Appalachian State University

Department of Economics Working Paper

Number 24-12| March 2024

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Last Revised: March 10, 2024

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ABSTRACT:

Sea-level rise poses a growing threat to coastal communities and economies across the globe. North Carolina (NC) is no exception, with coastal communities facing annual sea-level rise rates of 2.01 to 4.55 mm/year (NOAA, 2018). Sea-level rise can affect key ecosystem services to coastal communities, including the provision of clean drinking water and adequate wastewater treatment. We examine how increases in the cost of these services and possible negative effects on coastal house prices due to sea-level rise impact residential location decisions. Administering a stated preference survey to NC homeowners in counties adjacent to the coast, we assess how households might respond to the increasing costs of drinking water and wastewater treatment due to sea-level rise. We present a novel framework to estimate expected welfare impacts under illustrative scenarios. Our results can inform local communities and benefit-cost analyses of future adaptation strategies and infrastructure investments.

Keywords: drinking water; ecosystem service; groundwater; housing; stated preference; sea-level rise; wastewater

JEL Codes: D6; Q51; Q54; Q57; R2

This research was supported by a Dean's Club Grant from the Walker College of Business (WCOB) and a 2019 CONCERT grant from the Research Institute for Environment, Energy, and Economics (RIEEE) at Appalachian State University. We thank participants at the Northeastern Agricultural and Resource Economics Association's 2023 conference for helpful comments.

INTRODUCTION

Sea-level rise poses many current and growing threats to coastal communities and economies across the United States and the World. North Carolina (NC) is no exception, with coastal communities facing annual sea-level rise rates of 2.01 to 4.55 mm/y (NOAA, 2018). The provision of adequate drinking water and wastewater treatment to coastal communities are key ecosystem services that are affected by sea-level rise. Most coastal NC municipalities and counties utilize groundwater as their primary source of potable water, particularly in the northern portion of the NC coast. Compromised water quality comes mainly in the form of chloride contamination due to saltwater intrusion into pumping wells and, what may be a larger problem, overwash during hurricanes and extratropical storms (Anderson, 2002; Anderson and Lauer, 2008). Additionally, much of coastal NC (outside of larger cities) relies on private septic systems to treat wastewater. Rising sea levels create higher water-tables as the freshwater lens works to adjust to a new, and changing, hydrologic equilibrium. This implies higher failure rates for septic systems and increased coastal water quality issues. The need for costly regional wastewater treatment systems will likely increase. At the same time, tourism and growing populations in some coastal areas of NC, such as New Hanover and Brunswick Counties, will increase the demand for clean potable water and wastewater services (Sea Grant North Carolina, 2018), thus further exacerbating the need for costly treatment technologies.

We develop and implement a stated preference (SP) survey of homeowners in NC counties that are adjacent to the coast or coastal estuaries. A series of dichotomous choice questions are posed to elicit whether homeowners would sell and move from their current home when faced with increasing costs for potable water and wastewater treatment services, and in some cases, changing market values for their home. The survey design allows us to assess how households will respond to the increasing costs, and in turn estimate welfare changes under various scenarios of environmental and economic changes.

We aim to meet three main study objectives. The first is to examine how households will respond to the increasing costs of drinking water and wastewater treatment due to sea-level rise. We estimate the extent to which households will either bear the increased costs or decide to sell their home and move out of the area. Place attachment, reflected in stated moving intentions, should play a role in the decision to sell. We hypothesize that a household is more likely to sell their home as water and wastewater costs increase but is less likely to sell if they receive a lower price for their home. There are potential endogeneity concerns regarding the latter – households are more likely to sell if they receive a higher price, but a higher home value may be correlated with unobserved housing amenities that a household may not want to give up. We implement an instrumental variables approach to address this potential omitted variable bias. Our second objective is to assess what mitigating/averting behaviors households may adopt to ensure adequate access to clean water and wastewater treatment services. Finally, we develop a novel theoretical framework and illustrate the expected welfare losses to households due to sea-level rise and its impacts on drinking water and wastewater treatment.

We advance the body of environmental economics literature in several ways. First, we examine an important, yet understudied threat from sea-level rise – impacts on the provision of clean potable water and wastewater treatment. Environmental economic studies to date have focused primarily on just a subset of threats from sea-level rise, namely flooding and coastal erosion (e.g., Landry et al., 2003; Whitehead et al., 2009; Bin et al, 2011; Gopalakrishnan et al., 2016; Walsh et al., 2019; Landry et al., 2020). Second, we add to a limited literature that examines how environmental commodities impact the probability of home selling or the duration that a home is on the market (Depro and Palmquist, 2012; Guignet and Martinez-Cruz, 2018; Huang and Palmquist, 2001; Irwin and Wolf, 2022; Simons et al., 1999).

