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Using simulations to forecast homeowner response to sea level rise in South Florida: Will they stay or will they go?

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ABSTRACT

Sea level rise threatens coastal communities around the world. Proactive investments in adaptive flood protection could reduce financial vulnerability, however it is unclear if local governments and homeowners will be willing to make those investments before it is too late. In this research we explore this issue by focusing on the case of South Florida, which is one of the most financially vulnerable regions in the world. We report the results of a novel online simulation that accelerates 348 South Florida homeowners thirty-five years into the future so that they can 'live' the effects of sea level rise. The results contain a mix of optimism and caution for the prospects of future adaptation. On the positive side, over 75% of participants indicated a willingness to support bond issues to pay for adaptation, even as the costs of the measures and effects of sea level rise increased over the years. Likewise, we find little evidence that politically conservative residents who normally have more skeptical views about climate change are any less inclined to support adaptation, or only look to information sources that downplay the threat. On the negative side, the number of homeowners interested in moving out of the region increases steadily over time as the sea level rises. This is driven by an increase in worry associated with viewing more information within the simulation.

1. Introduction

Sea level rise is a threat to coastal communities around the world. Recent research suggests that destabilization of ice sheets in Antarctica and Greenland is likely to combine with thermal expansion and land subsidence to cause a meter or more of sea level rise by 2100 (Carson et al., 2016; Church et al., 2013; Sweet et al., 2017). By 2025, it will be clear whether or not local sea levels have begun to accelerate away from historic rates sending us towards that future (Haigh et al., 2014). In response coastal cities will have to make substantial investments in flood protection or risk trillions of dollars in losses (Hallegatte et al., 2013; Hinkel et al., 2014). Because of variations in local geology and the built environment, cities' vulnerabilities differ. Some communities will have more options and more time than others to respond and adapt to rising sea levels. One obstacle they all face is overcoming the psychologically driven myopic tendency to focus on the present and avoid dealing with risks that feel distant because they are difficult to experience (Bazerman, 2006).

One location particularly vulnerable to the effects of sea level rise is South Florida, anchored by the densely developed Miami metropolitan area. The low-lying region rests on a porous limestone bedrock that limits the effectiveness of levee and pump systems as a means of dealing with flooding problems, such as those used in cities that are already below sea level like Amsterdam and New Orleans (Hughes and White, 2014; Park et al., 2011). One consequence of this geologic reality is that if no adaptation measures are taken a half-meter rise would threaten \$3.5 trillion in assets by 2070, and potentially displace over 300,000 residents, many from inland communities that are only a few meters above sea level but miles from the coast, as flood controls begin to fail (Hanson et al., 2011; Hauer et al., 2016).

If sea levels rise within the intermediate range of NOAA's latest scenarios by 2050 (Sweet et al., 2017), annual flood losses in South Florida could exceed \$25 billion. However, if adaptation investments are made to maintain current levels of flood protection annual losses could be reduced to \$2.9 billion (Hallegatte et al., 2013). While proactive investments in flood protection would thus appear to make strong economic sense, such investments require taxpayers and city officials to see merits in spending money now to ward off a hazard that lies in the distant future – something many appear averse to doing (Buchanan et al., 2016; Hinkel et al., 2014; Lickley et al., 2014). Moreover, because the funding for improvements would need to come, in large part, from local real-estate taxes, adaptation may prove even

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more difficult if sea level rise spurs out-migration as residents retreat from projected extreme consequences of climate change (New et al., 2010).

In this paper we explore the likely future effects of sea level rise on the region's adaptation efforts by reporting the findings of a novel online, interactive computer simulation in which 348 South Florida homeowners experience and respond to 45.7 cm (18 in) of sea level rise at different points in time between 2016 and 2050. The simulation allows participants to "live" in a future South Florida that is experiencing worsening effects of sea level rise, and where residents are being asked to support adaptation efforts thorough costly bond measures. As in a natural setting, participants learn about conditions by accessing online media, watching television news broadcasts, and hearing the views of local residents. As such, the simulation helps participants overcome temporal distance in an experimental setting to produce a more realistic understanding of how individual homeowners and specific populations will respond to anticipated future sea level rise.

Below, we provide background for the research by reviewing the specific challenges facing South Florida and the psychological barriers that may impede adaptation to sea level rise there and elsewhere. We then describe the simulation, including reasoning behind the scenarios presented, and our findings. We describe substantive findings regarding planning for sea level rise in Florida and adaptation to climate change more broadly as well as methodological findings about the potential use of immersive simulations as a tool for forecasting long-term response to environmental changes. We conclude with a discussion of the implications of the work for future research and local governments in communities threatened by sea level rise.

2. Background

Sea levels have been rising globally, prior to the start of consistent measurement in the 1800s, contributing to increased flooding in coastal cities (Sweet et al., 2014). While the global rate of rise is currently about 3 mm/year, evidence suggests that the rate of sea level rise is accelerating, and could increase exponentially by the end of the century (Haigh et al., 2014). Increased coastal flooding is already being observed in many areas, and the costs could be massive, including over $400 billion in lost home value in Florida alone by 2100 if sea level rises 2 m (Rao, 2016). Uncertainty and range of projected rise makes incorporating sea level rise into long-range planning at the local level difficult (Akerlof et al., 2017).

As an example, since 2006 the city of Miami Beach has experienced an effective rate of seal-level rise of 9 millimeters a year from a combination of sea level rise and land subsidence, resulting in increased flooding (Wdowinski et al., 2016). In response, the city is in the process of investing $500 million over five years to elevate roads, install pumps, and reinforce sea walls against rising seas in select, high value areas (Flechas and Staletovich, 2015). It has also begun updating building codes and emergency management plans. Its response is supported by a regional network, the Southeast Florida Climate Change Compact, that has been advocating for a comprehensive regional response to sea level rise since 2009 and has created a unified sea level rise projection to guide decision makers, (see Fig. 1; (Sea Level Rise Working Group, 2015)).

As a relatively small and wealthy community, however, Miami Beach is the exception in terms of its active response to sea level rise and its financial capabilities to do so. At 25%, participation in the National Flood Insurance Program in Florida is relatively high (Michel-Kerjan, 2010), but uncertainty about the accuracy of current maps, lack of incentives for risk reduction, and changes in federal policy could result in rate increases for many participants (National Academy, 2015). Spatial and socio-economic impacts will not be felt uniformly along the coast. For example, poor populations are expected to have more trouble responding to increased flooding (Chakraborty et al., 2014). Likewise, Florida's regional real estate market is significantly supported by overseas investment. If wealthy investors with homes in other cities choose to leave first, that could lay the expensive burden of adaptation on middle and lower income residents who do not have the option to leave.

