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Invasive Species and Delaying the Inevitable: Results from a Pilot Valuation Experiment

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Herein we explore the economic value of delaying inevitable environmental damage due to aquatic invasive species, which is a problem especially relevant to tropic and subtropical regions. We developed an analytical framework and tested it using a stated preference survey. The results suggest that delaying the impacts can be valuable. Other tests reveal characteristics of the willingness-to-pay estimates that are consistent with economic theory.

Key Words: environmental damage, invasive aquatic species, nonmarket valuation

JEL Classifications: Q00, Q20, Q29

Invasive species are a global problem that can cause widespread environmental and economic impacts (see, for example, the following organizations: National Invasive Species Information Center United States Department of Agriculture, The Global Invasive Species Programme, and The Global Invasive Species Database Invasive Species Specialist Group). Trade and trade routes amongst regions are known to be a primary vector in the spread of invasive species (several studies on trade and aquatic invasive species are reviewed in Lovell and Stone, p. 16–38). This is especially true for regions of the United States in tropical and subtropical climates (e.g. Florida, Virgin Islands, and Hawaii), which depend in large part on trade for their economic welfare. Dalmazzone reports a link between trade and nonindigenous species (NIS) that suggests that the number of plant NIS increases with more imports and lower trade tariffs. Following invasion, inland spread threatens regional lakes and rivers, which tend to provide market and nonmarket values for a region's inhabitants. As these resources are usually degraded by the invasion, there may be incentives for government intervention or for individual self protection (see, for example, Burnett et al.). Since it is in large part economically and politically infeasible to eliminate trade, invasions are more than *just likely*, they are *inevitable*.[1]

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[1] Anecdotal examples exist of policy makers framing invasions as *inevitable*. Consider two recent examples: First, an excerpt of a discussion between Lori Williams (executive director of the National Invasive Species Council) and Jeffery Kaye (KCET/Los Angeles) during a NewsHour with Jim Lehrer Public Broadcasting Service (PBS) program: LORI WILLIAMS: "We can't keep everything out and we're not going to stop trade, but it's worth considering the impacts of these species, taking the time to evaluate them and making sure that it's worth the risk to bring in some of these products or just change the way we bring them in by addressing the pathway." JEFFREY KAYE: "But as the world continues to shrink, thanks to increased trade and travel, those involved in the struggle against invasive species are fatalistic, knowing the arrival of new adversaries is inevitable." (PBS).

A critical step in deriving reasonable policy responses to combat biological invasions is to determine whether people value protection of natural ecosystems. Given the inevitability of invasion, perhaps the most pertinent question becomes: what are people willing to pay to maintain (at least temporarily) the current (high) level of environmental quality if environmental degradation from the invasive species is guaranteed at some future point?

Herein, we explore the economic value of delaying inevitable environmental damage due to aquatic invasive species, which is an especially relevant problem in tropic and subtropical regions.[2] We develop an analytical framework and test its predictions using a stated preference survey. The framework assumes that the timing of invasion (or time when damages occur) is a known parameter. Prior to the invasion, the state of nature is "good," and following invasion, it is "bad." In the good state, people gain utility from consumption and a high constant level of environmental quality. In the bad state (following an invasion), they gain utility from consumption net of direct damages and lose utility through a reduction in environmental quality. Although the bad state occurs with certainty at some future date, policy options make it possible to delay the timing of the event. Given this setting, the task is to derive what people are willing to pay (WTP) to incrementally delay the timing of invasion damages (or the WTP to *delay the inevitable*).

Based on the analytic framework, a survey was designed to elicit WTP to delay inevitable aquatic invasions of inland water bodies of the United States. Using the contingent value method (CVM), WTP to delay given impacts and degrees of severity of aquatic invasive species in regional lakes and rivers was elicited from respondents. WTP questions were focused on invasive species taxonomic groups and included species relevant for U.S. tropical and subtropical regions. Example species included carp (fishes group), snails (mollusks group), water fleas (crustaceans group), and milfoil (plants group), all of which are listed as exotic invaders in either Hawaii or Florida (and other states within these climatic regions).

The research is timely, following other work such as Burnett et al., who discussed the threat to Hawaii's direct ecosystem and indirect ecosystem benefits from invasive species. They demonstrated the importance of the relationship between native biota and residents' values. Maintaining native biodiversity while limiting introductions of nuisance species can assist locals by conserving critical fresh water supplies and protecting human health (among other benefits). Our study included six categories of aquatic invasive species impacts for respondents to consider in their valuation: lake aesthetics, risks to biodiversity health, risks to human health, economic production, navigation, and recreation.

