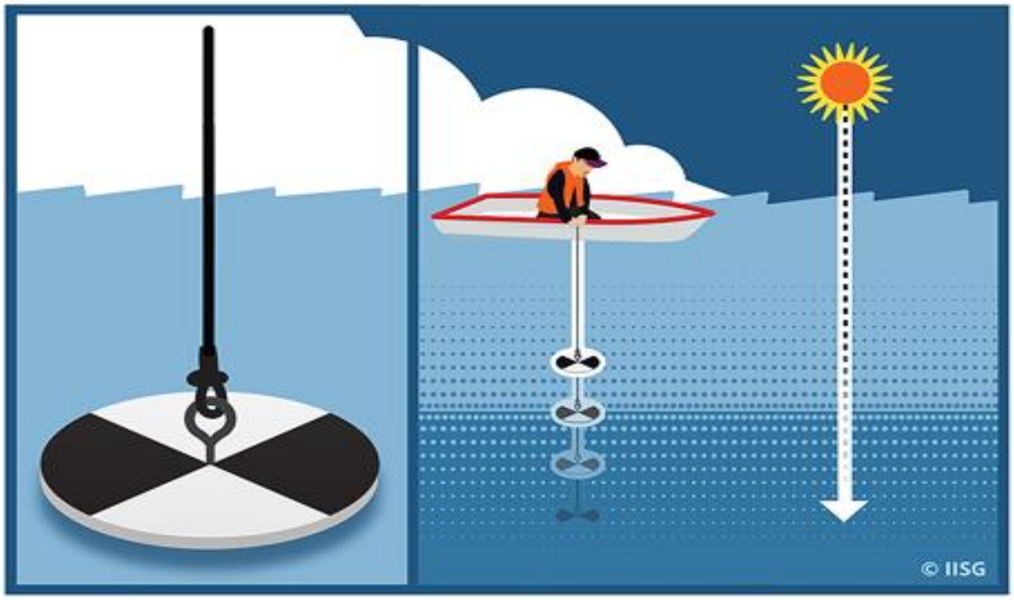

Figure 3.2. Measurement process of SD

Note: SD is measured by subtracting the water distance (distance from the observer to water) from the total distance (distance from the observer to the point where the disk is disappeared). *Source:* Limno Loan (n.d.)

Each water body has distinctive features that define the quality of water for that particular waterbody. I obtain the lake WQ data from the Government of Ontario website (Ontario Lake Partner 2012-18). I have obtained TP observations for each site; each observation can have up to 2 readings where some only have one. These observations have been collected on different dates of a year. As the data set has contained two different measurements of TP at the same time, I consider the mean value (mean TP) of TP_1 and TP_2 for a specific date. Then, I convert the observation dates into the year and take the yearly mean value of TP by averaging the mean TP values for the same year. Finally, I get a total of 15,639 TP observations, yearly mean value, for different station number (STN), and site IDs in different years. I have found 2 missing values for TP_1 and 385 missing values for TP_2 but both are not omitted on any occasion. So, I minimize this issue by taking the single value of either TP_1 or TP_2 as the mean value when the other is missing. I remove 7 observations from the data set as the geographical coordinate data is missing there; finally, get 15,632 observations for TP values.

I acquire Lake Name, township, STN, site ID, latitude, longitude, year (1980-2016), and SD average (in meters) from the Government of Ontario website (Ontario Lake Partner 2012-18). After removing the observations with missing values, I have found 13,166 observations for SD. Figure 3.3 shows the year wise boxplot of TP and SD level. The solid line connects the mean values across the years for both SD and TP. Some fluctuations are observed for mean TP values whereas the trend for mean SD slightly decreases.

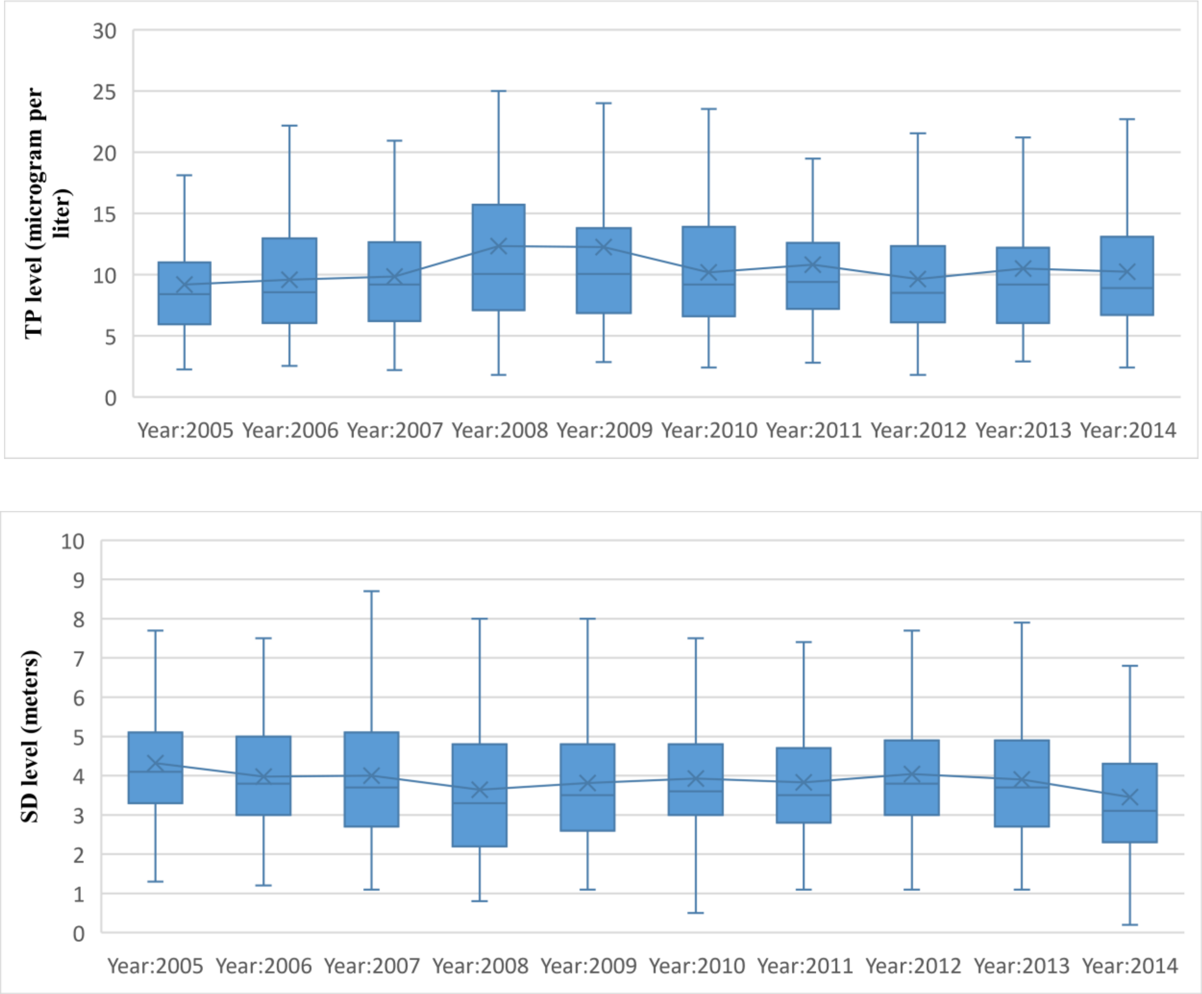

Figure 3.3. Graph of Yearly Reading of TP and SD

The geographical coordinate data is in Degree Minute Second (DMS) format that I have converted into Degree Decimal (DD) format for both (TP and SD) data sets. Then, TP and SD data have been joined based on geographical location (latitude and longitude), STN, site IDs, and year. By merging two different WQ data sets, I create a unique data set for WQ variables consisting of both TP and SD data of different lakes, stations, sites, locations, and years. I have assembled 9,648 observations for two WQ variables (TP and SD). I consider specific geographical coordinates based on my study area to specify the spatial variation. Based on this altitudinal variation, I have assembled 4,593 observations for WQ variables from 494 unique lakes for the study area.