2.1. The psychology of resistance to preparedness

Given the threats posed by sea level rise, why are efforts to address the threat not more widespread? Although some communities' limited financial resources play a role, we suggest that psychology may be an even larger factor. As real as the threat may be, its most severe impacts are thought to remain thirty years or more in the future, well beyond the normal planning horizons of developers or homebuyers, impeding proactive planning (Akerlof et al., 2017; Spence et al., 2012). Studies show individuals living in areas of the United Kingdom threatened by sea level rise perceive it as a relatively unimportant hazard that is more likely to impact other people in other areas (Thomas et al., 2015). Similarly, residents in New Zealand believe it is more of a problem for the world or other parts of New Zealand than themselves (Evans et al., 2012)

One of the most robust findings in studies of decision making is that people have difficulty making good decisions about prospective, uncertain outcomes that lie in the distant future. They typically err by putting too much weight on that which is immediate and concrete over that which is temporally distant and vague (e.g., Frederick et al. (2002) and Laibson (1997)). This myopic decision making is common with climate change because the impacts are uncertain, temporally distant, physically diffuse, and difficult to experience (Spence et al., 2012; Weber, 2016; Weber and Stern, 2011). One immediate consequence of such myopia is that residents and planners responding to climate threats will be prone to under-estimate the present value of investing in preventive adaptation. While everyone might benefit from addressing the distant threat, these benefits will pale next to the immediate psychic pain of paying for them.

An even more insidious consequence of myopia is that it fosters procrastination (Fischer, 2001). Even if both planners and residents fully accept the risk posed by rising seas, the fact that the increase in risk from one year to the next is small makes it easy to rationalize postponing action. A decision maker might have every intention to invest in protection but imagines that the pain of the expenditure will be easier to swallow next year, when it is temporally distant, as opposed to this year, when it is immediate. The following year the same logical argument will return, leading to a cycle of delays.

Americans as a whole are divided about the threat of climate change, impeding coordinated response (Lee et al., 2015; Roser-Renouf et al., 2016). Those most skeptical of climate change are less likely to be moved by arguments for action, and are less likely to worry about climate change impacts (Whitmarsh, 2011). Moreover, such skepticism may be self-reinforcing. A well-known bias in decision making is that when individuals hold strong world views, they are prone to seek out information that works to confirm it − that is, engage in motivated reasoning (Kunda, 1990). This confirmation bias has been observed in experiments with climate skeptics, who have been found to actively avoid learning about climate change risks (Kahan et al., 2012). Additionally, longitudinal surveys indicate that the 25% of Americans who feel most engaged, proactively or skeptically, about climate change are more likely to fall victim to motivated reasoning, while the remaining 75% require experience to motivate them to learn (Myers et al., 2012). Thus, a skeptical resident who engages in motivated reasoning will, for example, be more likely to attend to news and media sources that express similar views and see nuisance flooding as a temporary inconvenience of nature, not a harbinger of future calamity. And a disengaged resident will wait until they experience flooding to pursue any information about rising seas. However, recent evidence from experimental research on home buying in coastal flood zones suggests that when individuals are immersed in the details of sea level rise risk they

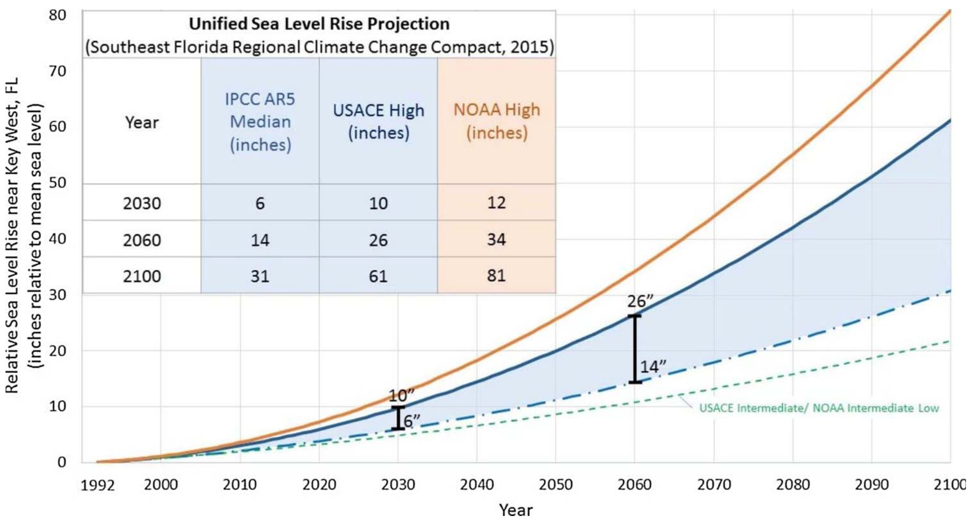

Fig. 1. Southeast Florida Climate Change Compact Unified Sea Level Rise projections, adopted as guidance for planning by Broward, Miami-Dade, Palm Beach, and Monroe Counties and used as the basis for the scenarios within our simulation (Sea Level Rise Working Group, 2015).

ignore political biases (Wong-Parodi and Fischhoff, 2015).

Willingness to invest in protective action is also likely to be influenced by herd effects or social norms, a tendency to make decisions by imitating the behavior of others (e.g., Meyer and Kunreuther, 2017). The greater the collective skepticism about the threat posed by sea level rise, or the more widespread the belief is that the region can take a "wait and see" approach, the more widespread such beliefs may become within a community. For example, research by Lo (2013) on how homeowners decide whether to purchase flood insurance found that decisions were primarily driven by whether neighbors had purchased it. In essence, social norms trumped private calculations when making these decisions.

We should emphasize, however, that the same psychological factors that can impede investments in protection, can, in some cases, also work to foster it. For example, while motivated reasoning biases can work to reinforce prior skepticism about the threat, it can also work to reinforce affirmative beliefs. A resident who believes that the threat posed by sea level rise is real might be prone to see incidences of nuisance flooding as evidence that the worst predictions about sea level rise are beginning to be realized and spur vocal support for immediate action.

Consistent with this, past research has shown that those who have directly experienced harmful effects of hazards triggered by climate change are much more likely to be convinced of its existence (Moser, 2010; Reser et al., 2014) and more likely to support preventive measures (Akerlof et al., 2013; McDonald et al., 2015). In the same way, social norms can also serve as a positive agent for change. For example, they have been shown to increase peoples' willingness to engage in pro-environmental behavior and energy conservation (Allcott and Rogers, 2014; Goldstein et al., 2008). The emergence of a social norm centered on concern about sea level rise and the risks it brings, e.g. community support for public flood mitigation investments could also work to increase individual support for action.

