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Immersive Virtual Reality and Willingness to Pay

Kevin Meyer

This paper illustrates how to improve the immersiveness of an environmental valuation study using virtual reality (VR) headsets and real video footage. Recent research has used "virtual environments" to study this issue, but technological advances in VR headsets allow for a far greater degree of immersion. In this study, subjects were randomly shown either a VR video or static pictures of a polluted lake, before and after cleanup. They were then asked to indicate whether they would be willing to pay a random amount to improve lake water quality to the level shown. A discrete choice model is used to estimate and compare the willingness to pay for both groups. In this case study, there was no detectable effect on willingness to pay estimates. However, the technology may be beneficial for other valuation scenarios, particularly when the environmental change is complex or difficult for participants to evaluate.

Key words: contingent valuation, water quality

Introduction

Recently released virtual reality (VR) head-mounted displays provide a high level of immersion through realistic head tracking, high-definition screens, and surround sound. The cost of this technology has also decreased to the point that it is easily accessible to most researchers, providing a powerful tool to investigate research questions with a visual element. In this paper, I use a contingent valuation (CV) survey to analyze whether the increased immersion induced by VR affects a subject's estimated willingness to pay (WTP) for an improvement in lake water quality relative to static images.

In stated preference studies, subjects often lack the experience necessary to accurately evaluate changes in environmental quality. For example, it is difficult for anyone to imagine the possible impacts of climate change, much less assign a personal value to avoiding the damages. This knowledge gap can lead to "hypothetical bias," whereby the estimates from stated preferences differ from estimates that utilize revealed preferences (Johnston et al., 2017).

A potential solution to this problem is to provide detailed information on the environmental change being addressed. Presenting the subjects with photographs of the potential change is a popular way to summarize complex information, although its effects on subjects should be pretested (Arrow et al., 1993). Labao et al. (2008), for example, examined the effects of color versus black and white photographs and found that color photographs induce a higher WTP.

Research in other fields has shown that immersive VR, which allows for freedom of head movement and surround sound, can significantly affect the subject's experience (Krokos, Plaisant, and Varshney, 2018; Makransky and Lilleholt, 2018; Parong and Mayer, 2018). In this paper, I use

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VR videos to provide the subjects a high-quality, immersive view of a lake that has become polluted. Rather than having a subject view computer-generated videos on a computer screen, subjects are shown footage of a real lake through a head-mounted display, which allows them to look in every direction of the environment. In addition, they hear ambient sound in the video (e.g., wind, water lapping). Their WTP are compared to a control group, presented only with static pictures of the same lake before and after cleanup. Despite the added visual detail, the results did not show a statistically significant difference in WTP between the two groups. Although the outcome did not show a difference, the process of designing and administering a VR experiment revealed key issues that may be addressed in future research as well as practical issues that must be addressed in any VR survey.

Background

One of the main goals of VR is to establish a sense of “presence” in participants, defined as “the degree to which participants feel that they are somewhere other than where they physically are when they experience the effects of a computer-generated simulation” (Bystrom, Barfield, and Hendrix, 1999, p. 241). Whether an application of VR achieves presence depends on the immersiveness of its visual and audio elements. Slater and Wilbur (1997) described three elements that may increase the effectiveness of the elements: the degree to which stimuli from the real world are excluded from the user, the number of senses accommodated by the system (e.g., sight, sound, touch), and using panoramic displays with high resolution.

A sense of presence in a VR world can affect a participant’s preferences by evoking the same reactions and emotions as a real experience (Schuemie et al., 2001). Several studies on tourism, for example, show that participants who view potential destinations using VR have an increased level of interest in the destination (Hassan et al., 2018; Tussyadiah et al., 2018). The marketing field, which is typically quick to adopt new technology, has turned to virtual reality to create experiences that evoke an emotional connection between the product and the consumer. Volvo, for example, allows customers to test drive their newest model through VR (Van Kerrebroeck, Brengman, and Willems, 2017). Adidas provides a VR experience with NBA player James Harden in some stores (Van Kerrebroeck, Brengman, and Willems, 2017). Research is also underway on recreating the traditional “brick and mortar” shopping experience through VR, which could allow firms to use eye movement as a measure of consumer attention (Meißner et al., 2019).