3.3 Closest City Distance

I use three cities Peterborough, Orillia, and Belleville that are positioned outside of the study area but adjacent to it. I further identify two towns Huntsville and Bracebridge. I consider all these five different locations to measure the shortest distance from houses to the nearest cities or towns thus I can control the effect of the nearest city on house prices. Cities may offer various amenities which may influence house price. This may cause a biased estimation of WQ values where controlling city effect may help overcome this issue.

3.4 Housing Data

Housing data over multiple years (2005-2014) were purchased from ‘Teranet’, an international commercial organization of data support and provider of Ontario’s property-related data. Teranet provided the house price (sold price), location (latitude and longitude), and sold year data; structural data for houses like lot size are extracted from MPAC. All the house data are provided by the source organizations based on the specific study area (polygon). A total of 58191 observations are available in the data set but I include 58087 observations after omitting the observations which have missing values. The house price has been adjusted with the new HPI for Ontario provided by Statistics Canada (2019) where December 2016 is considered as the base case. For housing price adjustment, I consider the total HPI value and convert the date from *month-date-year* to *year-month* format for housing data to merge it with the HPI data based on date. After joining both data sets, I divide the total HPI value of a specific date (*year-month*) by 100 and then multiplied the result with the house price that has been sold on the same date (month and year) to get the real house price or to adjust the inflation.

The target is to use all the important structural characteristics for this study. However, the unavailability of house size, number of bedrooms, and number of bathrooms, fireplace, garage, and age of the housing data is a big limitation. Adding those variables may contribute to a robust model. The estimation with the single structural attribute, lot size, may be biased. For example, a large lot does not guarantee a large house. A large lot may carry a small structure that may lower the house price. Again, two houses with the same lot size and location may have price differences. This price alteration may be caused by other structural attributes. A new house with better facilities may have a higher price which is not possible to consider for this study.

3.5 Data Merging

While house price data is obtained for ten consecutive years (2005-2014), WQ data is not available for all the WQ stations and site IDs on a consecutive year (2005-14) basis. To address this WQ data limitation issue, I consider the closest reading for WQ variables available within 3 kilometers in the same year when the house has been sold. In other cases, I have taken the available measurement or the average reading (if multiple stations exist) for the WQ variable. This approach enables assembling all the WQ data on different years for each of the houses listed in the data set. I have created a distance matrix for all the lakes against each of the houses. Based on this distance matrix, I calculate the lake distance. I pick the lowest distance (i.e. house to the closest lake stations) for each house. Through merging the house data and WQ data, finally, I obtain 58085 observations for the study.

Table 3.1. Summary Statistics of Variables used in Analysis

Variable	**Mean**	**Std. Dev.**	**Min**	**Max**
Real house price (in 2016 Canadian dollars)	238893	273783.8	35726	6644400
Lake Distance (in meter)	4408.95	3366.73	38.73	31041.17
Year	2009	2.89	2005	2014
Mean TP (yearly)	10.43	6.43	1.80	93.35
Secchi depth (in meter)	3.89	1.61	0.20	10.80
City distance (in kilometre)	40.74	28.20	0.14	131.04

The descriptive statistics of the WQ variables are reported in Table 3.1 which provides a broad idea of data for the study. These statistics portray a wide variation in the house price as well as in the house and WQ attributes. The WQ data is gathered from a total of 494 unique lakes. In figure

3.4, I depict the house locations along with the unique lakes. As I have already discussed that a single lake may have multiple stations, here, I tried to specify the unique lake. In the map, I have found several plots outside of the polygon but I consider all those houses as they are very close to the polygon boundary.

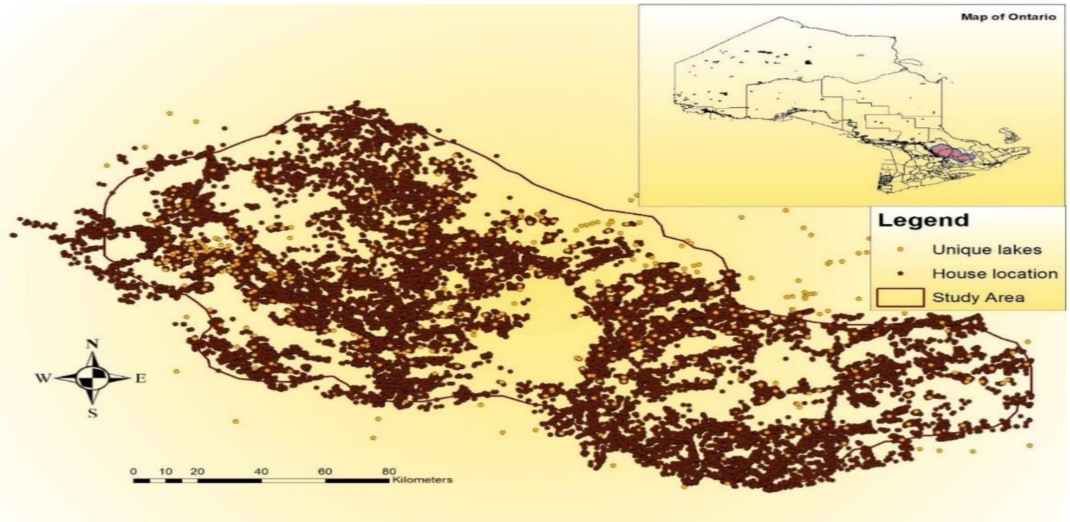

Figure 3.4. Map of House Locations and Unique Lakes

Chapter 4
Methodology

The goal of this study is to estimate the implicit price of WQ improvement in Lakes. The estimation is based on applying the hedonic property value model. As WQ is a non-market good, there is no price. The hedonic price method reveals the price of a non-market attribute based on observed house price (Rosen 1974). Here, we use the prices of nearby houses to uncover the value of WQ. In this section, I discuss the concepts outlining the hedonic property value model, the variables I use for the model construction, the empirical model of this valuation study, and the spatial heterogeneity models.

4.1 Conceptual Framework

A house can be conceptualized as a bundle of distinctive structural, neighborhood, and environmental characteristics that jointly determine its price. There may be heterogeneity in qualitative and quantitative attributes (Michael, Boyle and Bouchard 2000), causing a difference in property sale value within a given housing market (Taylor 2003). House buyers may be willing to pay a higher/lower price for any change in a specific characteristic. In the hedonic analysis, this change in the price level can reveal the implicit price of a non-market good. Here, the marginal price of the change is equal to the marginal benefit gained by the property purchaser from that change. For example, I consider a hypothetical scenario of two similar type lakes consist of many lakefront houses with the same attributes. The equilibrium price is the same for all properties, for example- \$50,000, located adjacent to both lakes. However, better WQ in one of the lakes, Lake 1, may stimulate higher consumer demand that may raise the price of houses adjacent to Lake 1. If the new house price adjacent to Lake 1 increases to \$60,000, this extra \$10,000 is the implicit price that consumers are willing to pay for the WQ improvement (Taylor 2003). However, the non-market valuation approach is not as simple as the example describes because of the diversity of a housing market.