Our results show that people find value in delaying inevitable impacts. Other tests reveal characteristics of the WTP estimates consistent with economic theory, which provides some validation to the idea that subjects can provide reasonable WTP values for invasive species.

Analytical Framework

The willingness-to-pay measure that we used is rather unique: we measured the WTP for

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Second, Jim Worrall with the USDA Forest Service and Forest Health Protection for the National Invasive Species Council: "It is universally agreed that prevention/exclusion is the most effective approach to the problem of invasive species. However, there is a similar consensus that more introductions are inevitable in the current climate of trade and travel." (Worrall).

[2] Better integration of ecology and economics has been discussed for many years (see, e.g., Clark; Crocker and Tschirhart; Daly; Dasgupta, Levin, and Lubshenco; Finnoff and Tschirhart; Settle and Shogren; Sohngen and Mendelsohn; Wilson). This problem has brought together several biologists, economists, and mathematical modelers to create a National Science Foundation (NSF)–funded program called Integrated Systems for Invasive Species (ISIS). Based out of Notre Dame and Wyoming, the ISIS group cooperates to develop bioeconomic models to merge ecology and economics and identify optimal strategies, acceptable invasion risks, and consequences of invasion to economic investments.

a marginal delay in invasion damages, given the assumption that these damages will occur with certainty at some point in time. Derivation of this WTP necessarily requires a dynamic model, taken to be one in which a person maximizes lifetime utility over good and bad states while facing a budget constraint. During periods in the good state, the individual receives constant utility from consumption and the corresponding (high) level of environmental quality. When the bad state is realized, utility then depends on consumption minus some market damage and the lower level of environmental quality. This model closely follows Rosen and Shogren et al., and it is presented in full in McIntosh, Shogren, and Finnoff. A representative person's lifetime utility is:

$$(1)\ \bar{U} = \int_0^{\tau} \bar{U}^0 e^{-\rho t} dt + \int_{\tau}^{T} \bar{U}^1 (c(t) - \alpha D(x(t) + \tilde{x}(t)), Q^1) e^{-\rho t} dt,$$

where $\bar{U}^0$ is the constant utility in the good state, ρ is the rate of time preference, $\bar{U}^1$ is the utility in the bad state, c is consumption in period t, α represents the proportion of damages faced by the person, D is the damage function, x is the monetary contribution to invasion control, $\tilde{x}$ represents all contributions to invasion control by other parties, Q^1 is environmental quality in the bad state, τ reflects the invasion time, and T is the time of death.

The complexity of the problem is reduced if either ρ or T is assumed to be sufficiently large such that $e^{-\rho T} \to 0$. The intertemporal budget constraint follows from the assumption that the individual is endowed with wealth W. He or she confronts a pure–consumption–loans market at interest rate r and cannot die in debt. All capital is consumed in the lifetime, so consumption choices $c(t)$ and contributions toward lowering market damages $x(t)$ are constrained by:

$$W = \int_0^T (c(t) + x(t)) e^{-rt} dt.$$

It is also assumed that the person receives no utility in the good state from contributions, and contributions cannot be saved into a rainy-day fund to reduce market damages in the bad state. This provides no incentive for the person to contribute to damage protection in the good state, making the budget constraint:

$$W = \int_0^{\tau} c(t) e^{-rt} dt + \int_{\tau}^{T} (c(t) + x(t)) e^{-rt} dt.$$

Since good state utility is constant and determined by consumption and the unchanging environmental state, utility from consumption in each good state period should be the same (as discounting is multiplicative).[3] As consumption in the good state is equal over each period in that state and discounted at the rate of interest, the budget constraint becomes:

$$(2)\quad W = \left(\frac{c(0)}{r}\right)(1 - e^{-r\tau}) + \int_{\tau}^{T} (c(t) + x(t)) e^{-rt}.$$

The Lagrangian expression for a person's problem of maximizing utility over good and bad states subject to a budget constraint is:

$$(3)\quad \underset{c,x}{L} = \int_{\tau}^{T} \left(\bar{U}^1 - \bar{U}^0\right) e^{-\rho t} dt + \lambda\left(W - \frac{c(0)}{r}(1 - e^{-rt})\right) - \lambda\left(\int_{\tau}^{T} [c(t) + x(t)] e^{-rt} dt\right).$$