As technology has improved, researchers have begun to use “virtual experiments”—lab experiments that use VR—to evaluate how increased realism can affect WTP estimates. (Fiore et al., 2009, p. 70) identified the main advantage of VR as the ability to “generate counter-factual dynamic scenarios with naturalistic field cues and scientific realism.” In their experiment, subjects were shown the outcomes of two different fire prevention policies through images on a flat computer screen. The images of the trees, fire, and smoke were all computer generated, and subjects interacted with the environment using a keyboard to move and a mouse to change perspective. Subjects were randomly shown either two-dimensional images of the fire or the video simulation. Their results indicate that the mean WTP was lower for VR than for pictures; however, the VR subject’s subjective beliefs about the risk of each policy were closer to the actual risk.

Bateman et al. (2009) investigated whether VR has an effect on gain–loss asymmetry—the tendency for subjects to prefer avoiding losses rather than acquiring gains. Like Fiore et al. (2009), their visualizations were computer-generated images, in this case simulated gains and losses in freshwater nature reserves and tidal saltmarsh mudflats. Subjects in the VR group viewed these images on computer screens and had the ability to “fly” across the landscape, change altitude, and land on the ground, although subjects were constrained to a predetermined “flight path.” They concluded that the VR group had less gain–loss asymmetry and suggested that this is due to less reliance on the loss-aversion heuristic due to a better understanding of the scenario through increased realism.

More recently, Matthews, Scarpa, and Marsh (2017) used virtual environments to investigate the effects of VR on choice consistency and anomaly reduction. Their visualizations were created using free software and administered over the Internet, an example of the increasing ease of employing VR tools in research. Specifically, they used a free three-dimensional (3D) drawing tool to insert houses into images from Google Streetview. Subjects were randomly assigned to either a group that viewed videos or one that did not. Their results indicated the VR subjects had a lower WTP for seawalls and a lower choice error variance but similar stated choice certainty relative to the control group. They suggested future research into more realistic virtual environments and "under what circumstances the extra development effort is a worthwhile investment" (p. 204).

Rid et al. (2018) tested whether showing subjects 3D film sequences of sustainable housing development produced different responses compared to static 3D images. They find that the heightened realism of the 3D film sequence actually made it more difficult for subjects to formulate their preferences. They also suggest "a comparison of still-image and VR environments in which respondents are allowed to free interact with the visualized environment" (p. 215), which is the focus of this paper.

These and other studies that use virtual environments face limitations which can be overcome with new advances in VR. Creating virtual environments may be costly if they require hiring a software developer, as most researchers do not posses the programming ability to create the environments themselves. In contrast, creating VR videos only requires careful planning and the proper equipment. VR also adds new audio possibilities by recording surround sound along with the video, which can be key to establishing presence (Nordahl and Nilsson, 2014). With the cost of VR cameras and headsets dropping into the hundreds of dollars, this technology is now far more accessible to a wide range of researchers.

Method

Hypothesis

I use a stated choice survey to assess a respondent's WTP an annual tax for a discrete change in lake water quality. The responses are used to test whether there is sufficient evidence that the average WTP for a VR subject (indicated by the subscript *VR*) is different from a subject who views a pictures (indicated by the subscript *pic*), as summarized by the following hypotheses:

$$H_0 : E(WTP_{VR}) = E(WTP_{pic});$$
$$H_1 : E(WTP_{VR}) \neq E(WTP_{pic}). \tag{1}$$

Modeling Framework

The visuals in the survey are actual footage of lakes rather than a computer simulation. A trade-off to this degree of realism is the difficulty of adjusting multiple attributes of the lake (e.g., clarity, turbidity), especially if one is only interested in pollution. Thus, the survey is limited to a binary choice format: A "yes" vote indicates a respondent would be willing to pay a randomly chosen amount to improve the lake to the specific conditions shown in the second video, while a "no" vote indicates they would prefer the status quo from the first video. A respondent's vote reveals information about their underlying preferences. To focus on the main hypothesis, and due to a limited number of observations (361), I use a parsimonious model. Let $j \in (0,1)$ signify a subject's vote, where a 1 corresponds to "yes" and a 0 corresponds to "no." Assume that the utility U that person n obtains from a "yes" vote is the following:

$$U_{n,j=1} = \beta_0 + \beta_1 P_n + \beta_X \boldsymbol{X}_n + \varepsilon_{n,j=1}, \tag{2}$$

where P is the subject's randomly chosen price for the environmental improvement; $\boldsymbol{X}_n$ is a vector of individual attributes, including age, gender, and education; β_1 and β_x are parameters to be estimated; and $\varepsilon_{n,j=1}$ is the subject's unobserved utility from improving the lake. Voting "no" indicates the subject would prefer the current, lower-quality level, which has a price of $P = 0$. This produces the following utility:

$$U_{n,j=0} = \beta_0 + \beta_X \boldsymbol{X}_n + \varepsilon_{n,j=0}, \tag{3}$$