Finally, the degree to which individuals are willing to invest in protection may also be influenced by the nature and framing of the impacts themselves (Allcott and Mullainathan, 2010; Kidwell et al., 2013). Thus far, we have emphasized the personal economic impacts of sea level rise, but the environmental impacts on ecosystems like South Florida's Everglades may be even more immediate and harder to address (Nungesser et al., 2015). However, whether presenting the impacts of climate change as economic or environmental will be more persuasive is unclear (Moser, 2014).

2.2. Immersive simulation as a tool for forecasting public response to sea level rise

The above discussion provides an uncertain view of how South Florida will respond to the growing effects of sea level rise over the coming decades. On one hand, if residents in the region remain collectively myopic in their planning and skeptical about the seriousness of the risk, one might see limited support for preventive investments – at least until it is too late for them to be cost-effective. On the other hand, one might predict that as residents experience an increase in the observed effects of sea level rise (e.g., more nuisance flooding and higher taxes) they will work to galvanize support and allow the area to survive as a sustainable place to live well into the future.

Which of these scenarios is more likely to pan out? Addressing this empirically is difficult because it requires us to anticipate how residents will respond to environmental, economic, and social scenarios that are not yet in existence. While one could conduct surveys that ask residents today how likely they would be to remain in the area conditional on different future conditions (e.g., a three-foot rise in sea levels), survey approaches, while very useful in some cases lack face validity as a research tool for accurately portraying future behavior (Gilbert and Wilson, 2007; Trope and Liberman, 2003). Additionally, actual future responses to such conditions will be a function of a range of complex factors that are difficult to capture in simple what-if scenarios, such as the time path of change, social norms in the future, and how such an event would alter the living environment in South Florida.

In this research we attempt to overcome this measurement problem through the use of an immersive simulation that allows study participants to virtually "experience" 35 years of sea level rise in South Florida. In the simulation participants are able to learn about the effects of sea level rise as they would in a natural environment by reading different sources of on-line media, watching television programs, and hearing the views of local residents. The approach attempts to overcome the limitations of simple what-if scenarios by allowing participants to realistically control how they will experience the future. A climate skeptic, for example, may opt to learn about the evolving effects of sea level rise through the filtered lens of conservative news media (e.g., following Fox News), while someone who is already worried about climate change and sea level rise might seek out other sources, such as a concerned neighbor or an objective scientific report.

We note the approach has its origins in the method of "Information Acceleration" that was first introduced as a means for forecasting demand for complex novel consumer products in marketing in the 1990s (Urban et al., 1997), and variations have more recently been applied to such environmental domains as water management (White et al., 2010) and hurricane evacuation and preparation responses (Meyer et al., 2014, 2013). The current work goes beyond prior applications, however, by extending the simulation over a multi-decade cycle of sea level rise and adaptation in which the future that participants experience at any given point is dependent upon collective responses to sea level rise at prior points. The limitations of information acceleration mirror those of many experimental approaches that limit the details of a real world decision making context. In our study, all activity was online and participants made decisions as individuals rather than in a group context, as many real world decisions are made. That said, our simulation design allowed participants to gather opinions from other people. However, we realize that in order to gather a statistically significant sample size, our study trades off the nuance that a more in-depth ethnographic study could reveal.

3. Simulation design and data collection

The study was conducted online using a web based application designed to accelerate participants through a future experience: sea level rise over a thirty-five year period. The platform was designed using a new web-based programming tool called *Choiceflow*, co-developed by two of the authors. It allows non-technical users to rapidly develop and deploy immersive "information acceleration" applications (for more information visit www.deckspire.com/products/choiceflow/).

The simulation was composed of five phases:

(1) Instructions and orientation – After consenting to participate, participants are given a brief description of the study. They are informed that they will be "accelerated" years into the future over the next twenty minutes and are asked to imagine themselves as they are now but in that future situation. The simulation begins with a series of images that depict Miami-Dade county as it appears today (2016 at the time of the study) and a brief narrative of the effect that sea level rise is currently having (e.g., minor nuisance flooding). Participants are then told that their main initial goal in the simulation will be to decide whether to support a County bond issue that would pay for flood-control measures (i.e., a sea level rise adaptation bond).

(2) Information gathering – After orientation, participants are taken to a virtual "living room" where they have the opportunity to learn more about conditions in South Florida, sea level rise impacts (e.g. harm to ecosystems, water supply, rising cost of infrastructure, and increases in flood risk), and the bond measure by clicking on three different kinds of media: television, neighbor testimonials, and online articles. When turning on the television they can view two brief news stories about flooding impacts and the sea level rise adaptation bond proposed by Miami-Dade County. Neighbor testimonials provided 10–30 s statements from worried and unworried residents. Online articles include an article on scientific fact (e.g. from the IPCC or NOAA), an agency impact statement (e.g. from FEMA or the Army Corps of Engineers), a neutral article about the adaptation bond from the Miami Herald (the local newspaper of record), a less worried article on sea level rise from Fox News (a TV and online news source that is recognized as a conservative platform for climate "skeptics") and an article from either Huffington Post or Buzzfeed (online news sources recognized for liberal editorial positions that recognize climate change) that highlights negative impacts. The living room and sample media are illustrated in the screenshots shown in Fig. 2.

(3) Decision making – After viewing as much or little media as they like, participants are asked to vote on the bond measure and answer a series of survey questions about worry, willingness to move, and willingness to invest in self-protective measures.

(4) Voting outcome – After indicating their vote, participants are taken to a new page that informed them of whether the bond issue passed or failed (randomly determined). The outcome of this vote then dictates the effects of sea level rise that participants experience in the next phase of the simulation (2030). If it passed the 2030 conditions are only modestly worse than those in 2016, but if it failed they are more significantly worse.

(5) Acceleration – After seeing the voting outcome participants are "accelerated" to the next time point, 2030. To make the passage of time appear more realistic, the acceleration phase involves viewing a sequence of online newspapers from 2018, 2022, and 2028 that depict technological advances and environmental changes that are occurring due to sea level rise in South Florida.

(6) After the 2030 outcome is revealed phases (2) through (4) are repeated again, this time for 2050. The sea level rise scenarios used in the simulation are based on rates agreed upon by the Southeast Florida Climate Change Compact, see Fig. 1 (Sea Level Rise Working Group, 2015). Though most projections predict increasing acceleration in sea level, we use a single rate in 2050 to increase comparability across experimental conditions which results in only a moderate acceleration from 2030 to 2050, i.e. 25.4 cm by 2030 (8.5 cm/decade) and 45.7 cm by 2050 (10 cm/decade).

3.1. Experimental design and measures

The simulation studied responses to the effect of social norms, rate of sea level rise, and framing on decision making using a factorial design in which three factors, or variables, were manipulated at two levels each (see Fig. 3).

(1) Passage or failure of the 2016 bond measure, to observe the impact of social norms and the willingness of others to pay for adaptation when considering the subsequent bond in 2030.

