Evading Invasives:

How Eurasian Water-Milfoil Effects the Development of Lakefront Properties

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

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Abstract

Eurasian water-milfoil is an aquatic invasive plant that has moved rapidly through lakes across the United States. Along with being a hazard to local ecosystems, water-milfoil is a nuisance to those who use lakes for recreation, and its presence even lowers the value of lakefront properties. Though its effects can cause great disutility to lake users, no empirical studies have emerged that investigate the impacts that Eurasian water-milfoil, or any other invasive species, have on human behavior. This study investigates the effects of Eurasian water-milfoil on the probability that undeveloped lakefront properties are developed into single-family housing units. Using a comprehensive dataset from the Twin Cities, Minnesota region, a proportional hazards duration model of land conversion is estimated with a number of covariates. It is found that undeveloped parcels of land on lakes invaded by Eurasian water-milfoil are 28% less likely to be developed than their counterparts on non-invaded lakes. These results are just the beginning of a new line of research aimed at the interaction of invasive species and human behavior.

Keywords: Invasive species; Housing supply; Hazard model; Milfoil; Lakes

JEL Codes: Q57

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1. Introduction

Biologists and ecologists have long studied invasive species and the changes to ecosystems that stem from their presence. Whether these changes are driven by the invasive species itself (Clavero and García-Berthou 2005), or by exogenous factors that make domestic ecosystems vulnerable to such an invasion (i.e. habitat destruction (MacDougall and Turkington 2005)), the final outcome is often one of inferior quality to the original environment.

Other than biological damages, invasive species cause immense economic losses. In a study estimating these losses, Pimentel, Zuniga, and Morrison (2005) recognized over 50,000 invasive species in the United States, and reported damages totaling $120 billion dollars per year. This number looms even larger when compared to the seemingly trivial $459 million and $556 million spent in 1999 and 2000 by the government on invasive species prevention (Lovell and Stone 2005) [2].

With damages this large and government spending on the rise, economists have begun to investigate the effects of optimal control strategies, policy measures, and management practices on limiting the spread of invasive species (Epanchin-Niell and Wilen 2012; Timar and Phaneuf 2009; MacPherson 2006). What is currently lacking in the literature is empirical evidence of changes in human behavior driven not by invasive species policy, but rather by the invasive itself. Since invasive species can cause significant environmental change, it is reasonable to anticipate that their presence may also change how humans conduct themselves in the afflicted areas. Research in this area is vital to the recreation industry and to government agencies in charge of developing invasive species policy. As a jumping off point for this empirical literature, this paper considers the idea that Eurasian water-milfoil, an aquatic

[2] Lovell and Stone (2005) is a good literature review which provides a very nice background for the economic literature on invasive species, especially aquatic invasives.

invasive plant, affects the probability that lakefront properties will be developed into single-family housing units. Using a parcel-level property dataset from the Twin Cities area, and a Geographic Information System (ARC-GIS), which allows the incorporation of landscape and lake characteristics, lakefront property development is examined over a 17-year time period to determine whether land developers avoid developing invaded lakes.

2. Eurasian Water-Milfoil Background

Eurasian water-milfoil is an aquatic invasive plant native to Europe, Asia, and northern Africa. Though the exact date of arrival to North America is not known, the plant was reported in several states by 1950 (Smith and Barko 1990). As of 2003, Eurasian water-milfoil was present in nearly every state, as shown in figure 1.