Assuming ε is an *i.i.d.* extreme value type-1 error term gives the following probability of a "yes" vote:

$$P(j=1) = \frac{e^{\beta' X_{j=1}}}{\sum_j e^{\beta' X_j}} \tag{4}$$

The WTP of individual n for the clean lake is calculated using the following equation, based on Hanemann (1989):

$$WTP_n = \frac{1}{-\beta_b}\left(\ln\left(1 + \exp\left(\sum bmbeta_n \boldsymbol{X}_n\right)\right)\right), \tag{5}$$

where β_b is the coefficient on the bid price presented to each subject, and $\boldsymbol{beta}_n$ is a vector of parameters related to the observed data, $\boldsymbol{X}_n$. The empirical model used to estimate the model parameters is conditional logit. Following estimation, the mean WTP can be found by averaging equation (5) across the treatment and control groups.

As an alternative to conditional logit, I also directly asked each subject for the maximum amount they would be willing to pay to clean up the lake, on an annual basis over 5 years. Although these results are reported, they are considered less reliable because open-ended questions may not be incentive compatible (Johnston et al., 2017).

Previous research has found differences in the choice certainty of subjects who view virtual environments relative to static images (Matthews, Scarpa, and Marsh, 2017; Rid et al., 2018). Choice uncertainty can be ascertained by directly asking subject's about the certainty of their vote (Carson and Mitchell, 1993). In this study, a follow up question asks the subject to rate their certainty on a 1–5 scale, with 1 being completely uncertain, and 5 being completely certain.

Another concern is whether the subject feels their vote will matter, or the "consequentiality" of their vote. Research has shown that consequentiality can affect an individual's WTP (Herriges et al., 2010). To address this, I emphasize in the presurvey script that their response may help shape the decisions of Michigan lawmakers (i.e. "cheap talk"). I also include a follow-up question—"How likely do you think it is that the results of surveys such as this one will affect decisions about water quality in Michigan?"—where the subject rates their answer on a scale from 1 to 5.

Experimental Design

To estimate the causal effect of VR on a subject's WTP, each subject was randomly assigned to either the treatment (VR) group or the control (picture) group. The randomization was done before the survey was administered, and a discreet mark was printed on each survey to indicate the chosen group. Subjects were approached in public environments such as a college campus, craft fair, and farmers' markets. This survey method has the limitation that the subjects were not likely to be representative of an average Michigan resident. For example, customers at a farmers' market may have an above-average income or place a higher weight on environmental issues. If that were the case, the estimated WTP would be biased. However, the goal of this project is to measure the differences in WTP between the treatment and control groups. It is not my intention to generalize the results to the wider population and therefore not necessary in this case to have a representative sample.

Development of VR Videos

A challenge of this study was how to capture videos of the same lake in two visually distinct states of environmental quality. I started the study in Iowa, where algal blooms consistently appear annually on many of its lakes. However, it is not certain when and where they might occur. My solution was to film several different lakes that were likely to become visibly polluted at some point during the summer and then choose the lake that displayed the most distinct changes. To choose the set of lakes, I relied on the suggestions of the Limnology department at Iowa State University, which collects and analyzes lake water samples from around the state. Next, I filmed short videos of the suggested lakes in May 2017—when the water was still relatively clear—using a camera that films 360°high definition (HD) quality video and audio. I returned to the same lakes in July to film their current state. The videos were filmed at approximately the same time of day and weather conditions in an attempt to control for any other visual differences. In the end, the videos of Lake Laverne at Iowa State University were chosen for the survey because they showed the highest contrast between the visual states. The videos were edited together into a VR video using Adobe Premier Pro software, which allows the user to convert the raw 360°film footage into a format suitable for VR headsets. The final video shows approximately 20 seconds of the impaired lake from the July video followed by 20 seconds of the unimpaired lake from the May video.[1]

Survey Instrument and Recruitment

The survey is based on the Iowa Lakes Survey, which has been administered intermittently since 2002 and has been used to estimate WTP for environmental improvements (Egan et al., 2009). The survey was altered to reflect Michigan residents (replacing "Iowa" with "Michigan") and to increase response time, since this project's survey is face to face while the original Iowa Lakes Survey was completed through mail.