(2) Rate of sea level rise in 2030, fast 25.4 cm (10 in) or moderate 7.6 cm (3 in) since 2000.

(3) Framing of the impact – i.e., environmental or economic, from 45.7 cm (18 in) of sea level rise in 2050 since 2000 (a high sea level rise scenario). The *environmental frame* presents articles and neighbor testimonials that focus on the impact of sea level rise on regional ecosystems and Everglades National Park as versus the *economic frame* in which articles and testimonials focus on economic impact of sea level rise on jobs and real estate.

Two types of response measures were collected at each time period. First, at the conclusion of each section participants were asked to complete a series of ratings scales that elicited: 1) their degree of worry about sea level rise (i.e. "How worried are you about sea level rise"); 2) their willingness to move out of the region "to escape the effects of sea level rise"; 3) their willingness to undertake self-protective actions like elevating a home or purchasing additional flood insurance; and 4) the aspects of sea level rise that formed their greatest source of worry. Second, in addition to these rating-scale responses, we gathered measures of information use that include when and how often each type of media (TV clip, online article, or neighbor testimonial) is clicked and time spent consuming that media. Finally, at the conclusion of the study participants were posed with a series of socio-demographic questions such as age and household income as well as questions about political orientation. The full set of questions, measures, and scales is summarized in Appendix A.

3.2. Data collection procedure

Between March 29 and April 12, 2016, a representative sample of 348 (206 female) homeowners from four Southeast Florida counties were recruited through Pureprofile, a third party panel provider. Recruits were offered a nominal fee (< $10) to participate in a 20 to 25 min online simulation (median time 23.4 min). As a quality control, of the 506 participants who completed the survey, 158 who took less

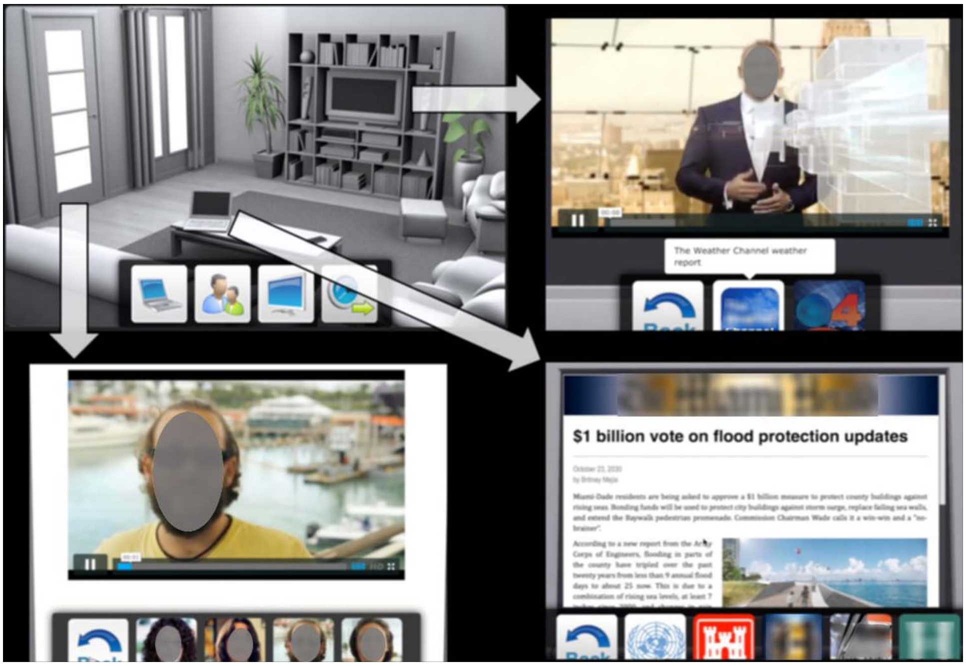

Fig. 2. Screenshot of the living room simulation environment (upper left) with examples of each media type (clockwise from the upper right): TV, online article, and neighbor testimonial. All content in the simulation is original or used minimally following the principles of fair use.

than 9 min and/or clicked on less than two pieces of media were discarded from the analysis. This discard rate of 31% is in the anticipated range for this panel, included in our contract with the panel provider.

The sample was recruited by the panel provider to resemble the census demographics of Miami-Dade, Broward, Palm Beach, and Monroe Counties. Slight differences from census data appear to reflect the bias of homeownership towards an older, wealthier, whiter, better educated population. The age of respondents was roughly evenly split between 45 years-old or older (185) and below 45 (163). All respondents were homeowners when they signed up with the panel provider, however when asked for their current living situation 4 said they were renters and 2 selected ‘other’. Please note that because participants were given the option to not respond to individual questions some groups do not add up to 348.

The sample was diverse in income, ethnicity, and political views. The median household income within the sample was above the region’s median, with 34% of the sample indicating that they earned $45,000 or less (low income), 39% earning $45,001 to $80,000 (middle income), and 27% earning over $80,000 (high income). 80% of respondents self-reported as white (34% Hispanic), 10% as black or African American, 3% as Asian, and 7% as other or multiple groups. In terms of political views, on a 1–7 scale of increasing conservatism, 31% of respondents were liberal (less than 3.5), 31% centrist (3.5 to 4.5), and 38% conservative (greater than 4.5). Overall, this sample of homeowners had higher educational achievement than the general population: 2% attended some high school, 9% were high school graduates, 26% attended some college, 40% were college graduates, 8% pursued some post-graduate studies, and 13% had obtained a masters or Ph.D.

4. Results

We divide our results into three phases. First, we provide an overview of the main findings by describing how two key response measures – support for the bond issue and intentions to move – varied in response to our three experimental manipulations. We then explore how these responses varied by socio-demographic and other characteristics of the participants. We conclude by exploring the patterns of information gathering revealed by participants – data that can provide deeper insights into the decision-making processes that led to the responses.

4.1. Support for adaptation bonds

In Fig. 4, we plot the mean percentage of participants who voted in favor of bond issues supporting sea level rise adaption measures by year and rate of sea level rise in 2030, a low-rate of 7.6 cm (3 in) versus a

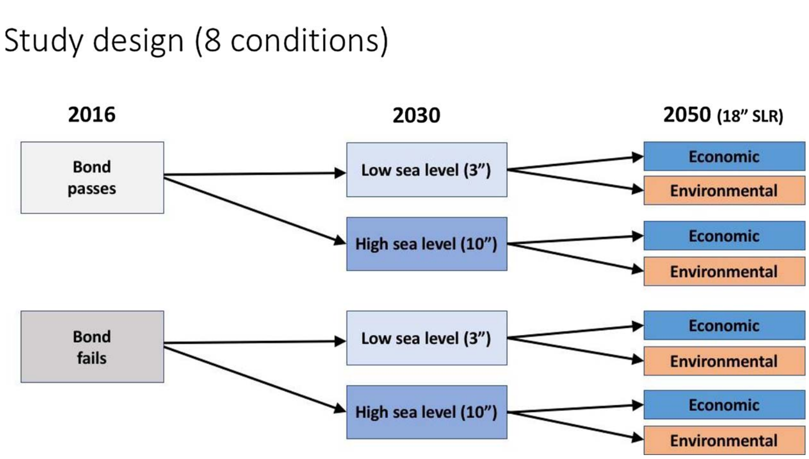

Fig. 3. The experimental design includes three manipulations with two conditions each introduced one at a time in 2016, 2030, and 2050.