Maximizing Equation (3) with respect to consumption and control expenditures and letting $M^1 = c(t) - \alpha D[x(t) + \tilde{x}(t)]$ and $\hat{X} = x + \tilde{x}$ leads to the following first-order conditions:

$$(4)\quad c(t) : \bar{U}^1_{M^1} e^{-\rho t} - \lambda e^{-rt} = 0, \quad \text{for } \tau \le t \le T.$$

$$(5)\quad x(t) : -\alpha \bar{U}^1_{M^1} D_{\hat{X}} e^{-\rho t} - \lambda e^{-rt} = 0, \quad \text{for } \tau \le t \le T,\ D_{\hat{X}} \le 0.$$

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[3] The model assumes c(t) is constant for $t < \tau$. While we acknowledge that this is a strong assumption, we find it convenient to write the problem so the integrals are over the same limits. We are most interested in what happens at the time of invasion and WTP to extend invasion time rather than how the person consumes preinvasion.

If the optimality conditions in Equations (4) and (5) are solved simultaneously for λ, the result is:

$$(6) \qquad \rightarrow \lambda = \frac{\bar{U}^1_{M^1}\left(1 - \alpha D_{\hat{X}}\right)e^{-\rho t}}{2e^{-rt}}.$$

The WTP is found as the value of a change in the time of transition from good to bad states, τ. Indirect utility is a function of W and τ (and the other parameters held at their original levels) and defines (W, τ) indifference curves. By holding utility constant at the original level and viewing wealth, W, as a function of the exogenous probability of the good state, τ, the slope of the indifference curve (MRS) can be found as:

$$(7) \qquad -\frac{dW}{d\tau} = \frac{\frac{\partial L}{\partial \tau}}{\frac{\partial L}{\partial W}}.$$

By applying the envelope theorem to Equation (3), the partial derivatives necessary to determine the WTP value, V, can be calculated.

$$V = -\frac{dW}{d\tau} = \frac{\frac{\partial L}{\partial \tau}}{\frac{\partial L}{\partial W}} = -\frac{\left(U^1 - \bar{U}^0\right)e^{-\rho\tau}}{\lambda}$$
$$+\lambda[(-c(0) + c(\tau) + x(\tau))e^{-r\tau}]/\lambda.$$

If c and x are held at their optimum levels (given by Equations [4] and [5]), and the dual optimality condition in Equation (6) is used to simplify, the value at $t = \tau$ can be determined:

$$(8) \qquad V = \left(\left\{\left[\bar{U}^0 - \bar{U}^1\{c(\tau) - \alpha D[x(\tau) + \tilde{x}(\tau)], Q^1\}\right]e^{-rt}\right\} \div \frac{\left[\bar{U}^1_{M^1}\cdot(1 - \alpha D_{\hat{X}})\right]}{2}\right) + [-c(0) + c(\tau) + x(\tau)]e^{-r\tau}.$$

Assuming $\bar{U}^0 > \bar{U}^1$, $D_{\hat{X}} < 0$, and total expenditures at τ do not decrease, V is always positive, and this provides the testable implication that a person faced with an inevitable loss from environmental degradation should be willing to pay to delay this loss. V is discounted to time τ and has a familiar value of a statistical life (VSL) component in the first term, where the difference in state utilities is divided by a marginal utility measure (see Hammitt). The second set of terms adds the change in expenditures from the good to bad state since the difference can be used to extend the time experienced in the good state instead of the alternative of spending it in the bad state.

The model's general result suggests that if people experience utility loss from a degraded environmental state, they should be willing to pay to delay this loss *even if damages are inevitable*. Empirical results are the focus of the remainder of the paper. We tested the model's validity by designing a survey as described in the next section.

Survey Design

The model's implications were tested using a survey designed to elicit a subject's willingness to pay to delay the inevitable.[4] Conducted at the University of Wyoming, the study was administered in economics courses. The average respondent completed the survey in less than 15 min. The instrument initially defined lakes and rivers, the respondent's region, invasive species, impact of invasive species, and impact severity levels. This introductory section was created to inform the respondents of the terminology used in the valuation questions. The survey used the contingent valuation method (CVM) of eliciting demand for delaying the inevitable, i.e., WTP to delay the impacts of aquatic invasive species in regional lakes and rivers (the full survey is available on request).[5]

The valuation task asked respondents for their WTP to delay impacts of a given level for a given time in regional water bodies. Before being asked the valuation questions, respondents were given preliminary information and

[4] There are several papers that attempt the valuation of invasion prevention and control. For a survey of papers broken down by evaluation characteristics, see Born, Rauschmayer, and Brauer.