A third contribution is that our SP design is unique in that the tradeoffs households consider are measured solely in dollar terms – increases in drinking water and wastewater costs versus the price received if a household decides to sell their home. A key challenge in SP studies valuing environmental quality, including those in the context of housing decisions (e.g., Bin et al., 2011), is how to communicate and measure environmental changes in salient ways to respondents (Johnston et al., 2017). We demonstrate that in some settings, in particular when the ecosystem or substitute service is a necessity (whether by law or otherwise), the relevant endpoints may be expressed in financial terms. Communicating tradeoffs in dollar terms is perhaps one of the most salient ways to communicate a change. If potentially applicable, this is a useful approach for researchers to keep in mind when designing future studies to value ecosystem services.

Our fourth contribution is that we illustrate a novel theoretical framework to infer welfare estimates with data on households' decisions to sell their home. Although we use SP data in this application, our approach could be applied to revealed preference data of residential parcels and transactions, and to settings where the environmental tradeoffs are not expressed solely in financial terms. Hedonic pricing methods and locational sorting models provide the means for estimating welfare effects using such data, but involve tradeoffs in terms of the necessary information, assumptions needed, and ability to estimate non-marginal welfare changes (Ma, 2018). We illustrate a new, fairly simple alternative approach for estimating non-marginal welfare effects in the housing choice context. Like sorting models, we more directly examine utility-maximizing decisions, and hence welfare impacts. But much like the hedonic price model, our approach does not require knowledge of where a household would optimally decide to move (if they do sell their home).

Our results suggest that households are more likely to sell their home as they face higher drinking water and wastewater treatment costs due to sea-level rise, but they are less likely to sell if the market value of their home decreases. These findings are in line with theory, and the magnitude of the estimates seem reasonable. For example, from the results we infer a discount rate of 6.4 to 6.6%, which is within the range traditionally recommended for policy analysis (OMB, 2003). Our illustrative welfare exercises suggest that if households experience even just a $100 increase in monthly water and wastewater costs due to sea-level rise, then they are 3-percentage points more likely to sell their home, on average (an average increase from 30% to 33%). The expected average loss in welfare is about $15,000 in this illustrative scenario. The expected welfare loss becomes greater as the monthly costs and loss in home value increase, with our most extreme scenario – a $500 increase in monthly costs and $50,000 loss in home value – suggesting an expected welfare loss of over $83,000 for the average household. Our results provide insight to coastal communities about the potential emigration of residents in response to sea-level rise, and they can inform benefit-cost analyses of future adaptation strategies and infrastructure investments, such as providing alternative water sources, updating desalinization capabilities, and installing centralized wastewater treatment facilities.

The remainder of the paper is organized as follows. We next discuss the survey instrument, implementation, and resulting data. We then outline the underlying theory and subsequent econometric model of a household's decision to sell their home, followed by presentation of the regression results and welfare estimates under a series of illustrative scenarios. Lastly, we discuss the implications and conclude.

SURVEY AND DATA

We developed and administered a SP survey to a sample of 415 NC homeowners that lived in counties adjacent to the coast or coastal estuaries (see Figure 1). Survey respondents were drawn from a representative internet panel maintained by Dynata, a global market research and data firm.[1] The survey was implemented by internet in September of 2020.

To establish consequentiality and encourage valid responses, the survey stated that respondents' opinions were needed to inform local and state policies on how their community can best prepare for the future. The survey instrument assessed where respondents live, how long they had lived there, whether their home is a full-time residence, and a series of questions to measure households' place attachment (e.g., family history in the area, bequest intentions, and how long they intend to live there). Respondents were then asked to provide information about the home itself, including the type of home, interior square footage, lot size, number of bathrooms, distance to the coast (defined as the nearest bay, estuary, or part of the Atlantic Ocean), the general quality of the home, and the year it was built. Respondents were also asked to assess the current value of their home. To help with this task, respondents were provided links to both Zillow and Trulia – real estate companies that provide publicly available information on residential properties, including home-specific market value assessments. In addition, we provided information to respondents on the median home value in their county, which was based on data for owner-occupied housing units from the U.S. Census Bureau's 2014-2018 American Communities Survey.[2]

Table 1 presents descriptive statistics for several of the house characteristics that were collected. The average home is valued at about $292,900 (2020$ USD), has an interior size of about 2,700 square feet and 2.4 bathrooms. Self-reported housing quality was measured on a five-point Likert scale, ranging from "1 = below average" to "5 = above average". The self-reported quality of the average home is 3.94. Most respondents live in single-family homes (84%); followed by duplexes,

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[1] For details see https://www.dynata.com, 21 January 2022.
[2] Accessed at https://www.census.gov/programs-surveys/acs, 3 July 2020.

twin homes and town/row homes (7%), condos (7%), and mobile homes (3%). The average home is located about 22 miles from the coast, with quartiles at 4, 12, and 33 miles.