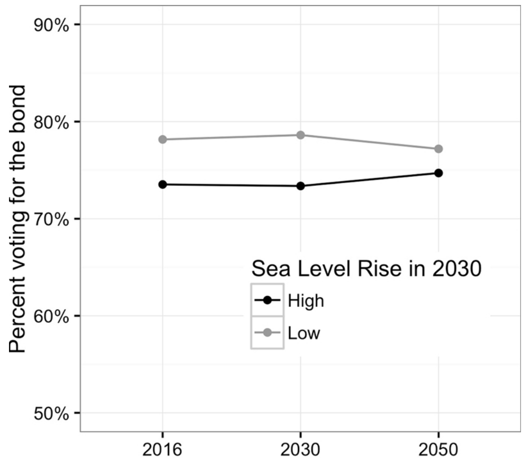

Fig. 4. Bond support by year. The percentage of respondents voting for the bond measures at each period, indicating no significant difference between the High (25.4 cm) and Low (7.6 cm) sea level rise conditions in 2030.

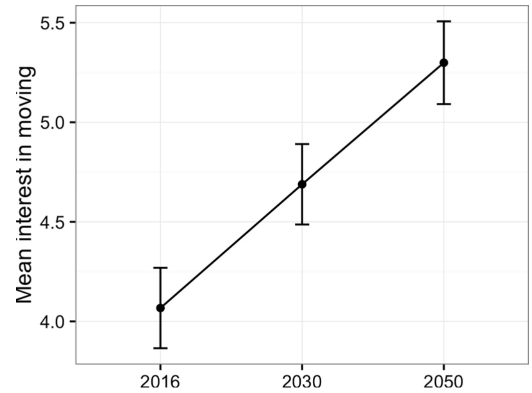

Fig. 6. Interest in moving. Mean interest in moving out of the region to avoid impacts of sea level rise in each time period (2016, 2030, 2050) with standard error bars on a 1 to 7 point Likert type scale of increased interest.

high-rate of 25.4 cm (10 in). The figure yields what might be seen as a surprising result: support for the measures was uniformly high (over 75% support) across all time periods and sea level rise rate conditions. While there was a nominal tendency for support to be higher in the high-rate condition (79% versus 73% in 2030) the effect did not approach standard levels of significance in a repeated-measures ANOVA ($F(1, 340) = 1.29$, $P > 0.25$). Hence, a hypothesis that support for investments in adaptation might decline in future years as the effects of sea level rise is strongly rejected by the data.

To better understand the basis of this constant support, we analyzed the percentage of participants who *switched* their votes from one period to the next. The goal of this analysis was to see whether the stability was due to all participants maintaining constant attitudes over time, or a result of switching, where decreases from those who stopped supporting bond measure in one year are compensated for by gains from new supporters. In Fig. 5 we plot the percentage of participants switching their vote between 2016 and 2030, and those switching between 2030 and 2050. The data provide support for the latter explanation for the stability in mean voting. From 2030 to 2050, 30% of participants switched support, for or against, the bond, significantly more than from 2016 to 2030 ($X^2(1) = 80$, $p < 0.001$). The direction of switching, however, was equally balanced; i.e. the percentage of participants who terminated their support after seeing the worsening conditions was matched by the percentage who renewed their support. Those who removed their support for the bond in 2050 were more worried and more willing to move than those who were first time supporters of the bond in 2050.

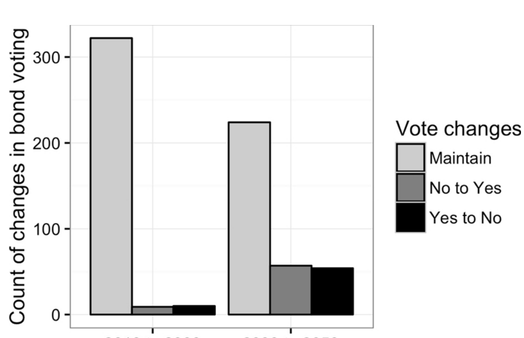

Fig. 5. Change in bond support over time. Count of participants switching their support for the bond measure from 2016 to 2030 and 2030 to 2050.

4.2. Intentions to migrate and expressed worry

The robust willingness of participants to support bond measures regardless of the severity of sea level rise conditions, however, was not reflected in their willingness to remain as residents of South Florida as conditions worsened. To see this, in Fig. 6 we plot mean intentions to move on (a 7-point Likert scale) as a function of year and sea level rise. Between 2016 and 2030 there is a 0.5 point rise in the mean stated intention to move ($M = 4.1$ v 4.7, $F(1674) = 18.3$, $P < 0.001$), there is another 0.6 point increase between 2030 and 2050 ($M = 4.7$ v 5.3, $F(1663) = 17.2$, $P < 0.001$). In addition, as willingness to move increases over time, the percentage of participants who intend to leave *within the next five years* increases from 18% in 2016 to 41% in 2050, when sea level rise is portrayed in its most extreme state.

Likewise, we observe a marginally significant effect of the rate of sea level rise in 2030 on intentions to move. In Fig. 7, we plot the difference in move intention between the two 2030 sea level rise scenarios, 7.6 cm (3 in) versus 25.4 cm (10 in). As expected intention to move is greater when sea levels rise faster, though the mean effect is not statistically significant ($M = 4.5$ v 4.9, $F(1332) = 2.5$, $p > 0.12$).