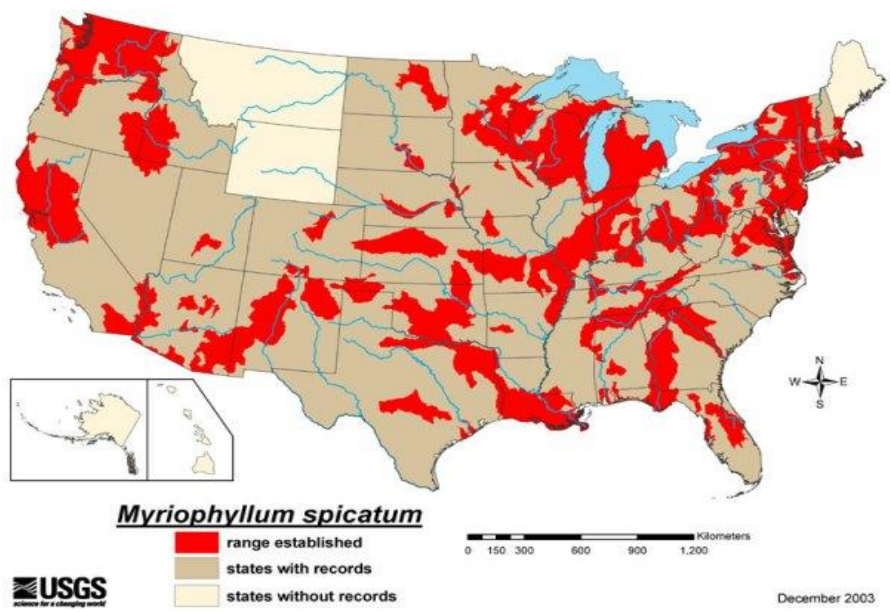

Figure 1: 2003 Map of Eurasian water-milfoil spread (http://nas.er.usgs.gov).

What makes milfoil such a nuisance are its growth and propagation characteristics. Growing up from the bottom of a lake, the plant branches out after reaching the surface, forming a thick canopy of leaves and vines. This canopy is a deterrent to those who recreate, since the vines tangle in boat motors and cling to swimmers[3]. The canopy also changes the ecology of the lake because it provides hiding places for invertebrates and small fish, thereby changing predation patterns. Getting rid of the milfoil is nearly impossible given its remarkable reproductive characteristics. Milfoil has the ability to reproduce from stem fragments, so simply pulling the plants out or mowing it down only serves to scatter these fragments and further the milfoil's spread (Smith and Barko 1990).

Lakefront homeowners are also affected by the presence of milfoil. Along with depleted utility from lake recreation, homeowners on impacted lakes face reduced property values, as several hedonic studies have shown. For one such study done in New Hampshire, Halstead and Michaud (2003) used a dummy variable to identify lakes invaded by milfoil as well as an interaction term between the size of the lake and the presence of milfoil. Using ordinary least squares estimation, the authors conclude that the presence of milfoil led to decreased property value of 20%-40%. However, since unmeasurable location characteristics (fishing quality or aesthetic views) are likely to play a role in determining housing prices as well as influencing the number of boaters on the lake, a milfoil variable is likely to be endogenous. This endogeneity will cause estimates to be biased upward. Horsch and Lewis (2009) address this issue in their hedonic study of lakes in Wisconsin by using a difference in differences method to account for all time-invariant neighborhood characteristics. This method results in a 13% reduction in land values for those properties on milfoil invaded lakes. One final hedonic study, Zhang and Boyle (2010), uses a measure of aquatic macrophyte cover on five Vermont lakes. What makes this study unique is that measurements of submerged macrophyte can be found for each individual property, which is more accurate than a simple dummy variable for each lake. Milfoil can also be measured as a percentage of total lake plant life. Final results from this study show that as milfoil increases and adds to the macrophyte already present in the lake, property values decrease by 1% - 16% for each incremental increase.

[3] Eurasian water-milfoil has even been known to be a drowning hazard.

On the housing supply side, profit maximizing land developers are expected to see these decreased property values as direct losses in potential revenue. Therefore, this paper tests the hypothesis that properties on non-invaded lakes will be developed at a more rapid rate than those properties on invaded lakes. To carry-out this analysis, we employ a hazard duration model to measure the time that a parcel survives in an undeveloped state prior to development.

3. Theoretical Background of Duration Models

3.1 The Survival Function and Hazard Rate

Many questions take the form "how long until some event will occur?" These questions can be answered by modeling the time it takes (the duration) for some transition (the failure) to occur. The transition event of interest to this paper is the conversion of undeveloped lakefront property into developed single-family housing units.