[5] For further accounts of CVM, see Bateman and Willis; Hanley and Spash; Hanley, Shogren, and White; and Mitchell and Carson.

questions to encourage them to think about aquatic invasive species and the different impacts they may cause. Respondents were initially informed of the definition of lakes and rivers in their region. Any water body within 100 mi. (161 km) of their home was considered to be in their region. After these terms were defined, the respondents were asked about usage, including the number of trips to lakes and rivers (within and outside of their region) they had made in the last year, and the activities engaged in during their visits.[6] These questions were included to help participants consider how invasive species protection may be of value and may be important in explaining the magnitude of their values.

Next, respondents were given information about invasive species and whether a water body was considered invaded or not invaded. The following definitions were provided in the survey:[7]

Invasive Species

An "invasive species" is defined as a species that:

- is non-native (or alien) to the ecosystem under consideration *and*
- causes or is likely to cause economic or environmental harm or harm to human health when introduced.

Invaded Water Bodies

Specifically, a water body is **Invaded** if the lake or river has a non-native species and if the species:

- disrupts natural ecosystems and causes irreversible ecological harm,
- eliminates native plants, fish, and other aquatic life, or
- damages the economy.

A water body is **Not Invaded** if the lake or river either does not have a non-native species or if it has a noninvasive species that:

- does not disrupt natural ecosystems and cause irreversible ecological harm,
- does not eliminate native plants, fish, and other aquatic life, and
- does not damage the economy.

Following these definitions, participants were asked about their level of familiarity with aquatic invasive species. They answered this question in general and then were given four species and asked if they had "never heard of it," "heard of it," or were "familiar" with each species. The instrument then asked respondents to choose the perceived level of risk (none, low, medium, high) that invasive species pose to lakes and rivers in their area in each of three major categories; environmental risk, economic risk, and human health risk. Again, *ex ante* experience and perception may be important factors in the valuations provided. Participants were also introduced to the impact types and severities. Figure 1 shows the impact chart that was created by working with members of the Integrated Systems for Invasive Species group to summarize the different types of impacts that may be expected from aquatic invasive species.[8] There were six impact categories: lake aesthetics, risks to biodiversity health, risks to human health, economic production, navigation, and recreation. Impacts were originally listed for individual species; however, even when limited to seven species, the chart was intimidating. The chart was then simplified by creating rows for species groups (e.g., fishes, mollusks, crustaceans, and aquatic plants). The listed impacts

[6] The definitions for lake, river, and region, and several usage questions are from Viscusi, Huber, and Bell.

[7] For invasive species definitions, see USDA National Invasive Species Information Center. The invaded water bodies' definitions were based on the invasive species definitions and formed by collaboration among ISIS group members.

[8] The ISIS group (Integrated Systems for Invasive Species) helped summarize the different impacts from several references. (For invasive fish impacts, see: Eddy and Underhill; Fullerton et al.; Rosch and Schmid; Savino and Kolar; and University of Minnesota. For invasive mollusk impacts, see D'Itri. For invasive crustacean impacts, see Lodge and Lorman; Lodge et al.; Manca and Ruggiu; Yan, Girard, and Boudreau; and Yan and Pawson. For invasive aquatic plant impacts, see Boylen et al; and Eiswerth, Donaldson, and Johnson.)

Invasive Species Group	Lake aesthetics	Risks to biodiversity health	Risks to human health	Economic production	Navigation	Recreation
Fishes *(e.g., Round Goby, carp)*	Reduce lake clarity	Reduce native fish and aquatic plants		Reduce commercial fish		Reduce sport fish
Mollusks *(e.g., snails, mussels)*	Improve lake clarity	Reduce native mollusks; Can kill wildlife that eats them	Cut feet; Can make people sick	Clog pipes; Reduce filtering; Stick to boat hulls; Reduce commercial fish	Clog locks, dams, and canals	
Crustaceans *(e.g., Spiny Water Flea, Rusty Crayfish)*		Reduce native aquatic animals and plants; Cross-breeds with native species			Improve by reducing native plants	Stick to fishing lines and nets; Reduce sport fish
Aquatic Plants *(e.g., Eurasian Water Milfoil)*	Lake can look full of weeds	Reduce native aquatic plants	Increase mosquitoes and swimmers' itch	Clog irrigation and water treatment intake pipes	Stick to boat propellers	Stick to fishing lines and nets; Reduce sport fish; Reduce swimming areas

Figure 1. Impact Chart Describing the Types of Impacts if the Species Groups Invade

for the species groups were compiled from the union of the impacts expected from individual species within the group, i.e., the fishes group contained expected impacts from both the round goby and carp. The survey also described how to consider different levels of severities of the impacts. Severities were described as either causing low- or high-intensity impacts and were defined as follows:

In this survey, we divided impacts into two levels:

- *Low*: minimally impacted—sites or conditions with *trivial* invasive species impacts.
- *High*: impacted—sites or conditions with *significant* invasive species impacts.