Two focus groups were given the survey prior to final implementation. Although the lakes were filmed in Iowa, these groups unanimously believed the lake to be in Michigan. When asked to describe the VR experience, several participants commented that they felt like they were "there," indicating they experienced a level of presence. The feedback from these groups also helped improve the clarity of the questions. Perhaps the most helpful aspect of these focus groups was learning the most efficient, hygienic, and unobtrusive way to administer the survey via a VR headset. For example, respondents were hesitant to reuse the headset before it had been cleaned with an antibacterial wipe.

Prior to each experiment, subjects were read the following:

> We will be asking you how you would vote on a special ballot regarding the water quality of a Michigan lake. While there is currently no such vote scheduled, we would like you to respond as if you were actually voting. This is important because your answers may influence the decisions of future state leaders in Michigan. In answering the following questions, please keep in mind both the benefits of improved water quality as well as the cost to you in dollars.
>
> Suppose that a public lake near you has poor water quality. The water quality can be improved if certain changes are made around the edges of the lake or surrounding area. These changes could include, for example, dredging (removing sediment from the lake), building protection strips along the edge of the lake, or other similar activities. These changes would improve the lake water quality over the next 5 years from the original condition to the final condition shown in the following (videos/pictures),

[1] Written descriptions and still pictures are inadequate to describe the experience of watching the VR video through a headset, but the video and pictures can be viewed at http://www.kmmeyer.com/online-appendix-immersive-vr.

The choice was presented as a binary choice voting referendum on improving the water quality of a Michigan lake. Each survey was randomly assigned an amount to be paid annually for 5 years, with annual payments ranging from $5 to $200, for a total payment of $25 to $1,000.

Subjects were recruited both on and off campus. Off-campus locations included the Saginaw Farmers' Market, the Frankenmuth Farmers Market, City Market in Bay City, and the 2018 Craft Fair. Subjects were randomly assigned to either the control group, which viewed static pictures, or the treatment group, which viewed the VR videos.[2]

Administering a VR Survey

This section provides some practical tips for researchers interested in administering a public survey using VR. Although recent VR headsets such as the Oculus Go are self-contained, portable, and intuitive, there are still technical and logistical complications that require careful preparation. For example, it is important to describe to the subject what they can and cannot do in VR before they put on the headset. With the Oculus Go, viewers can move their head in any direction, but their location in virtual space remains fixed. In the pilot studies I found that—unless they were explicitly told that they had the ability to look around—subjects tended to keep their viewpoint fixed, as if they were watching a traditional movie, which negates one of the main advantages of immersive VR.

For this project, subjects were recruited using an intercept survey. I set up a booth in a public setting, such as an indoor market, and asked random adults passing by whether they would be willing to take a survey. This approach presents some challenges that should be considered. First, it is helpful to emphasize at the start that this is a research project and not a sales pitch (having student assistants helps make this convincing). Second, the technology may be intimidating to people who have never used a VR headset before, so I found it helpful to keep the headsets fairly inconspicuous. I found that once a subject agreed to be a part of a survey, they would in general be willing to complete it (subject to time constraints), even if it involved new technology. Third, it is helpful to have a space available that provides some degree of privacy, as people may feel self-conscious about wearing a headset in public. This can be done by setting up a large poster display and then administering the survey behind the display. One should also be able to give a subject an estimate for the amount of time a survey should take per person. In my experience, the whole process of explaining the survey, administering the VR videos, and completing the survey took about 10 minutes per person.

Once a subject is prepared for the experience, the biggest obstacle is getting the headset on and starting the footage. VR headsets tend to have straps that go around as well as over the head, meaning they have to be adjusted for each subject. Given the initial hesitancy many subjects had with trying VR for the first time in a public location, there tends to be a very limited window of time to get the experiment started before the subject gives up and walks away. The most successful setup was to simply remove the straps from the headset and have the subjects hold the headset to their eyes. This also likely alleviated some concern that was expressed in the pilot study about the hygienic aspects of reusing a headset over and over. To this point, I also left bacterial wipes in plain view of the public and frequently wiped down the foam padding of the headset to explicitly signal the cleanliness of the experiment.