The theoretical background[4] of duration analysis is based around a measure of the time to failure. This is represented by the random variable, T, which has a continuous probability distribution $f(t)$, where t is a realization of T. The cumulative probability of an observation surviving until at least t is given by the survival function

$$S(t) = 1 - \int_0^t f(s)\, ds = Prob(T \geq t). \tag{1}$$

While this function is useful, analysts often wish to know the probability that an observation fails in a particular time period. For the land conversion problem addressed in this paper, the previous statement is equivalent to asking "What is the probability that a lakefront property will be developed in time period t given that it has not been developed in all time periods before t?" A useful expression for addressing this question is the hazard rate, given by

$$\lambda(t) = \frac{f(t)}{S(t)} \tag{2}$$

[4] This theoretical background largely follows the notation used in Greene (2012)

Or equivalently,

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{Prob(t \leq T \leq t + \Delta t \mid T \geq t)}{\Delta t} \tag{3}$$

3.2 Modelling the Hazard Function and Cox's Partial Likelihood Estimation

There are several ways of modelling the hazard function (parametric, semi-parametric, and nonparametric[5]), all of which have pros and cons. The first method is to assume a parametric form of the hazard function, the most common of which are exponential, Weibull, and lognormal. While the simplicity of estimation that results from these assumptions is appealing, parametric models impose structure on the data. Semi-parametric approaches allow more flexibility. This study makes use of a semi-parametric approach, specifically, Cox's method for estimating proportional hazards using partial likelihood (Cox 1972).

A common way to parameterize the hazard function is

$$\lambda_i(t) = \lambda_0(t)\exp(x_i\beta), \tag{4}$$

where $\lambda_0(t)$ is the baseline hazard, x_i is a vector of covariates, and β is a vector of the coefficients to be estimated. Cox's partial likelihood estimator allows for the estimation of β without estimating the baseline hazard; therefore, no assumption needs to be made about baseline hazard's distribution. By dividing the hazard function of a developed parcel by the sum of the hazard functions of parcels that could have been developed, the portion of the likelihood function that arises from property i's development is

$$L_i = \frac{\exp(x_i'\beta)}{\sum_{j=1}^{J}\exp(x_j'\beta)}, \tag{5}$$

where J is the set of "at risk" properties that could have been developed. Taking into consideration the entire set of properties that were developed, the partial likelihood function becomes

[5] Non-parametric approaches will not be discussed here, but for interested readers, Kaplan and Meier (1958) is an early example of such a method .

$$L_i = \prod_{i=1}^{N} \left(\frac{\exp(x_i' \beta)}{\sum_{j=1}^{J} \exp(x_j' \beta)} \right). \tag{6}$$

Cox's proportional hazards method has been used quite extensively in land conversion models. In a land conversion context, baseline hazards are the portion of the hazard function that is identical across parcels, covariates are any variables that may influence the development of parcels (neighborhood characteristics, public policies, etc.), and coefficients are estimates of the likelihood change caused by shifts in the covariates (Irwin and Bockstael (2004); Klaiber and Wang (2012)).

4. **Data**

The study area for this project is a seven county region encompassing the Twin Cities area of Minnesota[6] (see figure 2).