A series of Likert scale questions were then presented to respondents, asking about the quality of and satisfaction with their neighborhood and their expectations of future property values and taxes. Most notably, we ask respondents how much they agree with the statement "I do not plan to sell or move out of this home in the foreseeable future." About 25% and 45% of respondents somewhat agree or strongly agree with this statement, respectively. Only 13% of respondents somewhat or strongly disagreed that they were not planning to move in the future. In the empirical analysis we use these responses as the primary measure of a household's home "attachment."

The survey then provided background information on different ways households can have access to potable water (i.e., public water system or private groundwater wells) and wastewater treatment services (i.e., public wastewater treatment systems or privately-owned septic tanks). We ask respondents about their primary water source, drinking water source, use of water filters, and whether they have had water quality issues in the past. A similar series of questions are asked regarding the treatment and disposal of wastewater at their home.

Most respondents are connected to a public water system (81%), but about 17% use a private or shared groundwater well. Nine respondents (2%) were not sure of their water source. Most also report that they primarily rely on water from their tap for drinking (77%), although 23% mainly use bottled water for drinking. About 58% of respondents use a water filter at their home. Sixty-six percent of respondents were connected to the public sewer system, and roughly 30% rely on a private septic tank; about 4% were not sure about their wastewater treatment.

Following the baseline questions, we provide respondents with background information and prime them for the idea that (i) sea-level rise can increase the cost of obtaining potable water and wastewater treatment, and (ii) these increased costs could be capitalized in the value of their home and result in a lower market value:

> "The National Oceanic and Atmospheric Administration (NOAA) estimates that sea-levels along the North Carolina Coast have been rising at a rate of 2.01 to 4.55 millimeters per year over the last several decades. At that rate, sea-levels in your community and along the entire North Carolina coast will be more than ¾ to 1 ¾ inches higher in the next 10 years. This increase in sea-level poses issues to your community because saltwater can more easily mix with freshwater sources of drinking water, and because sewage treatment through septic systems becomes less effective."
>
> "Sea-level rise may lead to a small decrease in the demand for homes in counties along the North Carolina coast. This would cause the value of some homes to decrease. This decrease in value, however, may be relatively small because people still like living near the coast and having access to beaches and other amenities."

The increase in water and treatment costs are described in abstract terms, in order to remain applicable to all respondents, and include buying more bottled water, installing filters, upgrading septic systems, connecting to public systems, and/or experiencing higher utility bills. We then asked respondents to estimate their current average monthly costs for potable water and wastewater services.

Each of the 415 respondents are presented with four separate dichotomous choice questions asking whether they would sell their home or bear the increased water and wastewater costs. This implies a sample of n=1,660 observations. For each question, respondents are randomly assigned an increase in monthly drinking water and wastewater costs (Δc), and in some cases, a decrease in the market value of their home (ΔP). For the first choice question a value of Δc = \$75, \$235, \$425, or \$725 per month was randomly assigned, and ΔP was always set equal to zero. For the remaining three questions, an orthogonal experimental design was used to determine the randomly assigned values for Δc (as shown above) and ΔP = -\$10,000, -\$25,000, and -\$50,000.

An example choice question is shown in Figure 2. Respondents could either choose to sell their home, not sell and continue to live in their current home, or select an "I'm not sure" option. Across the 1,660 choice occasions, about 32% of the time respondents chose to sell their home. About half the time respondents said they would not sell their home. For just under 18% of the choice occasions, respondents said they were not sure. In our main empirical analysis, we code the dependent variable equal to one if a respondent selected to sell their home, and zero otherwise (including "I'm not sure" responses). The results are robust, however, if we instead exclude "I'm not sure" responses from the estimating sample (see Appendix B).