The hedonic valuation approach is conducted in two steps. The first step of the model estimates the hedonic price function for houses. The implicit price of a non-market good is estimated by regressing the property prices on different characteristics of houses (Rosen 1974; Poor, Pessagno and Paul 2007). These implicit prices from the first-stage model are then used as a price variable in the second stage of the model to estimate the demand equation for the specific attribute. The first stage of the hedonic model is widely used in non-market valuation studies as it requires minimal data; very often involves only marginal price information to cover economic intuition. However, the second stage of the model is more complex with additional data requirements (Taylor 2003) and is rarely conducted in empirical research. I only have one observation per person, therefore I cannot uniquely identify the demand curve. I am focused on the first stage of the hedonic model to estimate the marginal implicit prices of lake WQ improvements.

4.2 Theoretical Background

It is assumed that the market interactions between the house buyers and sellers occur under a perfectly competitive market that determines the equilibrium price schedule for the differentiated good. Here, the equilibrium price for the differentiated good is a function of property attributes for the model (Taylor 2003). For example, a house can be differentiated by its attributes (z) where the vector of the housing attributes is $z = (z_1, z_2, ..., z_n)$. If the property price is denoted by HP then the general hedonic equation is $HP = f(z)$.

The heterogeneity in the property is observed by the qualitative and quantitative differences in property attributes that causes the price differentials (Michael, Boyle and Bouchard 2000). Consumers' utility depends on the differentiated good (z) and the composite bundle of all other goods (X); X is purchased with the additional income left over after purchasing z. The utility function of a representative consumer is $U = f(X, z_1, z_2, ..., z_n)$. I assume that buyers will purchase a single unit of differentiated goods (one house). They maximize their utility (U) by selecting a bundle of house attributes (z) along with all other goods (X) considering his/her budget restrictions $Y = P_xX + P_z(z_1, z_2, ..., z_n)$ (Michael, Boyle and Bouchard 2000; Taylor 2003). The purchasers' decision of choosing z and X satisfies the condition: the marginal rate of substitution between *z* and *X* is equal to the rate at which *z* can be traded for *X* in the market. The consumer spends the money that is left from the income after offering the optimal bid for product *z* to purchase good *X*. If the utility and income of the consumer remain the same, the optimal bid for *z* may vary with the change in the bundle of housing attributes (*z*). To maximize the utility, the marginal bid of a purchaser for *z* will be equal to the marginal rate of substation between *z* and *X*. Based on the purchasing condition of *z* and *X*, the necessary condition for maximizing utility is the marginal bid a purchaser is willing to pay for a specific attribute of *z* must be equal to the price of that attribute. The concave shape of bid functions demonstrates that the optimal bid increases at a decreasing rate. The ideal situation for a consumer is where the lowest possible bid function remains tangent to the equilibrium price. The marginal price of an attribute is equal to the marginal change in the optimal bid amount (MWTP) (Taylor 2003).

4.3 Structural, Neighborhood and Environmental Variables

For the hedonic regression model, it is important to consider variables that influence price. I consider three broad housing characteristics (structural, neighborhood and environmental) which assumes that house price is a function of these three attributes. The general hedonic price function for the study is $HP = f(S, N, E)$. Here, *HP* denotes the house price and *S*, *N* and *E* symbolizes the vector of structural, neighborhood and environmental characteristics. Structural variables are important as they specify the quality of the house and any change in the quality of the property that may affect the house price. For structural characteristics, the commonly used variables from the literature are lot size, size of the structure, number of bedrooms, number of bathrooms, fireplace, garage, age of the house, etc. I only consider lot size as a structural attribute for this study where incomplete data, unavailability of other structural attributes, is a limitation.

Two neighborhood characteristics lake distance and city distance are used for this study. Here, lake distance describes the distance to the nearest lake stations from the house and city distance represents the distance to the nearest city. The proximity of the city location may influence house prices. A portion of house buyers may not be interested in urban houses because of traffic and chaos while some may have intended to be close to the city. Keeping this in mind, I avoid houses located within big cities and consider rural houses situated close to the cities or towns. This may help maintaining the homogeneity in neighborhood characteristics of the housing observations. I consider three different cities (Peterborough, Orillia, and Belleville) and two towns (Huntsville and Bracebridge) as neighboring cities to find the distance from house to the closest city; every house is part of at least one of these cities or towns. I use the spatial fixed effects to control for city effects in the model.

Environmental characteristics are identified by environmental amenities and dis-amenities, for example clear water of a nearby lake, water pollution in lakes or air quality of the location. To address the environmental attributes, I consider the quality of water of the nearby lakes. The two WQ variables are SD and TP. SD denotes the level of water clarity of the nearest lake. The greater the value of SD indicates better WQ with more clear water; the more the cleaner water leads to higher house prices. The other WQ attribute of the lake is TP which represents the phosphorus level in the water. From the literature, I have found that a higher phosphorus concentration in lake water increases turbidity, along with algae growth and odor problems. It also reduces the water clarity level and decreases WQ. So an inverse relationship between TP and house price is expected from the estimation.

Table 4.1. Structural, Neighborhood and WQ Variables

Variable Type	Variable Name	Description
Structural		
	LOT SIZE	Lot size in square feet
Neighborhood		
	LAKE DISTANCE	Distance between house and closest lake station (in meter)
	CITY DISTANCE	Distance between house and closest city (in kilometre)
Environmental		
	SECCHI DEPTH	Average length of SD that measures the water clarity (in meter)
	TOTAL PHOSPHORUS	Average yearly total phosphorus (micrograms per liter)

4.4 Empirical Model

The common intuition is house buyers are willing to pay more for a marginal improvement of the

WQ of a lake. A linear form of hedonic price function results in a constant price for an incremental change in the attribute. However, the marginal implicit price of an attribute is not likely to be constant for all homes. For example, a marginal improvement in a lake with low WQ may have a higher implicit price than a marginal change in cleaner water implying that the implicit price of WQ and the level of WQ may have a diminishing relationship (Michael, Boyle and Bouchard 2000). The general intuition is the property price increases at a decreasing rate with the increase in WQ or other property attributes. Considering this, alternative forms of the model are applied through transforming the variables. The literature recommends different functional forms of the model like semi-log, log-log, and Box-Cox, but stops short of suggesting a specific form of hedonic equation (Gibbs et al. 2002). Michael, Boyle and Bouchard (2000) argued that flexible Box-Cox approach is not appropriate for estimating the marginal price of an environmental attribute. However, the studies have considered the best suited functional forms for their empirical models. Poor, Pessagno and Paul (2007) used a semi-log functional form of the equation as they have found it the best fitted for their empirical application. I estimate the log-linear form of models that have a natural semi-elasticity interpretation.