Creating discrete impact levels simplified a difficult concept into a manageable amount of information for a short survey.It also matched with the *delaying the inevitable* theory in which discrete environmental quality differences enter a person's utility function.

The next section in the survey described the delay-of-the-inevitable problem. Respondents were informed that all lakes and rivers in their region *will be* invaded, the only question was *when*. It was described that a prevention technology exists that can delay the invasion, and, if used, it will delay the invasion for the given amount of time from the present. After the specified delay, species would invade and spread quickly to regional lakes and rivers, causing a given level of damages. If the technology were not used, species would invade and spread to regional lakes and river within one month from the present. This information set up the valuation questions, which were given according to the three scenarios below:

- Scenario 1: What is the most you would be willing to pay to keep all lakes and rivers in your region Not Invaded (no impacts) from ALL GROUPS for ONE YEAR? These groups will cause LOW impacts after one year for the foreseeable future.
- Scenario 2: Imagine your lakes and rivers have been invaded. What is the most you would be willing to pay to keep all lakes and rivers in your region at LOW impacts from ALL GROUPS for ONE YEAR? These groups will cause HIGH impacts after one year for the foreseeable future.
- Scenario 3: Similar to scenario 2, only prevention lasts for TEN YEARS?

Respondents were given a table that summarized the scenarios and requested their WTP values. These could be given in dollars per year or a dollar interval per year, e.g., $20/yr or $10–$30/yr. The interval option gave participants a way to avoid specifying an exact dollar amount if they were unsure given the information provided. There were two treatments; one where respondents were asked to provide WTP values when all species groups invaded for the three scenarios, and one when only fish species invaded for the three scenarios. The final section of the survey asked a number of demographic and survey feedback questions.

Data and Hypothesis

In all, 120 surveys were collected; 106 were included in the statistical analysis.[9] There were 26 completed surveys for fish species invasions and 80 for all species. Since each respondent answered three WTP questions, there were 318 total observations in the data set.

All statistics discussed here are based on respondents WTP values *per year* for the given scenarios.[10]

Table 1 presents summary statistics for each of the six WTP question responses.[11] Mean WTP values per year from fish species were $57 for one year of protection from low impacts, $70 for one year of protection from high impacts, and $35 for ten years of protection from high impacts. Mean WTP values per year from all species were $108 for one year of protection from low impacts, $146 for one year of protection from high impacts, and $213 for ten years of protection from high impacts. As was expected, there was high heterogeneity across individuals and their willingness to pay to delay the inevitable. We empirically investigated causes of these heterogeneities and offer our explanation below.

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[9] Ten surveys were excluded because of missing WTP estimates for one of the three valuation questions. Three additional surveys were excluded since reported WTP values exceeded the reported annual household income. One more survey was excluded due to very high reported WTP values of $20,000 per year, $7,500 per year, and $7,500 per year for one year of protection from low impacts, one year of protection from high impacts, and ten years of protection from high impacts from all species. While these WTP values were less than reported household income ($80,000–99,000), they are large outliers that likely greatly overstate actual WTP (hypothetical bias).

[10] The conversion of total WTP in each scenario to WTP *per year* only affects scenario 3, in which households gave upfront WTP values for ten years. Total WTP for ten years was calculated as a WTP per year measure to simplify the results discussion.

[11] If respondents chose to use intervals, we assumed a uniform distribution and used the mean WTP per year.