We present several debriefing questions to assess attribute non-attendance, consequentiality, hypothetical bias, and protest responses. Few respondents report that the change in monthly cost or market value of their home was not important when making their choices (see Figure A1 in Appendix A). This suggests that attribute non-attendance is not a concern in this particular application, where only two attributes are presented. In terms of assessing hypothetical bias and consequentiality of responses, we find that most respondents somewhat or strongly agree that they made their stated choices as if they would actually face the posited changes in monthly costs and value of their home (76% and 75%, respectively), and that they are confident that they would make the same choices in reality (73%); see Figure A2 in Appendix A for details. This suggests that a lack of consequentiality and potential hypothetical bias may not be a glaring concern with these data. Nonetheless, we later test and confirm the robustness of the results to the exclusion of respondents who disagree with those statements and thus whose responses may not reflect their true preferences. To identify potential protest responses, we ask respondents the extent to which they agree that they value clean drinking water and adequate wastewater but do not believe they should have to pay the higher costs. About 28% and 18% of respondents somewhat or strongly agree with that statement. We later examine the sensitivity of our results to potential protest responses by excluding respondents who agreed, and find that the results are robust.[3]

We conclude the survey with a series of sociodemographic questions and inquiries about whether respondents are still paying off their mortgages. As shown in Table 2, the average respondent is about 53 years in age. About 26% of the respondents have at least one child under the age of 18 living at their home, and among those households they have 1.8 children, on average. Half of the sample is male, about 7% are of Hispanic or Latino origin. About 53% of respondents were employed at the time of the survey, and 34% were retired. The highest proportion of respondents

[3] The aforementioned robustness checks are included in Appendix B.

(41%) report an annual income between \$50k and \$100k per year. Most households are fulltime residents at their coastal home (87%), and just over half (56%) are still paying on their mortgage.

MODEL

Our empirical analysis is motivated by household utility theory, where a household decides whether or not to sell their home given an increase in the monthly costs of potable water and wastewater treatment and a market price that they would receive if they did opt to sell. Our theoretical framework builds on that laid out by Guignet and Martinez-Cruz (2018). First the theoretical motivation and empirical model of the probability a household sells their home are outlined. Then we layout the theoretical and empirical derivation for estimating the welfare effects under four cases, based on whether a household would sell their home or not in the baseline, as well as under a projected sea-level rise scenario. We formally derive the equations to calculate compensating variation (CV) in each case. The CV calculations are later used to calculate expected CV in the policy illustrations.

Model of Probability a Home is Sold

Suppose that the utility that household *i* derives from their current home is a function of the bundle of housing attributes $\overline{\boldsymbol{q}}_{\boldsymbol{i}}$ that define that home (e.g., house structure, location, and neighborhood), as well as numeraire good consumption. Assuming that utility is always increasing with numeraire consumption, we can define numeraire consumption as the difference between the household's annual disposable income y_{it} (after any housing payment) and annual costs of utilities, namely the provision of clean potable water and adequate wastewater treatment and disposal c_i. Given the long-term nature of housing ownership decisions, we expand the model to reflect the present value of the stream of annual disposable income $Y_i = \sum_{t=1}^{\infty}(1+r)^{-t}\, y_{it}$ and of ongoing costs $C_i = \sum_{t=1}^{\infty}(1+r)^{-t}\, c_i$, where *r* and *t* denote the discount rate and time period, respectively.

The decision of whether to sell one's home depends on the utility from remaining at their current home $v\left(Y_i - C_i, \overline{h}(\overline{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right)$ versus the utility from selling their current home and moving to a new home $v\left(Y_i + P(\overline{\boldsymbol{q}}_i), \overline{h} = 0\right)$. More formally:

$$v\left(Y_i - C_i, \overline{h}(\overline{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right) \gtreqless v\left(Y_i + \overline{P}_i, \overline{h} = 0\right) \tag{1}$$

where $\overline{P}_i = P(\overline{\boldsymbol{q}}_i)$ is the hedonic price (i.e., the market value) of household *i*'s current home. The housing services one derives from their *current* home are denoted by $\overline{h}(\cdot)$, and this is a function of the current housing bundle $\overline{\boldsymbol{q}}_i$ and characteristics of the household itself $\boldsymbol{x}_i$. Following equation (1), if the current home is sold, then household *i* experiences a gain in numeraire of $\overline{P}_i$. This numeraire consumption includes the purchase of a new housing bundle. If household *i* moves, then they no longer live in their current home, and so consumption of housing services from the current housing bundle is zero (i.e., $\overline{h} = 0$).