The final obstacle is starting the video for each subject. I initially gave the subjects a one-button controller and asked them to point at the "play" symbol within the virtual environment and press the button to start the video. It was soon apparent that this seemingly simple action can be overwhelming to an individual experiencing VR for the first time (and again, the subject's limited patience needs to be considered). Our final approach was to have the administrator start the video and then hand the headset to the subject. This highlights the main point I learned from administering a VR survey, which is to remove as many technological burdens on the subject as possible and to start the viewing experience quickly. Once these burdens are lifted, subjects tend to relax and enjoy the experience.

[2] The full survey can be viewed in the online appendix at http://www.kmmeyer.com/online-appendix-immersive-vr.

Table 1. Summary Statistics

	All	VR	Pictures	*p*
	1	2	3	4
Age	32.9	30.3	35.7	0.00
Household Income ($thousands)	71.7	68.3	75.1	0.13
Education (1–5)	3.00	2.90	3.00	0.31
Lakes visited per year	5.20	4.50	5.90	0.13
Time spent per lake (minutes)	262	233	291	0.57
No. of children (household)	0.70	0.70	0.60	0.20
No. of adults (household)	2.80	3.00	2.57	0.00
Gender (1 if female, 0 if male)	0.58	0.46	0.65	0.00
Student (1 if a student, 0 otherwise)	0.36	0.39	0.33	0.22
No. of obs.	361	183	178	

Notes: Column 1 displays the mean of the main variables used in the analysis, while columns 2 and 3 show the means of the variables for subjects shown VR videos and pictures, respectively. Column 4 shows the *p*-values for testing the difference in means between the two subsets using a Welch test (except for *Gender*, which uses a two-proportion *z*-test.)

Descriptive Statistics

Table 1 reports descriptive statistics for the variables used in the analysis. Column 1 gives the means for the full sample, while columns 2 and 3 give the means for the subsamples of the subjects who were shown VR and pictures, respectively. The average subject was about 33 years old, with a household income of a little over $70,000, had some college experience, and had roughly 3 adults and 1 child per household. To account for heterogeneity in lake visitation preferences, two additional variables were included to measure the number of lakes visited per year, as well as the average time spent per lake. The average subject visited a little over 5 lakes per year, and spent about 262 minutes (4.4 hours) at each lake per visit.

To assess the effectiveness of the randomization process, a Welch two-sample t-test was performed between the means of the variables for the two subsets. The results show no statistical differences between education, income, number of children per household, proportion of students, and both the number of lakes visited per year and the time spent per lake. There was a statistically significant difference between the ages, number of adults, and the proportion of females in the groups. Thus, while there are some demographic differences, the randomization process was effective for the majority of variables, including both variables that account for lake preference heterogeneity.

Results

Parameter Estimates

Table 2 gives the parameter estimates of the model. All models were estimated using the "mlogit" package in R. As expected, the price variable has a negative sign and is statistically significant at the 5% significance level. The income variable, though unexpectedly negative, is not statistically significant. In addition, a larger number of adults in the household increases the probability of voting "yes." Female subjects were also more likely to vote "yes." The "visual" variable, which is a dummy variable for whether the subject viewed the VR video or a picture, was not significant.[3]

[3] An alternative model included an interaction term between "visual" and "price," but this term was not statistically significant.

Table 2. Parameter Estimates (*N*=361)

Variable	CL	Certainty-Adjusted CL
Price	−0.0067**	−0.0063**
	(0.0029)	(0.0026)
Income	−0.0014	0.024
	(0.0389)	(0.036)
Education	0.15	0.14
	(0.20)	(0.18)
Age	0.016	0.01
	(0.012)	(0.01)
Gender	0.59*	0.28
	(0.33)	(0.29)
Student	−0.037	−0.13
	(0.36)	(0.32)
VR dummy variable	0.06	−0.07
	(0.32)	(0.29)
No. of children	0.23	0.03
	(0.20)	(0.17)
No. of adults	0.38**	0.32**
	(0.16)	(0.15)
No. of lakes visited	0.01	0.01
	(0.02)	(0.02)
Length of lake visit	0.00037	0.00052
	(0.00056)	(0.00058)
McFadden R^2	0.07	0.06
Likelihood ratio test (χ^2)	20.408**	19.27*

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Numbers in parentheses are standard errors. Estimates from a conditional logit models, where the dependent variable is equal to 1 if the subject would vote "yes" and 0 if they would vote "no." The "CL" is conditional logit using the raw data, while the "certainty-adjusted CL" is conditional logit using data that has been adjusted based on a subject's certainty of their response.