Table 1. Summary Statistics for WTP Question Responses

	All[a]	*FZL1Y*[b]	*FLH1Y*[c]	*FLH10Y*[d]	*AZL1Y*[e]	*ALH1Y*[f]	*ALH10Y*[g]
N[h]	318	26	26	26	80	80	80
Mean $/yr	131	57	70	35	108	146	213
StDev $/yr	286	107	111	35	219	289	420
Min $/yr	0	0	0	0	0	0	0
50% $/yr	28	18	33	28	28	28	43
Max $/yr	2,000	505	505	100	1,000	1,250	2,000

[a] All—Summary results when all WTP question responses are grouped.
[b] *FZL1Y*—Willingness to pay for one year (1Y) of protection from low damages (ZL) from fish species (F).
[c] *FLH1Y*—WTP for one year (1Y) of protection from high damages (LH) from fish species (F).
[d] *FLH10Y*—WTP *per year* for ten years (10Y) of protection from high damages (LH) from fish species (F).
[e] *AZL1Y*—WTP for one year (1Y) of protection from low damages (ZL) from all species (A).
[f] *ALH1Y*—WTP for one year (1Y) of protection from high damages (LH) from all species (A).
[g] *ALH10Y*—WTP *per year* for ten years (10Y) of protection from high damages (LH) from all species (A).
[h] *N*—Number of WTP question responses used in statistical analysis.

In general, the numbers given seem reasonable when compared to Nunes and van den Bergh. Their estimates of recreational costs (travel costs) for beach closure due to harmful algal blooms resulted in average values of approximately $45/yr. In addition, they implemented a CV survey to test for nonmarket benefits of a ballast water monitoring and treatment program. They found average values of these nonmarket benefits (associated with beach recreation, human health, and marine ecosystem impacts) of ~$62/yr. to prevent these invasions. The total of about $107 per year can be thought of as reasonably well matched to the result herein of $57 per year for fish species protection from low impacts for one year elicited from a geographically disparate sample. This comparison is valid because protection for one year is similar to preventing the invasion by *continuing* to have no impacts to regional lakes and rivers. The difference in magnitude is reasonable when one considers that their surveys were administered geographically close to the beach resort where the invasion would occur (with the implication that it is more likely for respondents to have recreational values).[12]

Hypotheses were created to test the theory and properties of the WTP estimates. The alternative hypotheses are:[13]

- Hypothesis 1 (H1)—Delaying the impacts of invasive species is valuable.
- Hypothesis 2 (H2)—Delaying *high impacts for ten years* is more valuable than delaying *high impacts for one year.*
- Hypothesis 3 (H3)—Delaying impacts from *all species groups* is more valuable than delaying impacts from *just invasive fishes.*
- Hypothesis 4 (H4)—Observations where participants have *higher incomes* result in greater WTP values.

The tests based on hypothesis H1 determine if delaying invasions is valuable; did participants have WTP values statistically different than zero for the given impact severities and delay times? It is expected that the continuation (albeit temporary) of baseline environmental quality (delaying impacts) is valuable. The survey results allowed us to test hypotheses H2, H3, and H4 in an attempt to determine if the subject's WTP estimates were consistent with economic theory.

Empirical Model

We used the survey data to explore the determinates of WTP to delay the inevitable.

[12] Some studies find individual valuations for similar, although less comparable, environmental changes. For example, for water-quality improvements, see Viscusi, Huber, and Bell; for catching native trout versus an invasive lake trout, see Settle and Shogren.

[13] Testing the hypothesis required many separate tests. See Table 3 for a summary of tests and results.

The model chosen was the multiplicative heteroscedastic model[14]

$$\begin{aligned} WTP/Yr = {} & \beta_1 + \beta_2 FishZL1Y \\ & + \beta_3 FishLH1Y + \beta_4 FishLH10 \\ & + \beta_5 AllLH1Y + \beta_6 AllLH10 \\ & + \beta_7 FishZL1YIncH + \beta_8 FishLH1YIncH \\ & + \beta_9 FishLH10IncH + \beta_{10} AllZL1YIncH \\ & + \beta_{11} AllLH1YIncH + \beta_{12} AllLH10IncH \\ & + \varepsilon(i, t). \end{aligned}$$

The dependent variable, *WTP/Yr*, is willingness to pay per year. Following a constant, independent variables reflect the fact that respondents were either asked their WTP for invasive protection from fish species or all species groups. The *Fish* prefix classifies a dummy variable for observations from fish species protection, while *All* are observations with all species groups invading. The two severity levels are represented as binary variables, where *ZL* is defined as impacts starting at zero then increasing to low intensity, and *LH* is defined as impacts starting at low then increasing to high intensity. There are two time frames for the length of invasion delay, one year (*1 Y*) and ten years (*10*). Finally, respondents were divided into two income categories, where *IncH* classifies observations corresponding to people with high household incomes.[15] For example, *FishZL1Y* is an observation where the respondent was asked their willingness to pay for protection from fish species creating low impacts (from zero) for one year. Similarly, *FishZL1YIncH*, is an observation with the same WTP question but from a respondent with a reported high household income.