Of particular interest in this study is the change in the annual costs of ensuring clean potable water and adequate wastewater treatment services, which are reflected in Δc_{ij}. These costs vary for each respondent i, across each choice scenario $j = 1, \dots, 4$. Similarly, the SP scenarios posit that decreases in the demand for coastal housing due to sea-level rise leads to some decrease in the market value of a coastal home $\Delta \bar{P}_{ij} = \Delta P_j(\bar{\boldsymbol{q}}_i)$. As depicted in this notation, the housing services and underlying vector of characteristics defining a home are held fixed, but the hedonic price surface, and hence the market value, are changing.

As posited under choice question j, the respondent's decision of whether to keep or sell their home depends on which option yields the greatest level of utility. More formally:

$$v\left(Y_i - \sum_{t=1}^{\infty}\{(1+r)^{-t}(c_i + \Delta c_{ij})\}, \bar{h}(\bar{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right) \gtreqless v(Y_i + \bar{P}_i + \Delta \bar{P}_{ij}, \bar{h} = 0) \qquad (2)$$

If we assume a linear-in-parameters utility function and housing services function, then the change in utility from selling your current home is:

$$\Delta v_{ij} = \alpha_S + \gamma(Y_i + \bar{P}_i + \Delta \bar{P}_{ij}) - \left\{\alpha_N + \gamma\left(Y_i - \sum_{t=1}^{\infty}\{(1+r)^{-t}(c_i + \Delta c_{ij})\}\right) + \bar{\boldsymbol{q}}_i \boldsymbol{\varphi} + \boldsymbol{x}_i \boldsymbol{\theta}\right\}$$

where α_S and α_N represent the constant terms from utility in the sell (S) and no-sell (N) states, respectively. With slight re-arrangement this difference can be expressed as:

$$\Delta v_{ij} = \alpha_S - \alpha_N + \gamma\left(\bar{P}_i + \Delta \bar{P}_{ij} + \sum_{t=1}^{\infty}\{(1+r)^{-t}(c_i + \Delta c_{ij})\}\right) - \bar{\boldsymbol{q}}_i \boldsymbol{\varphi} - \boldsymbol{x}_i \boldsymbol{\theta}$$

$$\Delta v_{ij} = \alpha_S - \alpha_N + \gamma\left(\bar{P}_i + \Delta \bar{P}_{ij} + \frac{1}{r}(c_i + \Delta c_{ij})\right) - \bar{\boldsymbol{q}}_i \boldsymbol{\varphi} - \boldsymbol{x}_i \boldsymbol{\theta} \qquad (3)$$

We attain the last simplification by applying the formula for an infinite geometric series $\left(\sum_{t=1}^{\infty}(1+r)^{-t} = \frac{1}{r}\right)$. The interpretation of equation (3) is that the change in utility from selling one's home reflects the increase in utility from the gain due to the increased numeraire consumption from selling, plus the present value of the avoided water and sewage costs, minus the foregone utility from the housing services you would have experienced from the current home.[4]

Following equation (3), we append an error term and re-express the coefficients as follows to get the following econometric model to be estimated:

$$\Delta v_{ij} = \beta_0 + \beta_1 \bar{P}_{ij}^1 + \beta_2 c_{ij}^1 + \bar{\boldsymbol{q}}_i \boldsymbol{\beta_3} + \boldsymbol{x}_i \boldsymbol{\beta_4} + \varepsilon_{ij} \qquad (4)$$

where $\bar{P}_{ij}^1 = \bar{P}_i + \Delta \bar{P}_{ij}$ is the market price of the home posited in choice scenario j, and $c_{ij}^1 = c_i + \Delta c_{ij}$ is the corresponding annual water and sewage costs. The parameters to be estimated are $\beta_0 =$

[4] Households who sell also benefit from any avoided payments for their current home, as implicitly reflected in $\bar{P}_i$. Let $R_i = \bar{P}_i - D_i$ denote the amount a household receives after selling their home and paying off any remaining housing payments D_i. Therefore, $\bar{P}_i = R_i + D_i$, whereD_i reflects the gain in numeraire consumption from avoided housing payments.

$\alpha_S - \alpha_N$, $\beta_1 = \gamma$ (which is the marginal utility of numeraire consumption), $\beta_2 = \frac{\gamma}{r}$ (which is the ratio between the marginal utility of numeraire consumption and the discount rate *r*), and $\boldsymbol{\beta_3} = -\boldsymbol{\varphi}$ and $\boldsymbol{\beta_4} = -\boldsymbol{\theta}$ (reflect the marginal losses in utility from giving up one's current housing bundle).