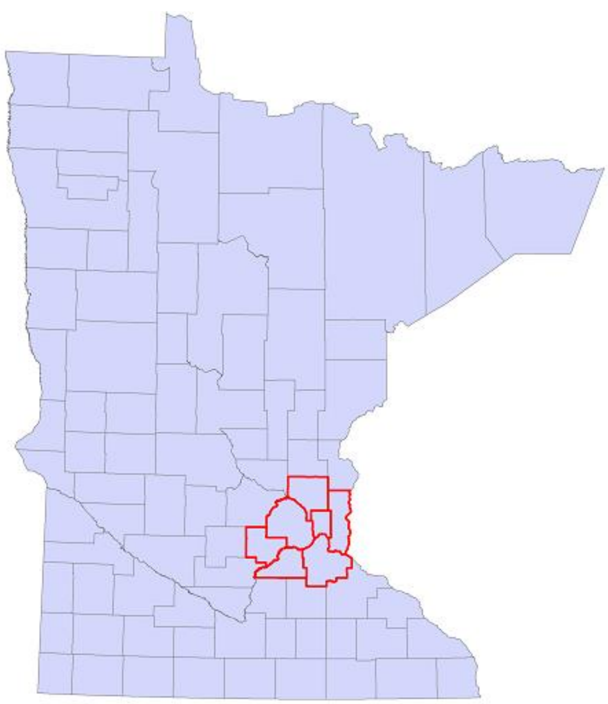

Figure 2: Seven county Twin Cities region

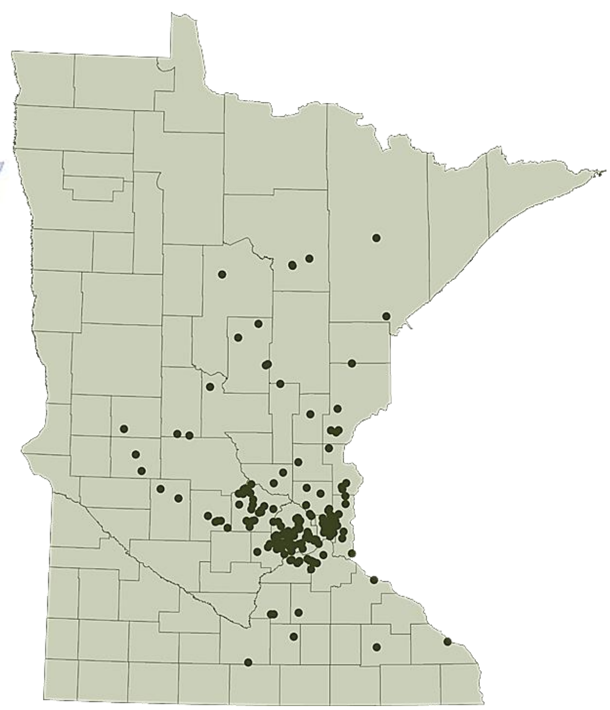

Figure 3: Milfoil invaded lakes (www.dnr.state.mn.us)

[6] The counties in the study are Anoka, Ramsey, Dakota, Scott, Washington, Hennepin, and Carver.

The Twin Cities metro area is an ideal location to study how milfoil changes the probability of development for lakefront properties. Water-milfoil was first discovered in Minnesota in 1987, and had spread to 203 Minnesota lakes by 2007. Nearly 60 percent of these invaded lakes are found within this seven county area.

The dataset used for this study was originally compiled by Klaiber (2008), and subsequently utilized by Klaiber and Phaneuf (2010) in a study of open space valuation in the Twin Cities area. This dataset contains an extensive set of housing attributes as well as information on lake proximity and characteristics.

The housing dataset contains 663,001 observations of property sales over the 17 year time period spanning 1990 to 2007. Basic housing characteristics are known such as the acres of land, square footage, the presence of a garage, the number of bedrooms, bathrooms, stories, and fireplaces, and finally, the age of the house. Also known was the year that each sale occurred and the year that each house was constructed.

A dataset on lakes in the seven county region was also used in this study. Assembled and made available by Metro GIS Datafinder, this dataset contains information on lake area, biodiversity, endangered species sightings, clarity, and whether lakes have public parks or public water access. To supplement this lake dataset, a list of Eurasian water-milfoil invaded lakes and the year of each invasion was merged with the lake characteristics. This is a publically available list constructed by the Minnesota Department of Natural Resources (DNR)[7]. It should be noted that only the bodies of water that are classified as a "lake" by the Minnesota DNR and that have an official Department of Wildlife (DOW) lake number are utilized in this study[8].

[7] The full list is available as of 5/26/13 at the following URL: http://files.dnr.state.mn.us/eco/invasives/infestedwaters_newmilfoil.pdf

[8] The list of waters invaded by milfoil only lists lakes with DOW lake numbers. Thus, it is not known whether lakes without these numbers are invaded or not. Consequently, all such lakes are dropped. These dropped lakes tend to be very small.

For this initial study, we focus on a subset of the original housing transaction data representing lake homes. Therefore, by defining "lakefront" to mean within 50 meters of a lake, Arc-GIS allows for the formation of a clean dataset of lakefront housing containing 8,951 *transactions* with house characteristics. Descriptive statistics of these housing characteristics are shown in table 1. Due to data limitations for the year 2007 resulting from incomplete data entry at the time of data purchase, all transactions occurring in 2007 are dropped from the dataset, and analysis is done over the time period 1990 to 2006. This dataset is used to estimate a housing price-index that is discussed in the next section.