Each parameter of the model describes an important relationship. The constant captures WTP responses in the low-income category for all species groups creating low impacts for one year. It is expected to be positive, since delaying impacts to environmental quality presumably has some value (such that a known invasion time suggests some consequence). This is the baseline case.

FishZL1Y is for a similar WTP question as the constant but regarding protection from fish species only. Since invasive fish have fewer types of impacts, this coefficient is predicted to be negative. The sign of the coefficient on *FishLH1Y* is difficult to predict. As it reflects just fish, the value is expected to be lower than for all species (as captured by the constant), but it is also for a change in quality, from low to high impacts. The trade-off is whether people place a higher value on keeping lakes and rivers unspoiled (zero to low impacts) or prefer protecting them from significant damages (low to high). It is expected that the value of keeping areas pristine is higher than the value of protecting against increased

[14] Given that people answered three WTP questions each, it would seem that fixed or random effects would be more appropriate to account for individual effects (see Green). Fixed effects, however, do not allow for independent variables that do not vary across individual observations (income), and models without income were not significant. After including the income terms, there was no longer a significant random error component, which implies that Ordinary Least Squares (OLS) is not rejected (see Hausman). After checking plots of OLS residuals against the independent variables, several of the interaction dummy terms were candidates for group heteroscedasticity. This problem can be addressed using a general heteroscedastic form or specifying the responsible variables. Since the plots indicated that using a group specification would be reasonable, Harvey's multiplicative heteroscedastic model was used to produce the OLS results (Maximum Likelihood Estimation results are similar). White's adjusted estimator allows for a more general form and yielded similar results. Other variables were included and determined insignificant, including lake and river visits, *ex ante* familiarity of invasive species, age, sex, race, marital status, earned college or technical school degree, membership to an environmental organization, survey clarity variables, and survey treatment dummies (three versions of survey were given). Given that the subjects were students in economics classes, there was little variation in many of these variables. They are intentionally excluded to increase the model's significance and keep the number of independent variables to a reasonable total given the number of observations.

[15] Defined as $45,000 or higher for the previous year; this corresponds to a household income above the average median over the three-year period 2002–2004 (U.S. Census Bureau).

Table 2. Multiplicative Heteroscedastic OLS Estimates

Variable	Prediction	Coefficient	*p*-value
Constant	+	57.01	0.000
FishZL1Y	–	−10.63	0.563
FishLH1Y	–	1.74	0.935
FishLH10	–	−21.38	0.182
AllLH1Yr	–	10.17	0.580
AllLH10Y	–	67.75	0.027
FZLIncH	?	46.96	0.588
FLHIncH	?	48.75	0.557
FLHTIncH	?	−3.88	0.820
AZLIncH	+	145.85	0.008
ALHIncH	+	226.57	0.027
ALHTIncH	+	252.03	0.042

Note: $N = 318$; adjusted $R^2 = 0.11$.

impacts of damaged goods, which would be reflected in a negative coefficient.

The severity of impacts assists in predicting the signs of the rest of the low-income variables: *FishLH10*, *AllLH1Y*, and *AllLH10*. One difference is that two of these variables capture WTP per year for a ten-year delay verses one year. If participants discount the future, it is likely, on a per year basis, that WTP will be higher in a one-year scenario. All three of these variables are predicted to be negative.

The final six variables (*FishZL1YIncH*, *FishLH1YIncH*, *FishLH10IncH*, *AllZL1YIncH*, *AllLH1YIncH*, *AllLH10IncH*) are observations from high-income subjects. It is expected that delaying impacts is a normal service, so their coefficients should be greater than the corresponding low-income coefficients. Since income was divided into only two groups,[16] it seems reasonable to think that these people may have significantly larger WTP values. These variables are expected to be positive.

Results and Discussion

Table 2 shows the results of the multiplicative heteroscedastic ordinary least squares estimates.[17] The regression model is significant at the 1% level. The constant is positive and significant as predicted. Two of the three low-income fish-species terms are negative (as expected), but all three are insignificant. The low-income all-species terms are positive (opposite of expected), but, again, they are insignificant. The high-income terms were predicted to be positive; the fish-species terms are insignificant, while the all-species terms are positive and significant.

Revisiting the four hypotheses with these results in hand reveals some implications (see Table 3 for a summary of hypotheses tested).