A household will sell their home if the change in utility from doing so is positive. The probability that household *i* sells their home under choice scenario *j* can thus be modelled as:

$$Pr\left(\Delta v_{ij} \geq 0\right) = f\left\{\beta_0 + \beta_1 \bar{P}_{ij}^1 + \beta_2 c_{ij}^1 + \bar{\boldsymbol{q}}_i \boldsymbol{\beta_3} + \boldsymbol{x}_i \boldsymbol{\beta_4} + \varepsilon_{ij}\right\} \qquad (5)$$

We estimate equation (5) as a probit model, and therefore assume that $f\{\cdot\}$ is a normal cumulative distribution function. The estimated coefficients can then be used to back out the original parameters as needed for the welfare calculations discussed later.

One issue with estimating equation (5) is the possible endogeneity of $\bar{P}_{ij}^1$. As implied by hedonic price theory, the market value of a home is a function of the numerous characteristics defining that home. At the same time, those characteristics also enter the household's utility function. It is quite possible that key characteristics of the housing bundle are unintentionally excluded from $\bar{\boldsymbol{q}}_i$ when estimating the model, in which case estimates of β_1 will suffer from an omitted variable bias.

To address this endogeneity, we carry out an instrumental variable (IV) approach. The first stage equation is:

$$\bar{P}_{ij}^1 = \lambda_0 + \lambda_1 \Delta \bar{P}_{ij} + \lambda_2 c_{ij}^1 + \bar{\boldsymbol{q}}_i \boldsymbol{\lambda_3} + \boldsymbol{x}_i \boldsymbol{\lambda_4} + u_{ij} \qquad (6)$$

where u_{ij} is the disturbance term, and $\lambda_0, \ldots, \boldsymbol{\lambda_4}$ are the coefficients to be estimated. The predicted values of the home price $\bar{P}_{ij}^{1IV}$ are then plugged into equation (5) to yield:

$$Pr(\Delta v_{im} \geq 0) = f\left\{\beta_0 + \beta_1 \bar{P}_{ij}^{1IV} + \beta_2 c_{ij}^1 + \bar{\boldsymbol{q}}_i \boldsymbol{\beta_3} + \boldsymbol{x}_i \boldsymbol{\beta_4} + \varepsilon_{ij}\right\} \qquad (7)$$

Equations (6) and (7) are estimated simultaneously using maximum likelihood. The necessary exclusion restriction for identification is based on the change in house value that is randomly assigned to respondent *i* in choice occasion *j* $\left(\Delta \bar{P}_{ij}\right)$. The value of $\Delta \bar{P}_{ij}$ is based on the experimental design in our survey and can therefore be assumed to be uncorrelated with ε_{ij}.[5] And by definition, $\Delta \bar{P}_{ij}$ should be strongly correlated with $\bar{P}_{ij}^1$. In fact, the theory tells us that $\lambda_1 = 1$; this is something we later directly test.

Calculating Changes in Welfare

The theoretical and empirical derivation for estimating compensating variation (CV) under four cases are presented, where each case is based on whether a household would sell their home in the

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[5] Similar instruments have been employed in randomized control trials. For example, Janzen and Carter (2019) instrument for endogenous insurance uptake using randomly assigned price discount coupons.

baseline (no change in market price or water costs), as well as under a projected sea-level rise scenario where costs and the market value of their home may be affected.[6]

Case 1: Does not sell in baseline and does not sell in response to increased costs.

In the somewhat trivial case where a household decides not to sell and agrees to pay Δc_{ij} each year, the welfare measure is simply the present value of that additional cost, $\Delta C_{ij} = \sum_{t=1}^{\infty}\{(1+r)^{-t}\Delta c_{ij}\} = \frac{\Delta c_{ij}}{r}$. As shown in Appendix C, in this "no sell / no sell" case the CV (CV_{NN}) can be estimated as:

$$CV_{NN} = \Delta C_{ij} = \frac{\Delta c_{ij}}{\beta_1/\beta_2} \quad (8)$$

This is the welfare loss only among those who do not sell in the baseline and would also optimally decide not to sell in response to the increased costs.

Case 2: Does not sell in baseline but does sell in response to increased costs.