I use ten consecutive years' of property sales data from the study area and use 58,085 observations for the model. I consider the year fixed effect (α_t) and the city fixed effect (γ_c) that removes the city invariant omitted variables effect. I use a series of dummy variables (for year and city fixed effect) in the hedonic regression to control the year (when the individual house has been sold) and city effect (in which nearest city the individual house is located). The city provides a wide range of amenities to the citizen. The nearness of the city thus influences the house price. To control this effect, I use city fixed effect. Again, the sold year may have an influence on house prices. The house price with the same bundle of attributes may differ with time due to various reasons like house demand, economic situation, etc. I control this temporal effect on the model by using the year fixed effect. The model with year and city fixed effect is:

$$log(HP_{it}) = \beta_0 + \beta_1\, log(LOT\ SIZE_i) + \beta_2\, log(LAKE\ DISTANCE_i) + \beta_3\, SECCHI\ DEPTH_{it} + \beta_4\, TOTAL\ PHOSPHORUS_{it} + \alpha_t + \gamma_c + \varepsilon_{it} \quad (4.1)$$

Here, the natural log of *HP* denotes the log value of real house price for house *i* in year *t*, β signifies the coefficients, α_t and γ_c denote the year fixed effect and city fixed effect and ε_{it} is the random error term.

Oster (2019) argued about observing the changes in coefficient by introducing control variables to evaluate the robustness to potential omitted variable bias. Considering the omitted variable bias in this research, I start with simple model and then add control variables. The first model (Model 1) considers only two WQ variables and the second one includes other explanatory variables along with the WQ variables. For both models, I am not going to incorporate spatial and temporal fixed effect. But I introduce the spatial and temporal fixed effects in the third model (Model 3). I use the threshold level of TP in Model 4 to find out the price variation caused by the change in TP. I use two categories for TP where TP value lies between 10 to 20 micrograms per liter are considered as 1 and the rest of the values are zero. I assume that the effect of TP beyond the threshold level on house prices is equal. Finally, to observe how the relationship changes with different WQ variables, I consider another three different regression models where I use only SD as a WQ variable in Model 5 and use only TP in Model 6. I use only the TP threshold level in Model 7.

4.5 Spatial Heterogeneity Models

To investigate the impact of spatial heterogeneity models on my findings, I estimate three additional model specifications. An improvement in WQ may not have the same effect for all the houses located at a different distance from the lake stations. Considering this impact of lake distance on house price from the previous studies, I use SD and log of lake distance interaction in Model 8 (Equation 4.2) to explore how lake distance impacts purchasers' MWTP for WQ. I also use lake distance dummy for the SD and lake distance interaction in Model 9 (Equation 4.3). It helps to estimate purchasers' MWTP for houses in different distance bins with a marginal improvement in WQ. The models are:

SD and Log Lake Distance Interaction Model:

$$\log(HP_{it}) = \beta_0 + \beta_1 \log(LOT\ SIZE_i) + \beta_2\ SECCHI\ \ DEPTH_{it} + \beta_3 \log(LAKE\ DISTANCE_i) + \beta_4 \log(LAKE\ DISTANCE_i) * SECCHI\ \ DEPTH_{it} + \alpha_t + \gamma_c + \varepsilon_{it} \tag{4.2}$$

<u>*SD and Lake Distance Dummy Interaction Model:*</u>

$$\log(HP_{it}) = \beta_0 + \beta_1 \log(LOT\ SIZE_i) + \beta_2\ SECCHI\ \ DEPTH_{it} + \beta_k(LAKE\ DISTANCE\ BIN_k)*SECCHI\ \ DEPTH_{it} + \alpha_t + \gamma_c + \varepsilon_{it} \tag{4.3}$$

Here, '*LAKE DISTANCE BIN$_k$*' is for different lake distance bins to explore the changes in the level of MWTP for SD. The different distance bins for the model is 500 meters (contains 1723 observations), 500 to 750 meters (2510 observations), 750 to 1000 meters (2402 observations), 1000 to 2000 meters (9653 observations), 2000 to 3000 meters (9084 observations) and, above 3000 meters (32713 observations).

The estimated models consider all the house sales data. However, the effect of lake WQ is not same for a lakefront house and a house located several kilometers distance from the lake. Considering this, I restrict the sample to only include house sales that are within 3 kilometres of a lake station and run Model 10 using the SD and lake distance dummy interaction considering this sample restriction. I use 500 meters, 500 to 750 meters, 750 to 1000 meters, 1000 to 2000 meters, and above 2000 meters bins for this model.

I use variation in house prices and WQ to identify the association between WQ and prices. Lack of structural attributes make omitted variable bias likely, but it's not clear to what degree it biases the results. If these omitted variables impact price and are correlated with WQ, than there is an issue. For example, if 'nicer' homes are built next to lakes with high WQ then the estimated coefficients are biased upwards. As WQ is not randomly allocated across space, I am not estimating a causal effect of WQ on prices, but an association.

Chapter 5
Results

In this chapter, I discuss the results estimated from all different specifications of hedonic price function. The first set of results for the log-linear hedonic price function are shown in Table 5.1 with the log-real price as a dependent variable. To estimate the impact of WQ on house prices, the coefficients of interest are SD and TP. I start with a simple model and only use the two WQ features (SD and TP) as explanatory variables for the first model (Model 1) estimation in Table 5.1. Along with WQ variables, I further include structural variables (log lot size) and neighborhood attributes (log lake distance and city distance) to estimate Model 2. I consider the time and spatial fixed effects for the estimation of the third model (Model 3). The city and year fixed effects help control for the spatial and time-invariant omitted variables effect from the estimation.

Results from the estimation in Table 5.1 show that house price has a negative correlation with SD and a positive correlation with TP for all three models. The model R^2 value is low, likely due to having no house structural characteristics except lot size. In Model 1, both the variables of interest are statistically significant at the 1% level. A 1- meter increase in the SD will reduce the real-house price by 2.6%. In addition, a 1- micrograms per liter increase in TP is associated with an increase in the real-house price by 0.40%. In Model 2, all the coefficients are statistically significant at a 1% level. The estimated result indicates a 1.5% decrease in real house prices for a marginal improvement in SD and a 0.40% increase in price for a unit increase of TP. This model further explores a negative relationship between house prices and neighboring cities; a 1-kilometer proximity to the neighboring town increases the house price by 0.20%. Model 3 results in significant relationships between house prices and all the explanatory variables like previous models. The coefficient value of SD is still negative with the spatial and time fixed effects. The estimated negative significant relationship (at 1% level) between log lake distance and log real-house price denotes that a 10% increase in house distance from the closest lake (WQ station) results a 0.58% (in Model 2) and 0.53% (in column 4) decline in house prices. However, the negative association of SD and positive connection of TP with the house price is unexpected and requires further investigation.

Table 5.1. Estimation Results for Log-Linear Hedonic Price Function

Dependent variable: Log Real price			
Variables	**Model 1**	**Model 2**	**Model 3**
Secchi depth (meters)	-0.026***	-0.015***	-0.013***
	(0.002)	(0.002)	(0.002)
Total phosphorus	0.004***	0.004***	0.005***
(micrograms per liter)	(0.0005)	(0.0005)	(0.001)
log lot size (square feet)		-0.006***	-0.006***
		(0.002)	(0.002)
log lake distance (meters)		-0.058***	-0.053***
		(0.003)	(0.003)
City distance (kilometres)		-0.002***	
		(0.0001)	
Constant	12.166***	12.704***	12.927***
	(0.011)	(0.031)	(0.031)
City fixed effect	No	No	Yes
Year fixed effect	No	No	Yes
Observations	58,085	58,085	58,085
R^2	0.007	0.016	0.082
Adjusted R^2	0.007	0.015	0.081

*p<0.1; **p<0.05; ***p<0.01.