One possible explanation for the marked increase in move intentions over time, of course, is that it could have been driven by factors other than the observed effects of sea level rise. For example, looking 35 years into the future, participants may have imagined that by that point they would have moved due to job changes, etc., regardless of environmental conditions. To address this, in Fig. 8 we plot mean ratings of worry about sea level rise as a function of year and severity. The data

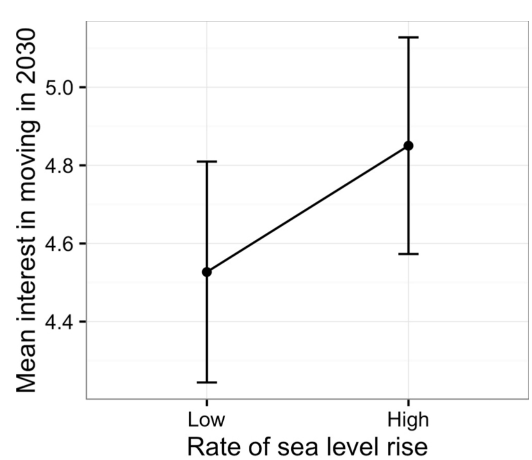

Fig. 7. Interest in moving in 2030. Mean interest in moving out of the region in 2030 by sea level rise rates with standard error bars on a 1 to 7 point Likert type scale of increased interest. Low = 7.6 cm (3 in) and High = 25.4 cm (10 in).

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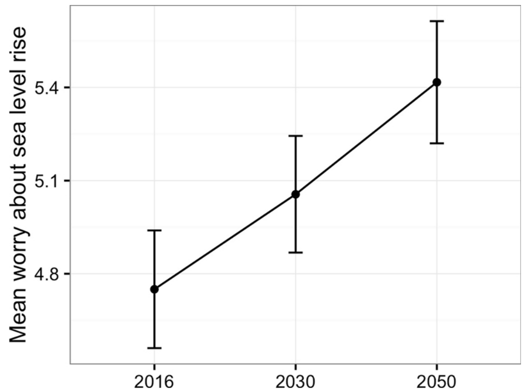

Fig. 8. Worry about sea level rise. Mean self-reported worry in each time period (2016, 2030, 2050) with standard error bars on a 1 to 7 point Likert type scale of increasing worry.

shows that increases in worry closely paralleled increases in move intentions: there was a nominally significant 0.3 point increase in worry between 2016 and 2030 ($M = 4.8$ v 5.1, $F(1,5.1)$, $p < 0.05$), followed by another significant 0.3 point increase in worry between 2030 and 2050 ($M = 5.1$ v 5.4, $F(1,6.8)$, $p < 0.01$). Similar to move intentions, a higher rate of sea level rise in 2030 is associated with greater worry ($M = 4.9$ v 5.2, $F(1319)$, $p < 0.1$).

Additionally, there is a positive correlation between worry and observed move intentions that increases over time from 0.49 in 2016($r(300) = 0.49$, $p < 0.001$) and 0.66 in 2030 ($r(300) = 0.66$, $p < 0.001$) to 0.71 to 2050 ($r(300) = 0.71$, $p < 0.001$). Hence, the data suggest increased expressed intentions to move in 2030 and 2050 could be induced by increased worry about the effects of sea level rise rather than other factors. Differences in social norms, i.e. passage or failure of the 2016 bond, has no effect on intention to move ($M = 4.7$ v 4.7, $F(1332) = 0.01$, $p = 0.9$) or worry ($M = 5.0$ v 5.1, $F(1319) = 0.5$, $p = 0.48$) in 2030. Likewise, framing the problem as economic versus environmental has no impact on intention to move ($M = 5.4$ v 5.2, $F(1329) = 0.78$, $p = 0.38$) or worry ($M = 5.5$ v 5.3, $F(1310) = 1.6$, $p = 0.21$) in 2050.

4.3. Individual differences in response to sea level rise scenarios

To investigate whether responses to sea level rise were homogeneous within the sample, we explore the degree to which the above results vary as a function of the political identity, age, and income of participants. Based on our earlier discussion, for example, we might expect participants who are more conservative in their political orientations to be both less likely to support bond measures and be more intent on staying in the area regardless of worsening conditions. More ambiguous, however, were the likely effects of age and income. On one hand, because of their more limited mobility and resources one might expect to see higher degrees of worry and a greater desire to move from the area among more vulnerable populations who are likely to experience more impacts and have a harder time responding, including young and low income homeowners. On the other hand, these same constraints could produce the opposite response: a greater intention to persist and avoid learning about risks due to a limited ability to move.

To explore these issues, in Fig. 9 we first plot intentions to move by year as a function of aggregate political identity. Political identity was calculated by averaging responses to individual measures of social, economic, and political identity on a 1 to 7 scale of increasing conservatism. Beginning in 2016, centrists ($n = 125$) have less interest in moving ($M = 3.7$ v 4.2 v 4.5, $F(2318) = 5.3$, $p < 0.01$) and less worry ($M = 4.5$ v 4.7 v 5.1, $F(2302) = 3.1$, $p < 0.05$) than conservatives ($n = 112$) or liberals ($n = 90$). In 2030 and 2050 all three groups report increased intentions to move (2030: $M = 4.3$ v 4.8 v 5.1, $F(2, 311)$

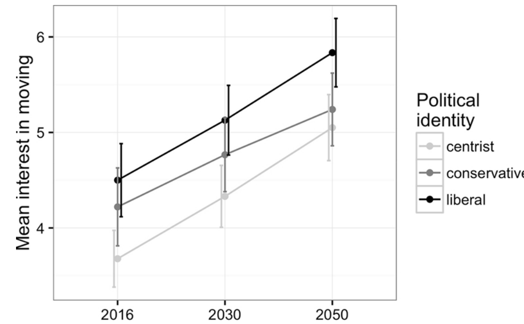

Fig. 9. Political identity and interest in moving. Mean interest in moving out of the region to avoid impacts of sea level rise in each time period (2016, 2030, 2050) by political identity (conservative, centrist, liberal) with standard error bars on a 1 to 7 point Likert type scale of increased interest.

$= 4.8$, $p < 0.001$; 2050 $M = 5.1$ v 5.2 v 5.8, $F(2309) = 4.5$, $p < 0.05$) and worry (2030: $M = 4.9$ v 5 v 5.4, $F(2, 301) = 1.82$, $p = 0.16$; 2050 $M = 5.1$ v 5.3 v 6, $F(2291) = 6.2$, $p < 0.01$) with liberals consistently leading other subgroups. In terms of voting, all three subgroups consistently support bond measures at rates near or above 70%, centrists at slightly lower rate than liberals and conservatives in 2016 (M = 71% v 77% v 79%) and 2030 (M = 69% v 83% v 75%) but at the same rate in 2050 (M = 78% v 75% v 76%). An ANOVA of voting by year and identity over all three time periods indicates no significant difference in voting due to identity ($F(2959) = 1.57$, $p = 0.21$).