Table 1: Housing summary statistics

Variable	**Mean**	**Std. Deviation**	**Min**	**Max**
# Acres	0.529	0.521	0.05	11.6
# Baths	2.54	0.904	1	8
# Bedrooms	3.466	1.032	1	8
# Fireplaces	0.725	0.938	0	4
# Sq. Feet	2451.737	1199.788	508	7892
# Stories	1.496	0.446	1	3
Garage Dummy	0.887	0.317	0	1
Log-Price	12.447	0.677	10.127	14.039
Age (years)	28.165	24.406	0	118

A separate dataset of parcels that are *developed* into single-family housing units between the years of 1990 and 2007 is also constructed. These parcels are also selected for being within 50 meters of a lake. Arc-GIS allows for the spatial overlap of landscape characteristics, such as slope and prime farm land, and the calculation of distances to the metro areas, parks, and highways. Like the transactions data, very few observations exist for the year 2007. However, instead of dropping them from the house development data, these observations are left in and treated as right censored observations, which will be discussed in section 5.2.

5. Estimation Methods

5.1 Housing Price-Index

Prior to estimating a duration model, a distinction needs to be made between the value a house receives from its structural characteristics, and the value it receives from its location. The expectation is that if two identical houses are built on different lakes, the home built on the lake with better amenities will have the higher value. Therefore, a housing price-index is estimated that controls for house characteristics.

Following a similar strategy to the one developed in Bayer, Keohane, and Timmins (2009), let $P_{i,l,t}$ denote the sale price of a single-family home in location i on lake l during year t. $P_{i,l,t}$ is modeled as

$$P_{i,l,t} = \rho_{l,t} e^{X_i \beta + \varepsilon_{i,l,t}} \tag{7}$$

where X_i is a vector of observable housing characteristics and $\rho_{l,t}$ is a scaling parameter for lake l during the year t. By taking the log of both sides, a form fit for estimation is derived

$$\ln P_{i,l,t} = ln\rho_{l,t} + X_i\beta + \varepsilon_{i,l,t}. \tag{8}$$

Using a fixed effects estimation[9], this function allows for the recovery of an index for the price of a homogenous house on a particular lake during a specific year[10]. Housing characteristic estimation results of this regression are reported in table 2. These results are largely as expected with positive coefficients on all characteristics except age and number of stories. Estimates of the price-index are not shown, as they number in the hundreds. The housing price-index that is found is then used in the duration model as a time-varying covariate.

[9] Because fixed effects regression uses intra-group variation over time, care must be taken to ensure that each group has enough variation. For this reason, all lakes with fewer than five transactions are dropped to ensure variation.
[10] Dummy variables for the year sold and for each lake are used in this regression. Due to the large number of lakes, it was infeasible to include lake/year sold interaction dummies. Therefore, the lake differentiates the price index in the initial period then all lakefront properties appreciate by the same amount each year.

Table 2: Housing Price Index Estimation Results (n = 8,951 and R-square = 0.9991)

Variable	**Coefficient**	**Robust Std. Error**	**t**
Acres	0.10205	0.01732	5.89
Baths	0.07512	0.00725	10.36
Bedrooms	0.04188	0.00603	6.94
Fireplaces	0.06540	0.00800	8.05
Sq. Feet	.00010	7.26e-06	13.28
Stories	-0.04890	0.01438	-3.40
Garage	0.19700	0.02222	8.87
Age	-0.00147	0.00027	-5.47

5.2 Cox Proportional Hazards Model

Cox's proportional hazard model makes some assumptions that are important to consider, the most fundamental of which is the proportional hazards condition. This condition states that covariates need to be multiplicatively related to the hazard over time. One way to check that this assumption is satisfied is to do an eyeball test using log-log plots[11]. However, since this is an eyeball test, accuracy is not guaranteed. A more precise way is to use the Schoenfeld residuals and test whether the slope in the regression of time versus the residuals is flat (Jones 2005). This test is easily accomplished in STATA with the phsttest command. For variables that reject the null hypothesis, that the slope is zero, the proportional hazards assumption does not hold. These variables can still be used, but an interaction term is needed between time and the variable to ensure that the original is no longer time dependent (Jones 2005). In all, 7 out of 15 variables used in this study's duration model required this fix, though the variable of interest, *postinvade*, did not. Special attention must be given to the interpretation of coefficients that require time-interaction variables, as the estimate of the coefficient now represents the

[11] For this test, simply look at the log-log plot to see whether the survival curves for each different value of the variable in question are parallel. This is the strategy applied by Klaiber and Wang (2012).

effect only when time equals zero, which never occurs since the time variable in this study begins at one. The coefficient on the time-interaction is now what dictates how these effects will change over time.