In Table A 2 (in Appendix), I emphasize that the relationship might not be linear for TP (at a threshold level) and house price. The threshold level for TP is 10-20 micrograms per liter for the lakes of Ontario (Ontario Ministry of Environment and Climate Change 2010). To construct the dummy variable for TP, I consider 1 for TP values between 10-20 micrograms per liter and 0 otherwise. Results from Table A 2 (Model 4 in Appendix) reveal that TP lying within the trigger range has a higher effect on house price than the TP beyond the trigger range. The house price increases by 4.1% due to the marginal increase in TP once the total phosphorus lies between 10 to 20 micrograms per liter. The price decreases by 1.7% for a marginal (1-meter) increase in SD. The estimated results for other variables are statistically significant (at 1% level except for log lot size) and almost similar to model 3 in Table 5.1.

Table 5.2. Estimated Results by Using a Single WQ Variable for Each Model

Dependent variable: log Real price			
Variable	**Model 5**	**Model 6**	**Model 7**
Secchi depth	-0.022***		
	(0.002)		
Total phosphorus		0.007***	
		(0.0005)	
Total phosphorus (10-20 micrograms per liter)			0.063***
			(0.006)
log lot size	-0.006***	-0.006***	-0.006***
	(0.002)	(0.002)	(0.002)
log lake distance	-0.053***	-0.051***	-0.050***
	(0.003)	(0.003)	(0.003)
Constant	13.002***	12.859***	12.889***
	(0.030)	(0.029)	(0.029)
City fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Observations	58,085	58,085	58,085
R^2	0.080	0.081	0.079
Adjusted R^2	0.080	0.081	0.079

*p<0.1;**p<0.05;***p<0.01

To explore how the relationship changes with different WQ variables, I estimate three alternative log-linear models (in Table 5.2) by considering a single WQ variable for each case. However, the relationship between house price and the interest variable remains the same as I have found in the previous estimation (Table 5.1 in Model 3). I only use SD in Model 5 and TP in Model 6 as a WQ variable. These are also my variables of interest for these two models. I estimate a negative coefficient value for SD (in Model 5) and a positive coefficient value for TP (in Model 6) at a 1% significance level. From the TP dummy model (in Model 7), TP within the 10-20 microgram threshold have a 6.3% higher house price effect than TP beyond the threshold level for a marginal change in TP. Despite changing the WQ variable in every model, all the other explanatory variables (log lot size and log lake distance) contain the same sign with similar coefficient values. However, the negative significant relationship between lake distance and house price indicates a spatial influence in house prices. Moreover, the negative relationship between house price and SD and positive relationship between house price and TP further raises the necessity of estimating spatial heterogeneity models to investigate any severe association between the WQ variable and other unobserved variables that influences the relationship between house price and WQ variables.

5.1 Spatial Heterogeneity Models

To estimate the impact of spatial heterogeneity, I consider three different models. As all the previous models estimate a negative correlation between log lake distance and the log-real price at a 1% significance level, I assess a separate log-linear model including a new explanatory variable- SD and log lake distance interaction. As SD and TP are correlated, I exclude TP as an explanatory variable from my model to avoid the impacts of this correlation. In Model 8 of Table 5.3, I use the log value of real-house sale price as a dependent variable. I consider SD as the only WQ variable that is also my variable of interest. I use SD and lake distance interaction as a continuous variable. The result shows that SD has a positive significant (at 1% level) association with house prices once the distance between lake station and house is zero. The negative significant (at 10% level) relationship between log lake distance and house price says that lesser the distance from lake stations to houses increases the price. The interaction term (SD* log lake distance) has a negative correlation with the log-real price; any increase in SD and any decrease in lake distance increase the marginal-implicit price of SD. The house buyers are willing to pay more for a marginal improvement in WQ once the house is closer to the lake. As the lake distance increases, the MWTP for WQ improvement decreases. With the average lake distance (4409 meters), house buyers are willing to pay 2.10% less for a marginal increase in SD. However, any decrease in the lake distance raises the MWTP for WQ improvement.

As lake distance is crucial in explaining the impacts of WQ improvement, I use distance bins to assess the changing relationship between WQ improvement and lake distance in Model 9 (in Table 5.3). I use five dummy variables for six different distance categories and use SD as a WQ variable with a log of the real-house price as a dependent variable. The result suggests that house buyers are willing to pay a 1.9% higher price for a marginal improvement in WQ (1-meter increase in SD) if the house is located within 500 meters of the WQ stations of a lake. Clapper and Caudil (2014) found a 6.4% increase in per square feet price of lakeshore cottages in Ontario for a unit more SD. However, property buyers are willing to pay 4.4% less for a marginal increase in SD if the house is located within 2000 to 3000 meters of the WQ stations. It appears that the value of WQ improvement decreases as the distance between lake location and house location increases. The result further shows that lot size is negatively correlated to the house price.

Table 5.3. Estimated Results Using SD and Log Lake Distance Interactions

Dependent variable: log Real price		
Variables	**Model 8**	**Model 9**
Secchi depth	0.059***	-0.024***
	(0.017)	(0.002)
SD* log lake distance	-0.010***	
	(0.002)	
log lot size	-0.006***	-0.007***
	(0.002)	(0.002)
log lake distance	-0.015*	
	(0.009)	
SD* lake distance dummy (within 500m)		0.043***
		(0.012)
SD* lake distance dummy (500m to 750m)		0.056***
		(0.009)
SD* lake distance dummy (750m to 1000m)		0.053***
		(0.009)
SD* lake distance dummy (1000m to 2000m)		0.021***
		(0.005)
SD* lake distance dummy (2000m to 3000m)		-0.020***
		(0.005)
Constant	12.689***	12.563***
	(0.072)	(0.018)
City fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
Lake distance fixed effect	No	Yes
Observations	58,085	58,085
R^2	0.080	0.082
Adjusted R^2	0.080	0.081

*p<0.1; **p<0.05; ***p<0.01

Figure 5.1 reports the MWTP for WQ improvement in different lake distance bins, estimated from Model 9, with a 95% confidence interval. I consider MWTP in the vertical axis and the distance between the house and the nearest WQ station in the horizontal axis. All the values of MWTP, except the 500 meters and the1000 to 2000 meters lake distance bin, are statistically significant at the 5% level. From the figure, the MWTP for WQ improvement is $ 4,577 for a property that is located within 500 meters of the lake. The MWTP increases, $7,627, for the immediate next bin (500 meters to 750 meters) that is the highest premium for a marginal improvement in WQ; start decreasing as the lake distance increases. House purchasers offer the highest amount to enjoy a marginal improvement in WQ for the houses closest to the lake. However, the MWTP value is greater for houses slightly further from the lake which is counterintuitive. The low sample size in the closest bin (within 500 meters) causes a wider confidence interval. Moreover, the distance I consider is not from the lake; it is from the WQ stations. A little farther houses from the lake may have relatively more importance to the quality of the water. Furthermore, a portion of house buyers may unwilling to be the closest to the lake to avoid crowd, boat traffic and chaos. The willingness to pay amount is close for properties locating 500 to the 750 meters ($7,627) and 750 to the 1000 meters ($6,770) range. However, house buyers are not willing to pay more for WQ improvement when houses are distant (more than 1 km distance from the lake) to lakes.