In Fig. 10 we divide participants into two groups by age, young (under 45 years old) and old (45 years and over) and plot mean intentions to move. Young homeowners have a measurably greater intention to move in 2016 ($M = 4.5$ v 3.7, $F(1340) = 16.9$, $p < 0.001$), 2030 ($M = 5$ v 4.5, $F(1332) = 5.7$, $p < 0.05$), and 2050 ($M = 5.6$ v 5.1, $F(1329) = 4.7$, $p < 0.05$). Both groups follow the familiar trend of becoming more interested in moving and more worried over time (2016: $M = 4.9$ v 4.6 $F(1322) = 2.8$,$p < 0.1$; 2030 $M = 5.3$ v 4.8, $F(1, 319) = 6.1$, $p < 0.05$; 2050: $M = 5.6$ v 5.3, $F(1310) = 1,9$, $p = 0.17$). As with political identity, support for bond measures is constantly high across groups, above 73% for both young and old homeowners.

We plot intention to move, in Fig. 11, by three income groups: low (< \$45,000/year), middle (\$45,000-80,000/year), and high (> \$80,000/year) and find a possible vulnerability among middle income homeowners in South Florida. Middle income homeowners are less interested in moving than other participants (2016: M(low, middle, high) = 4.1, 3.8, 4.4, $F(2338) = 1.9$, $p = 0.15$; 2030:M = 4.9, 4.4, 4.9 $F(2330) = 3$, $p < 0.1$); 2050: M = 5.4, 5.0, 5.5, $F(2327) = 2.25$, $p = 0.11$). This difference in move intention appears to be driven by significantly less initial worry among middle income homeowners in 2016 (M = 4.8, 4.4, 5.1, $F(2320) = 4$, $p < 0.05$) and 2030 (M = 5.3,

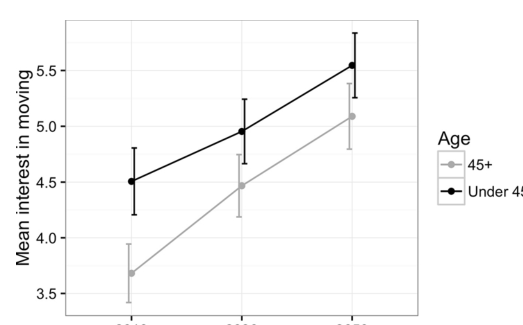

Fig. 10. Interest in moving and age. Mean interest in moving out of the region to avoid sea level rise in each time period (2016, 2030, 2050) by age (under 45, 45 and older) with standard error bars on a 1 to 7 point Likert type scale of increased interest.

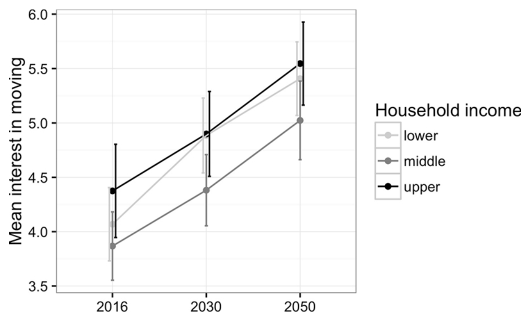

Fig. 11. Interest in moving and income. Mean interest in moving out of the region to avoid sea level rise in each time period (2016, 2030, 2050) by annual income (lower: < $45,000, middle: $45,000-80,000, upper: > $80,000) with standard error bars on a 1 to 7 point Likert type scale of increased interest.

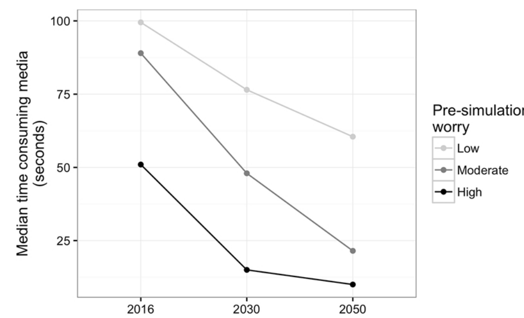

Fig. 13. Time pursuing information. Time spent consuming all types of media in each time period (2016, 2030, 2050) by self-reported worry about sea level rise before participating in the simulation (High, Moderate, Low).

4.7, 5.2, $F(2317) = 3.6$, $p < 0.05$) before they begin to catch up with their peers in 2050 ($M = 5.5, 5.2, 5.6$, $F(2308) = 2$, $p = 0.13$). Like we see with other groups, support for bonds is consistently high, above 70% in every time period, though middle income homeowners are consistently less supportive.

4.4. Information search and participant engagement

The Choiceflow platform allows participants to control their experience of the simulation and gives researchers insight into how participants pursue information. By measuring how participants engage with a variety of media sources we can see how information use changes throughout the simulation and look for evidence of confirmation bias. In Fig. 12, we plot the percentage of all participants who click on each type of media (TV clips, online articles, and neighbor testimonials) in each time period (2016, 2030, 2050). Overall media consumption declines in each successive time period, an unsurprising result as participants use the first time period to orient themselves within the simulation. Additionally, the rank order of media type consumed is constant over time, indicating a preference for TV over online articles and neighbor testimonials.

One important insight that can be gained from these data is whether participants selectively sought information in the simulation in a manner that served to reinforce their worldview about sea level rise and its effects; i.e. display motivated reasoning or confirmation bias. To explore this, in Fig. 13 we plot time spent viewing all types of media by year and pre-simulation worry about sea level rise. Because the simulation clearly presents sea level rise as a threat to South Florida, if confirmation bias were present we could expect those who are least worried to spend the least amount of time gathering information. We find the opposite is true. Participants who report the lowest level of pre-survey worry (1–2 on a 7 point scale of increasing worry) spent more time than those who report moderate per-survey worry (3–5) or high worry (6–7). The only suggestion of confirmation bias is among participants reporting high pre-survey worry who stop gathering new information by 2030–when the median high worry participant spent less than 20 s consuming media compared with 48 s for moderate and 77 s for low worry participants. This may reflect disengagement among participants most worried about sea level rise who have already made a decision to relocate. In 2030, 69% of high worry participants indicate a strong interest in moving, compared with 34% of moderate and 33% of low worry participants, which suggests a rational for disengagement and a problem for South Florida leaders wanting to convince this group to stay.

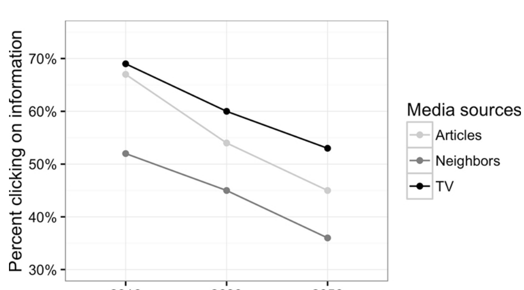

Fig. 12. Types of information pursued. The percent of participants who clicked on each source of media (television, online articles, and neighbors) at least once in each time period (2016,2030, 2050).