Willingness to Pay

Table 3 shows the estimates for the mean and standard deviations of the total WTP for the VR and picture groups, based on the parameter estimates. On average, the subjects shown the VR videos were willing to pay $390.10 over 5 years to clean up the lake, with a standard deviation of $92.53, while the subjects shown just the static pictures were willing to pay $391.60, with a standard deviation of $102.27. A Welch test does not reject the null hypothesis that the means are equivalent ($p = 0.89$). Figure 1 shows the distribution of the WTP for both subsets. Although the means are similar, the distribution for the group that viewed pictures display a smaller variance.

As an alternative to estimating their WTP, subjects were also directly asked to state their maximum annual WTP over 5 years for the clean lake. Using this method, the group that viewed pictures had an average annual WTP of $188, while the VR group had an average WTP of $147. Over 5 years, this would be a total WTP of $940 and $735, respectively. However, the means were not statistically different ($p = 0.15$).

Table 3. Estimates of Total Willingness to Pay

	CL		Certainty-Adjusted CL	
	VR	Picture	VR	Picture
Mean ($)	390.10	391.60	362.00	380.40
Std. dev. ($)	102.27	92.53	115.82	74.48
No. of obs.	183	178	183	178

Notes: Total WTP to clean up a polluted lake over 5 years, separated by subsample for two models. The "CL" is conditional logit using the raw data, while the "certainty-adjusted CL" is conditional logit using data that has been adjusted based upon a subject's certainty of their response.

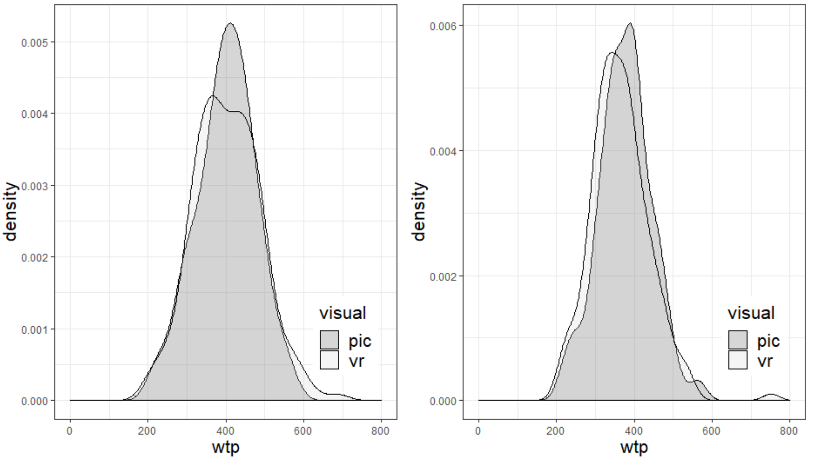

Figure 1. Distributions of Total Willingness to Pay

Notes: Distributions for total willingness to pay (over 5 years) for subjects who viewed pictures versus VR videos. On the left is the "CL" model, which uses the raw data, while the "certainty-adjusted CL" model is on the right.

Choice Certainty

After viewing their randomly assigned visual and voting on whether they were in favor of a tax, subjects were asked to rate the certainty of their vote on a scale from 1 to 5, with 1 being "not sure at all" and 5 being "certain." The mean answers were 3.7 and 4.0 for the VR and picture subgroups, respectively. A Welch two-sample t-test provided sufficient evidence that these two responses were different ($p = 0.01$). In other words, subjects who viewed the pictures were more certain about their votes. This is reflected in the smaller variance of the WTP distribution for the picture subgroup shown in Figure 1.

One technique used in the literature to try to address hypothetical bias (i.e., the difficulty subjects have in voting on hypothetical scenarios) is to adjust the stated answers from "yes" to "no" based on their stated choice certainty (Champ et al., 1997; Labao et al., 2008). The choice of where on the certainty scale an answer should change from "yes" to "no" is up to the researcher. On a 1–5 scale, I analyze the effect of changing the two most uncertain "yes" responses to a "no." That is, if a subject voted "yes" but marked a 1 or a 2 on the uncertainty scale, I changed their answer to "no." Using this criterion, 15 responses were changed. Column 2 of Tables 2 and 3 shows the results of this change on the estimated WTP, where this model is referred to as the "certainty-adjusted CL" to differentiate from the original conditional logit model, which is labeled "CL." Although the difference in WTP is larger for the subjects shown pictures, it is only marginally significant ($p = 0.07$). Figure 1 shows that the calibration in answers had little effect on the mean total WTP and a slight effect on the variance of total WTP.