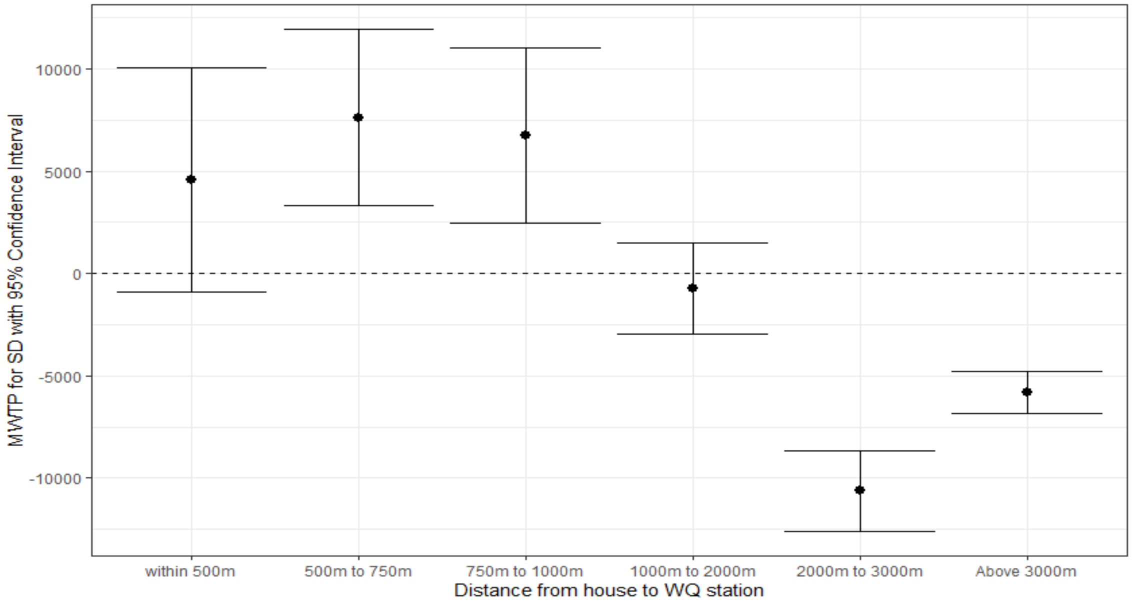

Figure 5.1. Marginal Willingness to Pay for SD with SD*Lake Distance Dummy

Figure 5.2 portrays the MWTP level for a marginal increase in SD for houses that are situated within 3000 meters distance from the lake. I estimate the model (Model 10) controlling with five different distance bins and the result follows a similar trend like the MWTP graph portrayed in Figure 5.1. The result provides a significant MWTP value for all the different distance bins except 'within 500' and '1000 meter to 2000' meter zone. The level of MWTP is the highest

($6,142) for houses that lie between 500-750 meter distances to the lake. The amount is almost the same ($5,837) for the next distance bin (750 to 1000 meter). However, the MWTP is negative for houses that lie on 1000-2000 meter and above 2000 meter distance bin.

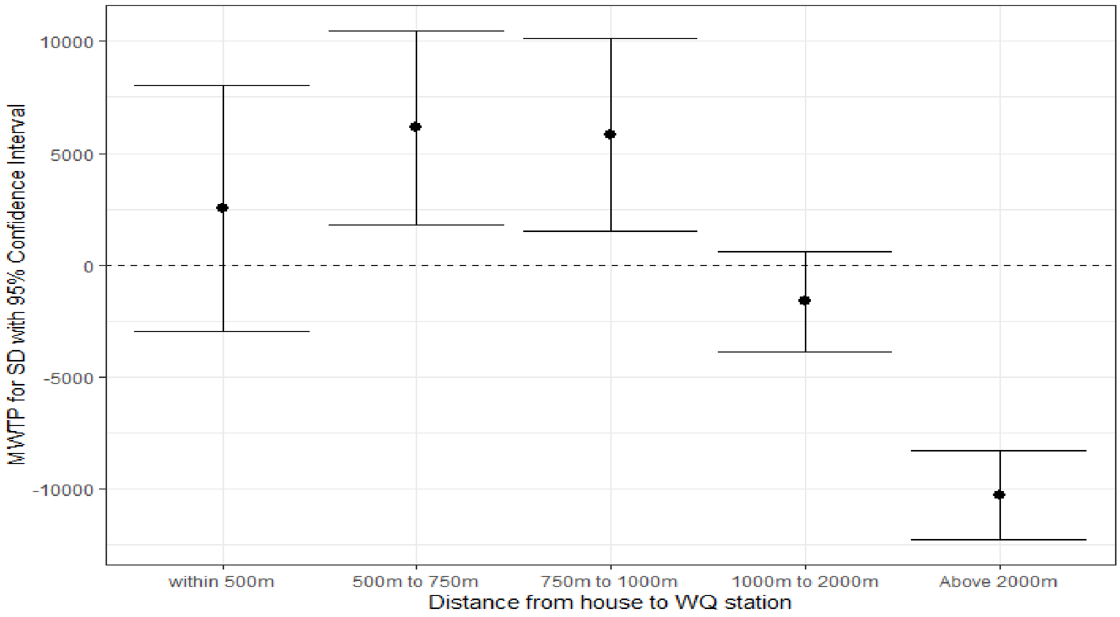

Figure 5.2. Marginal Willingness to Pay for SD with SD*Lake Distance Dummy including number of observations within 3000 meters

Considering all the results from the estimation, some important findings are unveiled. The overall results are mixed; some results are showing positive impacts of WQ improvements where others are showing negative impacts. The results from the initial hedonic estimation (from Table 5.1) have dissimilarities to the previous studies. The general intuition is that an improvement in WQ increases the MWTP. Any increase in SD improves the WQ and raises the adjacent house price. Similarly, any increase in TP, beyond the trigger range, reduces WQ and should decrease the house price. Based on this wide-ranging proposition, the expectation was a positive coefficient value for SD and a negative value for TP. However, the result reveals (from Table 5.1) a negative MWTP for SD and a positive MWTP for TP; house owners are willing to pay less for an increase in SD and more for higher phosphorus concentration. A higher concentration of TP causes eutrophication and reduces WQ. So any increase in TP beyond the trigger range is harmful. Considering this scenario, I estimate a separate model with a TP dummy (in Table 5.2) to investigate the relationship between TP (in different levels) and house prices. However, the result remains the same as the previous estimation.

The TP level in lake water is associated with the WQ. Sediments that carry phosphorus may come through rivers and streams from the sources of erosion or runoff from the watershed that may increase the TP level of the lake; reduces the WQ. It is clear that the two WQ variables for this study are negatively correlated; the correlation value is about 0.40. To investigate the impact of this correlation to the model, Table 5.2 considers a single WQ variable for each model by excluding the other WQ variable. These models explore how the relationship between house price and explanatory variables deviates from the change in WQ measurement. However, the association of WQ variables with house prices remain unchanged.