Another assumption of concern is non-informative censoring. The implication of this is that data censoring must not be related to the probability that parcels are developed. This study contains right censoring, meaning there are parcels that remain undeveloped from 1990 thru 2006. These observations are included in the study, but no failures occur. Therefore, the non-informative censoring assumption holds. Another form of censoring is left censoring, which refers to all parcels developed before 1990. This study assumes that all parcels that become developed will stay developed throughout the length of the study, and thus, there can be no redevelopment. For this reason, all left censored parcels are dropped from the dataset.

6. <u>Results</u>

The results of the duration model estimation are displayed in table 3. Estimates are reported as hazard ratios, which are measures of the probability of land conversion due to a change in a covariate (assuming that the parcel has not yet been developed). Hazard ratios are simply the exponential of the coefficients; therefore, hazard ratios greater than one imply an increase in the likelihood of the failure, whereas a hazard ratio less than one implies a decrease in the likelihood of the failure.

The covariates can be broken down into several categories: spatial characteristics that influence builder costs, parcel characteristics that influence demand, lake characteristics, and time-interaction terms. The covariates that influence builder costs are *steep_slope*, a dummy variable taking the value of one when a parcel contains slopes greater than 18 degrees, which are difficult to build upon, *prime_farm*, a dummy variable taking the value of one when a parcel's soil is composed of land deemed high quality for farming[12], and *prime_farm_metro*, an interaction variable between *prime_farm* and *logmetro_dist*, a log-distance measure to the closest metro center (either St. Paul or Minneapolis). As expected, steep

[12] High quality farm land is also good land for building houses, as the soil is easier to dig through for foundations and basements.

slopes decrease the likelihood of lakefront housing development, but as seen from the significant time-interaction term, the effect decreases over time. Next, parcels on prime farm land near to metro centers are much more likely to be developed, but as this distance increases, the likelihood drops. This verifies intuition because the further one goes from a metro center, the more demand there is to use high quality farmland for growing crops. Distance to a highway, *loghw_dist*, could be thought of as both a covariate that influences cost for developers and a parcel characteristic that would influence demand. Parcels far away from highways increase the cost of shipping supplies to the construction sites as well as increasing commuting times for residents. Therefore, it is no surprise to see that increasing distance to highways decreases the likelihood of parcel development.

Table 3: Estimation results for duration model (n=27,626)

Covariate	Hazard Ratio	Robust St.Error	z
Lake Characteristics			
Postinvade	.7234389	.0435508	-5.38
Area_acres	.9999551	.0000209	-2.14
Price_index	.7061908	.0776634	-3.16
Clarity	.9248299	.0191713	-3.77
Trout_fish	6.83104	1.131976	11.60
Pub_wat_acc	.9587833	.0546078	-0.74
Pub_park	1.187283	.0540369	3.77
Parcel Characteristics			
Park50	1.406304	.0944282	5.08
Golf50	.4214537	.1095139	-3.33
Cemetary50	.0029098	.0030361	-5.60
Logmetro_dis	.8459686	.0426666	-3.32

Loghw_dis	.8299983	.0236358	-6.54
Builder Cost Covariates			
Steep_slope	.6867933	.0690685	-3.74
Prime_farm	268.584	410.08	3.66
Prime_farm_metro	.5640229	.0862471	-3.74
Time-Interaction Terms			
Price_index_t	1.037778	.0135544	2.84
Loghw_dist_t	1.018363	.0034543	5.36
Steep_slope_t	1.026836	.0113072	2.40
Golf50_t	1.051342	.026444	1.99
Cemetery50_t	5.221174	.8348717	10.34
Prime_farm_t	.7769762	.1508097	-1.30
Prime_farm_metro_t	1.027324	.0197021	1.41