Additionally, limited evidence of confirmation bias is present when media consumption is analyzed by political identity. 54% of Conservatives click on Fox News in 2016, more than liberals (41%) or centrists (42%). However, conservatives, centrists, and liberals click on scientific reports and unbiased Miami Herald articles at the same rate in every time period. They each click on Fox News at approximately equal rates in 2030 (40%, 39%, 37%) and 2050 (33%,33%, 29%), though it is possible this is merely the result of participants attracted to novel sources of information within the simulation. Similarly, there is little evidence that participants pursue confirmatory information by only clicking on neighbor testimonials that reflect their own opinions.

5. Discussion

As sea levels rise, the future of densely developed coastal communities like South Florida is neither certain nor secure. In a worst case scenario, rising seas combined with myopic attitudes towards investing in adaptive flood protection could lead to a downward spiral of real estate disinvestment and loss of tax base, undermining the ability to adapt and other vital services as residents decamp for higher ground outside the region. The question is, will communities proactively invest in sea level rise adaptation without inciting a loss of confidence in public works and a widespread abandonment of properties?

This immersive simulation indicates that proactive investment could receive consistent support from residents of South Florida over the next three decades. By allowing homeowners to control their own experience within a simulated future, we demonstrate that engaged learning and experience provide a way to engage the risk of sea level rise and overcome psychological barriers that can get in the way of serious climate adaptation efforts. In this simulated future, South Florida homeowners become increasingly concerned as they actively learn about threats posed by sea level rise and as the impacts of those threats become tangible rather than speculative. Additionally, homeowners who are more concerned about sea level rise and climate change are more likely to take proactive steps to protect themselves and their community.

Within our simulation, a large majority of South Florida homeowners, over 75%, support higher taxes to pay for climate adaptation, now and into the future. However, our data contains a cautionary warning for policy makers and planners. Less than 25% of South Floridians in our sample are currently concerned or worried about sea level rise. Worry steadily grows as they experience the impacts of moderate to high sea level rise, 45.7 cm (18 in) over the next 35 years, and that growing concern appears to increase homeowners' willingness to move out of the region. Alarmingly, this is particularly true for high income individuals who have the greatest ability to pay for expensive adaptation investments through increased real estate and other luxury taxes.

We are encouraged to find that, in this sample of South Floridians, assumptions about the intractability of ideological divisions do not hold. In our study, centrists not conservatives are the least worried about sea level rise and the least willing to take the major step of moving. Similarly, middle income homeowners, who may have the most to lose because a large portion of their wealth is tied to their home, are less worried and less interested in moving than other residents. Due to South Florida's economic stratification, this could have important implications for suburban communities whose governments are funded by residential real estate taxes and many of which are focused on attracting new development and have not begun to address sea level rise.

Despite differences between demographic populations, we find that the response to sea level rise over time is more uniform than divided. Though individual groups begin at different levels of worry, as they engage with the simulation all demographic groups appear to become more worried and more willing to respond to sea level rise by taking self-protective actions or moving out of the region as they learn about and experience the impact the ocean rising 45.7 cm (18 in). Additionally, across all subgroups large majorities, over 70%, vote to raise taxes so that government can make adaptation investments.

The temporal and political challenges of climate adaptation are well documented. The results of this study, along with recent work that suggests simply communicating the consensus nature of climate facts, in our case, in an immersive and experiential format, can help people avoid biases like myopia and motivated reasoning (Myers et al., 2015; van der Linden et al., 2017). Two suggestions emerge for local policy makers and educators. First, work to communicate confidence in the possibility of future sea level rise scenarios with simple, clear facts about how community and daily life could be impacted. Second, provide opportunities for citizens to actively investigate those future scenarios through multiple sources of information: visuals, immersive simulations, scientific reports, stories, coastal flooding tours, and testimonials.

Additionally, this research illustrates how immersive simulations can be used as a tool to study behavioral intentions for future environmental scenarios. At the conclusion of the simulation participants were invited to comment on their experience. These comments provide anecdotal evidence that the simulation both helped them to imagine being in the future and allowed them to better understand the consequences of sea level rise. Representative comments include:

- "This simulation really brought home the real problem that South Florida is having and will encounter in the near future. Now is the time to act and have steps in place to correct and work with this problem."
- "I enjoyed this survey, it's a real eye opener on how my life and livelihood will be in the future. The last [scenario] is the most disturbing, I really never have plans on leaving South Florida but I realize that things are about to get more expensive for me and my family."
- "This is very great survey that paints a picture nicely on things to come…It was very informative, the fact that it shows me how the future of South Florida could look if water continues to raise and worsen."

By simulating impacts anticipated to occur decades into the future our research is more speculative than exhaustive. Future research on individual responses to environmental changes, including sea level rise, using Choiceflow or similar simulation tools could build upon our results in multiple ways. Hurricanes and associated storm surge can function as signal events, amplifying the perception of risk and leading to policy change (Wachinger et al., 2013). Extreme events could be included in future studies to understand how they shape perceptions of the threat from a relatively slow, creeping threat such as sea level rise. For example, would a hurricane with heavy damage multiply the concern about long term sea level rise and increase the willingness of homeowners to leave the region? One of the limits of our method is that participants are not making decisions with real life consequences and may be driven more by the novelty of the platform or information about an unfamiliar subject, i.e., sea level rise, that actual concern about future consequences. For this reason, in-depth follow up with small subsamples or focus groups could help understand how realistic participants feel the simulation is. Additionally, focus groups can be used to investigate the potential for simulations to educate and inform real life decision making. Future studies could test whether engaging in a realistic future sea level rise scenario leads to permanent changes in attitudes and behaviors, such as buying insurance or investing in flood protection.

Finally, the non-effect of traditional experimental manipulations reaffirms findings that immersion in details is more important than framing (Wong-Parodi and Fischhoff, 2015) and suggests that future simulation studies can keep manipulations to a minimum. Instead researchers can focus on creating rich scenarios and environments in which influential changes, such as norms about belief in climate change and proactive investment, can be modeled relatively complexly and participants are able to actively shape their own experience. Thus, widespread use of simulation experiences, including the incorporation of 360 video within augmented and virtual reality, like the Sustainable Behaviors project at Stanford's Human Interaction Lab (https://vhil.stanford.edu), have the potential to increase individuals' ability to engage with future climate risks.

Our research demonstrates that homeowners and other citizens are capable of imagining a future in which sea levels are rising much faster than today and are willing to support proactive adaptation. If they are engaged by local leaders sooner rather than later, communities will be able to invest in adaptations to reduce the impacts of sea level rise and encourage homeowners not to move away. If citizens become engaged too late for those investments to be made and the costs of sea level rise defrayed, communities like South Florida are likely to see a fairly large exodus in a short period of time once the actual impacts and large infrastructure bill come due. Further this departure could be led by the investment class, the service class, and younger residents – leaving middle income homeowners to foot the bill for rising sea levels as their property values stagnate or fall. This would be economically and socially devastating.

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