Some respondents will optimally decide to sell when faced with Δc_{ij}. Consider the case where the respondent is not initially going to sell, but decides to sell after being faced with having to pay more for the provision of water and wastewater disposal. In this "no sell / sell" case, some amount of compensating variation for individuals that sell their home (CV_{NS}) is required to get the respondent back to the initial utility level. As demonstrated in Appendix C, the CV in this case can be estimated as:

$$CV_{NS} = \frac{-(\beta_0 + \bar{\boldsymbol{q}}_i\boldsymbol{\beta_3} + \boldsymbol{x}_i\boldsymbol{\beta_4})}{\beta_1} - \left(\frac{c_i}{\beta_1/\beta_2} + \bar{P}_i + \Delta\bar{P}_{ij}\right) \quad (9)$$

The intuition is that for those who optimally decide to sell (but would not in the baseline), their welfare loss is the monetized value of the net loss in utility due to having to give up their current home (the first term in equation (9)), but this is partially offset by the savings from not having to incur increased water and wastewater costs, plus the gain in numeraire consumption due to the proceeds from selling one's current home (second term in equation (9)). Note that in our model this increased numeraire consumption implicitly includes the purchase of any new home.

Case 3: Does sell in baseline and does sell in response to increased costs.

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[6] The welfare calculations are adapted from theory originally laid out in an unpublished working paper by Guignet (2014).

Similar to *Case 1*, this “sell / sell” situation is somewhat trivial, but it does offer an interesting comparison to hedonic property value studies estimating capitalization effects. Our theoretical model illustrates that the capitalization effects estimated in most hedonic property value studies will generally only equal a theoretically valid welfare measure in this case where a household intended to sell in both the baseline and policy scenarios. As shown in Appendix C, the change in welfare in this case simplifies to:

$$CV_{SS} = -\Delta\bar{P}_{ij}. \tag{10}$$

In other cases, however, our framework suggests, consistent with other strands of hedonic theory (Klaiber and Smith, 2013; Kuminoff and Pope, 2014), that the change in price often estimated in first-stated hedonic price models does not equal the non-marginal change in welfare.

Case 4: Does sell in baseline but does not sell in response to increased costs.

In this case, in response to higher water and wastewater costs and a possible decrease in the market value of their home, a household can minimize their loss by opting to not sell and stay at their current home. As detailed in Appendix C, in this “sell / no sell” case, CV can be expressed as:

$$CV_{SN} = \bar{P}_i + \frac{c_i + \Delta c_{ij}}{\beta_1 / \beta_2} + \frac{\beta_0 + \bar{\boldsymbol{q}}_i \boldsymbol{\beta_3} + \boldsymbol{x}_i \boldsymbol{\beta_4}}{\beta_1} \tag{11}$$

The intuition is that the welfare effect is the loss in numeraire consumption because the household opts to keep their current home (first term in equation (11)), plus the present value of the additional costs for potable water and wastewater services one must now incur (second term in equation (11)). This loss is partially offset, however, by the monetized value of the utility differential from getting to continue to experience the housing services derived from the current home (third term in equation (11)).

Expected Welfare Changes.

The appropriate welfare calculation depends on both what a household decides to do in the baseline, as well as in response to the increase in costs due to sea-level rise and saltwater intrusion. An expected welfare framework is needed because we know neither of these decisions with certainty, but we can estimate the corresponding household-specific probabilities of selling their home under baseline and policy scenarios. Given that the realized welfare impact depends on whether a household would sell or not sell in the baseline, as well as under the sea-level rise scenario, there are four states that could be realized. The expected compensating variation for household *i* can be calculated as:

$$E(CV_i) = \left((1 - Pr_i^0)(1 - Pr_i^1)\right) CV_i^{NN} + \left((1 - Pr_i^0)Pr_i^1\right) CV_i^{NS}$$
$$+ (Pr_i^0 Pr_i^1) CV_i^{SS} + \left(Pr_i^0(1 - Pr_i^1)\right) CV_i^{SN} \tag{12}$$

where Pr_i^0 and Pr_i^1 are the household-specific probabilities of selling under a baseline and policy scenario, respectively. These probabilities and the corresponding CV values are estimated based on the regression results presented next.

EMPIRICAL RESULTS

We first present the main regression results, including both probit and Instrumental Variable (IV) probit models. Due to missing values for some independent variables, the final estimating sample entails n=1,588 observations, across 397 respondents.[7] Our two main hypotheses to test are whether households are more likely to sell their home if (i) they face higher water and wastewater costs, and (ii) if they receive a higher price for their home on the market. We then carry out a series of illustrative scenarios where we calculate household-specific changes in the propensity a household will sell their home and the expected welfare impacts.