Result 1. Delaying Impacts Is Valuable to Our Sampled Population

Support. The null hypothesis H1 (WTP values are zero) is rejected at the 1% significance level, and WTP values are positive, supporting the implications of the theoretical model. To study the results in greater detail, each of the three scenarios was tested. Joint tests (incorporating both income groups; low, high) for each of the three scenarios (WTP per year for delaying: low damages for one year, delaying high damages for one year, and delaying high damages for 10 years) are significant at the 1% level. Null hypotheses suggesting that delay of impacts is not valuable are all rejected. This result supports the notion that delaying environmental degradation is valuable, as anticipated from the terms of willingness to pay in the analytical model.

A common concern with stated preference surveys and hypothetical scenarios concerns the validity of the WTP estimates. To address these concerns, further tests were conducted.

[16] Other variations of income divisions were tested and were less significant.

[17] Results differ if the outlier previously mentioned in footnote 9 is included: maximum likelihood estimates cannot be completed due to estimates diverging from exploding variances; OLS estimates have much larger coefficients for the three all-species high-income terms; overall regression is insignificant ($R^2 = 0.015$ with probability value = 0.15).

Table 3. Referenced Null Hypotheses and Test Results

Null Hypotheses	Wald Stat
Delaying *low impacts for one year* is not valuable	49.1***
Delaying *high impacts for one year* is not valuable	50.4***
Delaying *high impacts for ten years* is not valuable	66.0***
WTP to delay *high impacts for ten years equals* WTP to delay *for one year*	9.0**
WTPs to delay impacts from *all species* equals WTP to delay impacts from *just fishes*	20.6***
Incomes have no effect on WTPs	14.8**

*** Null Hypothesis rejected at 1% significance level.
** Null Hypothesis rejected at 5% significance level.

Result 2. Characteristics of the WTP Estimates Are Consistent with Economic Theory

Support. The null hypotheses H2, H3, and H4 are rejected at the 5% significance level. Null hypothesis H2, that total WTP values for ten years of protection from high impacts is no more than WTP for one year of protection from high impacts, is rejected at the 5% significance level.[18] Null hypothesis H3, that protection from all species groups impacts is no more valuable than impacts from just invasive fishes, is rejected at the 1% significance level.[19] Null hypothesis H4, that subjects classified as having high incomes have no greater WTP values for invasive-species protection, is rejected at the 5% significance level.[20]

[18] This result is a joint test of four individual null hypotheses equaling zero relative to the baseline; fish-species low-income, all-species low-income, fish-species high-income, and all-species high-income.

[19] This result is a joint test of six individual null hypotheses equaling zero relative to the baseline; one-year low-impacts delay with low income, one-year high-impacts delay with low income, ten-year high-impacts delay with low income, one-year low-impacts delay with high income, one-year high-impacts delay with high income, and ten-year high-impacts delay with high income.

[20] This result is a joint test of six individual null hypotheses equaling zero relative to the baseline; fish-species one-year low-impacts delay, fish-species one-year high-impacts delay, fish-species ten-year high-impacts delay, all-species one-year low-impacts delay, all-species one-year high-impacts delay, and all-species ten-year high-impacts delay with high income.

Concluding Remarks

The tropic and subtropical regions face a tremendous environmental challenge from the barrage of potential invaders (e.g., Asian clam, water flea, carp, water hyacinth). Policy aimed at preventing all invasions seems futile given the current trade climate. While this may seem dismal, it may still be valuable to invest in delaying the timing of invasions and the severity of their impacts. Herein, we developed a dynamic framework for analyzing inevitable risks posed by invasive species to environmental quality. The theory was tested by an application to delaying the impacts of invasive species. This required the development of a survey instrument that tested the following theoretical result: if people experience utility loss from environmental degradation, they should have positive willingness-to-pay values for the temporary elimination of risk and damages. Consistent with our model, it was determined from the survey results that temporarily delaying impacts to regional lakes and rivers is valuable.

Policy makers and resource managers may hesitate to make investments when projects are ultimately destined to fail. Yet our survey results indicate expenditures to postpone market and nonmarket impacts may be justifiable. While longer delays were more valuable, even one year delays led to positive WTP values (on average). For invasive species policy, this suggests that it may be reasonable to continue fighting today for what is ultimately a losing battle tomorrow.

A practical extension to our pilot experiment is to test our results with a larger and more diverse survey population. We have enlisted the help of the Wyoming Survey and Analysis Center (WYSAC) to simplify the language and format of the survey, conduct focus groups, and perform a nationwide mailing. This will help us to determine if the results of our pilot experiment are robust to a national sample, and it will allow us to extend our analysis to consider other factors (such as regional differences) that may affect the value of delaying the inevitable.

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