Consequentiality

Finally, I examine the effect of the visual cue on the subject's perception of the consequentiality of their vote. Subjects were asked, on a 1–5 scale, "How likely do you think it is that the results of surveys such as this one will affect decisions about water quality in Michigan?" The average consequentiality for the VR group was virtually the same as the picture group (3.23 vs. 3.21).

Discussion and Future Research

As the first study in environmental economics to use immersive virtual reality, this project was subject to some limitations that provide opportunities for future researchers. A challenge of showing subjects real videos of the environment is the difficulty in adjusting multiple attributes, which limited this study to a binary choice format. With careful planning, it may be possible to film videos that capture changes along several dimensions, such as turbidity and clarity. Rather than relying on luck, one could potentially install an outdoor web cam to easily identify when conditions are suitable for a new video. In addition to capturing multiple attributes, one could also create videos with increasing levels of pollution in order to capture possible nonlinearities in the WTP estimates, as in Bateman et al. (2009). Finally, studies could attempt to capture different types of pollution, such as point-source discharge. While the current study relied on raw footage, it may be possible to introduce many of the changes described through video editing. For example, one could adjust the color of the lake or even insert objects into the footage. If the results appear natural, this could open up a world of opportunities for CV studies that utilize VR.

Although the average WTP for the treatment and control groups did not differ in this study, the results did provide evidence that the choice certainty of the group shown VR videos was less than the group shown pictures. This result is similar to Fiore et al. (2009) and Matthews, Scarpa, and Marsh (2017) but may seem somewhat counterintuitive. On one hand, increasing the immersiveness of the visual stimuli should reduce the cognitive load of the subject, who otherwise might rely on heuristics to evaluate unfamiliar scenarios (Bateman et al., 2009). The explanation for the result may be linked to the increased certainty of the group that viewed pictures, an outcome similar to Rid et al. (2018). Respondents may feel a sensory overload from the VR videos, making it difficult to accurately assess the value of each scenario, which can be explored in future studies. It would be helpful to assess a subject's previous VR experience in order to control for this in future research.

The VR videos in this study allowed for freedom of head movement, but the subject was still fixed in virtual space. This raises the question of whether allowing for multiple angles would increase the level of immersion, perhaps affecting WTP. In addition, the most recent VR headsets, such as the Oculus Quest, Oculus Rift, and HTC Vive, also allow for freedom of movement, although it is unclear whether this could be applied to actual footage. An alternative is to simulate the environments through a computer program, which could theoretically allow a subject to walk around an entire lake.

Another subject that could be explored through VR is the frequently observed disparity between willingness to pay and willingness to accept (Kim, Kling, and Zhao, 2015). Bateman et al. (2009) showed that using computer simulations reduced this gain–loss asymmetry, raising the question of whether VR would have the same effect. In this paper, videos were shown going from "polluted" to "clean" in order to estimate WTP. To estimate willingness to accept, the videos could simply be reversed, and the wording of the survey could be changed appropriately.

Conclusions

This is the first study to use immersive VR to measure a subject's WTP for environmental quality. A survey was carefully developed to estimate the causal effect of experiencing VR by randomly allocating subjects to treatment and control groups. The results show no statistical difference between the mean WTP of both groups. The results did provide evidence that the choice certainty of the group shown VR videos was less than that of the group shown pictures.

Although the estimates provided insufficient evidence of a treatment effect, VR offers unique possibilities to explore questions about how the degree of immersion effects the survey experience. To help future researchers, I included a short section on useful knowledge I gained through the practical experience of implementing a VR survey and several suggestions for future research questions.

The potential for VR extends well beyond the question of WTP for lake water quality. In particular, VR can be applied to research on multidimensional landscape differences, such as riparian planting, deforestation, animal stocking rates, or choice of recreation. Finally, VR could be helpful in public policy settings, such as informational meetings in which stakeholders could observe potential environmental impacts through VR, potentially leading to more informed decisions.

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