The estimated results from the models of Table 5.2 depict a positive and significant relationship between TP and property prices. In general, an increase in the TP level would be expected to reduce the recreational and aesthetic demand of the water body. So a positive MWTP for an increase in TP is not convincing. Here, TP may be correlated to any unobserved variables which are absent from the model. For example, a golf course may pollute the nearby lake but may increase the price of the property that is close to it. Likewise, a house that is close to a lake with unfavorable WQ may cost a high price because of its convenient location towards the city amenities. So things that influence property price and also correlated to WQ may be omitted from the model and affect the price estimation.

The result, in Table 5.2 and Table 5.3, further estimates negative MWTP for lot size. We presume that a larger lot size results in a higher house prices which may not be the same all the time. Lake side houses, on small lots, may dominate the values for larger lots away from the lake. Larger lot sizes are likely in areas with low land values while lots have been subdivided in areas with higher land values for development. Moreover, structural uniqueness, locational aspects, and neighborhood attributes like crime rate, the closeness of urban facilities, etc. may influence the house price. A small house near to the golf course facilities may cost higher than the larger house situated far from these amenities.

From the previous hedonic studies, it is clear that lake distance is one of the key components in

WQ valuation. A negative significant association between real house prices and lake distance (from previous estimation) states that house buyers are willing to pay more to be close to the lake. Based on the influence of lake distance on house price, I consider a new interacted variable (SD*log lake distance) in Table 5.3. This interaction term explores how lake distance impacts house prices for an improvement in WQ. The interaction model (model 8) also results higher MWTP for SD for a lower lake distance. With an average lake distance of 4409 meters, house buyers are willing to pay $5002 less for a marginal increase in WQ as the lake is far from the house. House buyers may not care about WQ for a house that is located 4.4 km distant to lake. However, the MWTP for WQ improvement increases as the lake distance decreases. Under this circumstance, it is crucial to explore how marginal improvement in WQ affects house prices located at different distances from the lake stations.

I further use SD and log lake distance dummy interaction (in column 3 of Table 5.3) to explore the influence of different distances on house price. The result shows that purchasers' MWTP level for WQ improvement changes with the distance from the lake stations. The highest MWTP ($7,627) for WQ improvement is found for houses that are positioned within 500 meters to 750 meters distance from the lakes. The result further suggests that purchasers don't want to pay more for the lake WQ improvement for a house that is far from the lake. However, numbers of observation are located far from the lake and may not have any significant influence by the lake WQ. Considering this scenario, a new estimation (in Figure 5.2) for houses within the 3000-meters lake distance suggests that purchasers are willing to pay the highest premium for houses lying in the 500-750 meter distance bin. However, I don't consider the position of the property, waterfront or non-waterfront, which may have a significant influence on the house price.

As a popular summer destination for local citizens as well as for tourists, this specific region (study area) has a high demand for lakeside houses. In general, a property close to the lake provides recreational and aesthetic benefits in addition to its other structural and neighborhood attributes that raise the price. Cleaner water increases the scenic beauty as well as provides higher recreational benefits. However, purchasers are not willing to pay a higher price for WQ improvement for a house distant from lakes. The previous hedonic studies also explore a similar type of relationship between lake distance and house price. The purchaser mostly relies on the current WQ that is visible in choosing a property (Michael, Boyle and Bouchard 2000). Here, observing the WQ level is more feasible for a property purchase decision; a better WQ with closeness to the lake increases the value of the lake water to the purchasers.

Chapter 6

Conclusion

Compared to some previous hedonic analyses in Ontario, this study deals with a larger housing data set of Southern Ontario to explore the impact of lake WQ improvement on nearby housing prices. The overall results are mixed; some results show positive impacts of WQ improvements where others show negative impacts on house price. The results from the initial models suggest counterintuitive results for both WQ variables. However, the distance from house to lake station is found as an influential component in estimating the impact of WQ improvement on house price; the price premium is strongly correlated to the proximity of the lake. The SD and lake distance dummy interaction model suggests that WQ improvement has a significant positive impact on price only for houses close to WQ station. A decrease in the lake distance enhances the house price for an improvement in WQ. House buyers are not willing to pay higher premium for any improvement in WQ if the house is located far from the lake.

There are several limitations to the study. Exploring the implicit price of WQ improvement from house prices is challenging as WQ may be correlated with unobserved variables; many price-determining factors are absent in the model that may influence the value estimation. One of the limitations of this study is that I am unable to include different structural and neighborhood price-influencing factors. I only include lot size as a structural characteristic, however including more structural attributes may result in a more robust model. Moreover, incorporating neighborhood variables that are associated with WQ may also increase robustness. The missing WQ data for some of the lake stations for different years is another challenge that has been minimized with the data of the closest station. With the first stage hedonic method, I only estimate the implicit price of WQ improvement but this implicit price can be used as a price variable in the second stage of the model to estimate the demand equation for the WQ improvement. The estimation of the demand function for the differentiated WQ is untouched here due to data limitation.

Policy makers need to decide how much to invest as water quality improvement is a costly project. Agricultural and industrial runoff increases the cost of water quality improvement. The results of this research quantify the benefits of WQ improvement that can be compared; this may contribute to the landscape management and management of effluent sources. The economic value of marginal WQ improvement may help to compare the costs of quality enhancement and the benefit gained from the improvement. This may help to enhance lake management projects in this specific region which may further raise the value of WQ and contribute to the regional economy. The benefits raised from the WQ management policy may help to increase the municipal property tax revenue as WQ improvement increases the house price. These additional funds from the beneficiaries can be used to finance WQ improvements (Kim, Boxall and Adamowicz 2016).

Finally, Clapper and Caudill (2014) and Calderón-Arrieta, Caudill and Mixon (2019) are the studies, examining the relationship between recreational WQ and residential property prices, that actually builds off the idea of conducting this research. Clapper and Caudill (2014) dealt with the cottage price that helps me to address the value of WQ improvement by using house prices on a popular lake-based housing area of Ontario. However, this study doesn’t cover the waterfront and non-waterfront characteristics of housing properties which may influence the value estimation. Including this attribute along with more structural and neighborhood factors may create the scope of future valuation study in this region.

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APPENDIX

Table A 1 Full Results of Model 3 with city and Year Fixed Effect

Variables	**Model 3**
Secchi depth	-0.013*** (0.002)
Total phosphorus	0.005*** (0.001)
Log lot size	-0.006*** (0.002)
Log lake distance	-0.053*** (0.003)
City dummy (Peterborough)	-0.175*** (0.007)
City dummy (Orillia)	-0.88*** (0.012)
City dummy (Huntsville)	-0.562*** (0.024)
City dummy (Bracebridge)	-0.219*** (0.007)
Year dummy (2005)	-0.491*** (0.012)
Year dummy (2006)	-0.386*** (0.012)
Year dummy (2007)	-0.320*** (0.012)
Year dummy (2008)	-0.295*** (0.012)
Year dummy (2009)	-0.247*** (0.012)
Year dummy (2010)	-0.181*** (0.012)
Year dummy (2011)	-0.121*** (0.012)
Year dummy (20012)	-0.072*** (0.012)
Year dummy (20013)	-0.052*** (0.012)
Constant	12.927*** (0.031)
Observations R^2 Adjusted R^2	58,085 0.082 0.081