Parcel characteristics influence the demand for development and therefore the revenue obtained by developers. In this model, these characteristics take the form of three dummy variables: *park50, golf50, and cemetary50*. These dummies take the value of one if a parcel is within 50 meters of a park, a golf course, or a cemetery, respectively. This is an attempt to group all parcels with direct line of sight to open green spaces. The hazard ratio on *Park50* indicates that parcels within 50 meters of a park are 41% more likely to be developed than those that are not. Parcels with views of golf courses are initially less likely to be developed, which possibly indicates some consumer's distain of golf ball damage. However, as indicated by the significant time-interaction term, these negative effects decrease over time. For the cemetery effect, adding the hazard ratio for the covariate with the hazard ratio for the time-interaction term shows that views of a cemetery increase the likelihood of development, and this effect increases over time.

As the parcels of interest are adjacent to lakes, it is expected that lake characteristics will affect the duration that the parcel remains undeveloped. At first, *price_index* has a hazard ratio less than one, indicating that parcels gaining more value from their surrounding amenities were less likely to be developed than those parcels that gained less value. However, this effect is diminishes over time. Both clarity and size have negative effects on the likelihood, whereas being labeled a trout lake and having a public park on the lakefront increase the likelihood.

Finally, the covariate named *postinvade* is a dummy variable taking the value of one if Eurasian water-milfoil has been discovered in the lake, and the value of zero if not. Since a lake can become invaded in any year, and a parcel's duration may span both sides of the year of invasion, therefore this covariate is estimated as a time-varying covariate. The estimate of the hazard ratio for *postinvade* is 0.7234389 and is significant at the 1% level, indicating that undeveloped parcels on lakes invaded by Eurasian water-milfoil are 28% less likely to be developed than their non-invaded counterparts. This result is robust to adding several more covariates including log-distances to the nearest airports, schools, state or regional parks, colleges, bike paths, bus lines, and also to a dummy variable measure of lake biodiversity.

7. <u>Discussion</u>

7.1 Possible Endogeneity

One could be concerned that endogeneity may impact the causal interpretation of results. This endogeneity concern arises if recreational boaters are the main transport mechanisms for Eurasian water-milfoil and they are attracted to a particular lake due to latent amenities. Unfortunately, to the author's knowledge, no boater behavior data exists for this region and time span, and it is not possible to go back and gather such information. A lake specific fixed effect will not fix this problem because it is unrealistic to assume that boater behavior will remain constant over time in the presence of a milfoil invasion, since Eurasian water-milfoil has adverse effects on boating. It is for these reasons that the covariate for public water access is included. By controlling for lakes that have public boat ramps, this study attempts, imperfectly, to protect itself from endogeneity. Future studies in this area should gather data on boater behavior to truly avert this problem.

7.2 Implications of results for future research

A possible implication of the finding that Eurasian water-milfoil decreases the likelihood that lakefront parcels will be developed is an increased demand for the development of non-invaded lakefront properties. An interesting question for further research is whether this finding creates a race to develop non-invaded lakes. Other interesting questions revolve around the risk of invasion. Are developers more likely to build on non-invaded lakes which have a higher risk of invasion in an attempt to capitalize on higher revenues before the invasion occurs? Or, do they prefer to build on non-invaded lakes that have lower invasion risks? These are all questions that can drive this line of research forward as economists continue to research the interactions between invasive species and human behavior.

8. <u>Conclusion</u>

Invasive species are a growing concern in the United States due to the large amounts damage they cause to ecosystems, biodiversity and businesses. This study concerns itself with Eurasian water-milfoil, an invasive aquatic plant that, with the help of recreational boaters, has puddle-jumped its way into many of the country's lakes. Several hedonic studies have shown that one of the damages of milfoil manifests itself in the form of diminished lakefront property values. What the current literature lacks, is empirical work looking at how human behavior changes due to the presence of an invasive. This study uses a rich dataset of land, lake, and property characteristics from the Twin Cities region of Minnesota to estimate a duration model of land conversion. It is found that currently undeveloped parcels on invaded lakes are 28% less likely to be developed in a given time period than undeveloped parcels on uninvaded lakes. This is evidence that humans do change their behavior in the presence of an invasive species.

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