Table A 2 Estimation Results for Log-Linear Hedonic Model with TP Dummy

Dependent variable: Log Real price	
Variables	**Model 4**
Secchi depth	-0.017*** (0.002)
Total phosphorus dummy	0.041*** (0.006)
Log lot size	-0.005*** (0.002)
Log lake distance	-0.053*** (0.003)
City dummy (Peterborough)	-0.169*** (0.007)
City dummy (Orillia)	-0.075*** (0.012)
City dummy (Huntsville)	-0.557*** (0.024)
City dummy (Bracebridge)	-0.224*** (0.007)
Year dummy (2005)	-0.489*** (0.012)
Year dummy (2006)	-0.382*** (0.012)
Year dummy (2007)	-0.321*** (0.012)
Year dummy (2008)	-0.281*** (0.012)
Year dummy (2009)	-0.236*** (0.012)
Year dummy (2010)	-0.179*** (0.012)
Year dummy (2011)	-0.115*** (0.012)
Year dummy (2012)	-0.071*** (0.012)
Year dummy (2013)	-0.047*** (0.012)
Constant	12.970*** (0.031)
Observations	58,085
R^2	0.081
Adjusted R^2	0.080

Table A 3 Full Results of Model 5, 6, 7 with City and Year Fixed Effect

Dependent variable: Log Real price			
Variable	**Model 5**	**Model 6**	**Model 7**
Secchi depth	-0.022*** (0.002)		
Total phosphorus		0.007*** (0.0005)	
Total phosphorus dummy			0.063*** (0.006)
Log lot size	-0.006*** (0.002)	-0.006*** (0.002)	-0.006*** (0.002)
Log lake distance	-0.053*** (0.003)	-0.051*** (0.003)	-0.050*** (0.003)
City dummy (Peterborough)	-0.155*** (0.007)	-0.184*** (0.007)	-0.181*** (0.007)
City dummy (Orillia)	-0.065*** (0.012)	-0.103*** (0.012)	-0.091*** (0.012)
City dummy (Huntsville)	-0.552*** (0.024)	-0.577*** (0.024)	-0.576*** (0.024)
City dummy (Bracebridge)	-0.224*** (0.007)	-0.219*** (0.007)	-0.225*** (0.007)
Year dummy (2005)	-0.489*** (0.012)	-0.502*** (0.012)	-0.502*** (0.012)
Year dummy (2006)	-0.383*** (0.012)	-0.392*** (0.012)	-0.389*** (0.012)
Year dummy (2007)	-0.317*** (0.012)	-0.327*** (0.012)	-0.331*** (0.012)
Year dummy (2008)	-0.282*** (0.012)	-0.302*** (0.012)	-0.284*** (0.012)
Year dummy (2009)	-0.233*** (0.012)	-0.254*** (0.012)	-0.243*** (0.012)
Year dummy (2010)	-0.177*** (0.012)	-0.188*** (0.012)	-0.187*** (0.012)
Year dummy (2011)	-0.114*** (0.012)	-0.127*** (0.012)	-0.121*** (0.012)
Year dummy (2012)	-0.070*** (0.012)	-0.079*** (0.012)	-0.080*** (0.012)
Year dummy (2013)	-0.046*** (0.012)	-0.058*** (0.012)	-0.055*** (0.012)
Constant	13.002*** (0.030)	12.859*** (0.029)	12.889*** (0.029)
Observations	58,085	58,085	58,085
R^2	0.080	0.081	0.079
Adjusted R^2	0.080	0.081	0.079

Table A 4 Full Results of Model 8, 9 with Lake Distance, City and Year Fixed Effect

Dependent variable: Log Real price		
Variables	**Model 8**	**Model 9**
Secchi depth	0.059*** (0.017)	-0.024*** (0.002)
SD* Log lake distance	-0.010*** (0.002)	
Log lot size	-0.006*** (0.002)	-0.007*** (0.002)
Log lake distance	-0.015* (0.009)	
SD* lake distance dummy (within 500m)		0.043*** (0.012)
SD* lake distance dummy (500m to 750m)		0.056*** (0.009)
SD* lake distance dummy (750m to 1000m)		0.053*** (0.009)
SD* lake distance dummy (1000m to 2000m)		0.021*** (0.005)
SD* lake distance dummy (2000m to 3000m)		-0.020*** (0.005)
Lake distance dummy (500m)		-0.047 (0.050)
Lake distance dummy (750m)		-0.105*** (0.040)
Lake distance dummy (1000m)		-0.137*** (0.040)
Lake distance dummy (2000m)		0.015 (0.022)
Lake distance dummy (3000m)		0.120*** (0.021)
City dummy (Peterborough)	-0.156*** (0.007)	-0.161*** (0.007)
City dummy (Orillia)	-0.062*** (0.012)	-0.075*** (0.012)
City dummy (Huntsville)	-0.552*** (0.024)	-0.553*** (0.024)
City dummy (Bracebridge)	-0.223*** (0.007)	-0.224*** (0.007)
Year dummy (2005)	-0.488*** (0.012)	-0.493*** (0.012)
Year dummy (2006)	-0.384*** (0.012)	-0.383*** (0.012)
Year dummy (2007)	-0.318*** (0.012)	-0.316*** (0.012)
Year dummy (2008)	-0.284*** (0.012)	-0.284*** (0.012)
Year dummy (2009)	-0.234*** (0.012)	-0.233*** (0.012)
Year dummy (2010)	-0.177*** (0.012)	-0.177*** (0.012)
Year dummy (2011)	-0.114*** (0.012)	-0.116*** (0.012)
Year dummy (2012)	-0.070*** (0.012)	-0.068*** (0.012)
Year dummy (2013)	-0.046*** (0.012)	-0.046*** (0.012)
Constant	12.689*** (0.072)	12.563*** (0.018)
Observations R^2 Adjusted R^2	58,085 0.080 0.080	58,085 0.082 0.081

Table A 5 Full Results of Model 10 with Lake Distance, City and Year Fixed Effect (for Observations within 3000m)

Variables	**Model 10**
Secchi depth	-0.042*** (0.004)
Log lot size	0.013*** (0.003)
SD* lake distance dummy (within 500m)	0.053*** (0.012)
SD* lake distance dummy (500m to 750m)	0.067*** (0.010)
SD* lake distance dummy (750m to 1000m)	0.066*** (0.010)
SD* lake distance dummy (1000m to 2000m)	0.036*** (0.006)
Lake distance dummy (500m)	-0.108** (0.052)
Lake distance dummy (750m)	-0.174*** (0.043)
Lake distance dummy (1000m)	-0.222*** (0.042)
Lake distance dummy (2000m)	-0.078*** (0.027)
City dummy (Peterborough)	-0.088*** (0.011)
City dummy (Orillia)	-0.026 (0.023)
City dummy (Huntsville)	-0.443*** (0.034)
City dummy (Bracebridge)	-0.128*** (0.010)
Year dummy (2005)	-0.488*** (0.019)
Year dummy (2006)	-0.384*** (0.018)
Year dummy (2007)	-0.305*** (0.018)
Year dummy (2008)	-0.298*** (0.018)
Year dummy (2009)	-0.230*** (0.018)
Year dummy (2010)	-0.196*** (0.018)
Year dummy (2011)	-0.117*** (0.018)
Year dummy (2012)	-0.038** (0.018)
Year dummy (2013)	-0.059*** (0.018)
Constant	12.451*** (0.032)
Observations R^2 Adjusted R^2	25,372 0.073 0.072