Regression Results

Following equation (5), model 1 in Table 3 shows the regression results of a simple probit model of the probability a household sells their home. We see some of the coefficients are statistically significant and of the expected sign. For example, we see households are less likely to sell their home if it is larger, farther from the coast, or if they were generally not planning to move in the baseline. Most importantly, as expected, households are more likely to sell if their annual water and sewage costs are larger due to sea-level rise and saltwater intrusion. Otherwise, the coefficients in model 1 are largely statistically insignificant, and of particular concern is the insignificant, negative sign associated with the market value of a home. This goes against our initial hypothesis that a household would be *more* likely to sell their home if they receive more money from doing so. As described earlier, this result likely reflects an omitted variable bias due to our limited set of housing bundle characteristics.

Model 2 in Table 3 shows the results of an IV Probit model to address that endogeneity concern. The first and second equations in this IV approach are estimated simultaneously via maximum likelihood. The first stage results of a linear model of home value are shown in Table 4. Several of the first-stage coefficients are significant and have the expected sign. Home values are increasing with the number of bathrooms and quality of the home. Mobile homes and condos have a lower value relative to the omitted category of single-family and duplex, twin homes and town/row homes, and home values decrease with distance from the coast. Most importantly is the 0.83 coefficient estimate corresponding to the change in home value that is randomly posed in each choice scenario and for each respondent. This variable provides the necessary exclusion

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[7] We exclude 18 respondents because the necessary information on baseline home values, water costs, and interior square footage was not reported.

restriction for statistical identification in the IV approach.[8] As expected, this coefficient is positive and strongly significant. In addition, our theoretical model posits that $\bar{P}_{ij}^{1} = \bar{P}_i + \Delta\bar{P}_{ij}$, and so the corresponding coefficient λ_1 from equation (6) should equal one. A Wald test fails to reject the null hypothesis that $\lambda_1 = 1$ ($F^2_{(1,\ 396)}$=2.15, p=0.1437).

Now turning back to the second equation IV probit results in model 2 of Table 3, the results are much more in line with expectations. We now see a positive and significant coefficient associated with home value. A household is more likely to sell their home if they are offered a higher price to do so. Similarly, we again see that households are more likely to sell if they would face higher water and wastewater treatment costs. The magnitudes of these coefficients also seem reasonable. Recall from our theoretical model that we can infer a discount rate by taking the ratio of the coefficients on home value and the water costs, i.e., $r = \frac{\beta_1}{\beta_2}$. As shown in Table 5, the inferred discount rate is a statistically significant 6.6%, which is in line with the range traditionally recommended for policy analysis (OMB, 2003). We construe this as evidence of internal validity.

As expected, the IV Probit results (Table 3) also suggest that people are less willing to sell their home if it has more desirable features. For example, the probability of selling decreases with increases in square footage, the number of bathrooms, and home quality, but increases if the home is a mobile home or condo (compared to the omitted category of single-family, duplex, twin homes and town/row homes). Additionally, we see that households are less likely to sell if they strongly agree that they do not plan to do so under baseline conditions.

These results are robust to subsequent models that control for income and other demographic characteristics. Controlling for household annual income in IV probit models (3) and (4) demonstrates that households with higher income are less likely to sell their home. This suggests that wealthier households are more willing to bear the additional water and wastewater costs in order to continue to live in their coastal home. Put another way, lower income households (those earning less than $50,000 a year) are more likely to be displaced due to the higher costs associated with sea-level rise. This is consistent with the literature on the potential for climate gentrification (Freeman and Cheyne 2008; Colburn and Jepson 2012; Smith and Whitmore 2020; Smith, et al. 2023). The inclusion of additional demographic characteristics (full-time residency, children, and mortgage and retirement status) in model (4) adds little to the first- and second-stage results, but the previous findings remain robust.

We re-estimate our models and find that the results are robust to alternative criteria to eliminate respondents that may be exhibiting hypothetical bias, protesting behaviors, or who may not have

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[8] To confirm the exogeneity of this assumed instrument, we estimated a series of regression models where the dependent variable is the randomly assigned $\Delta\bar{P}_{ij}$. This is estimated as a function of the baseline home value $\bar{P}_i$ and monthly water/wastewater cost c_i, as well as other home and household characteristics. As shown in Table B1 of Appendix B, the corresponding coefficients are statistically insignificant, which is consistent with the assumed exogeneity of $\Delta\bar{P}_{ij}$. The one exception is that the number of bathrooms appears to be associated with lower losses in price. The magnitude of this coefficient is relatively small compared to the imposed price changes, and the distributions of the number of bathrooms across the different $\Delta\bar{P}_{ij}$ levels are similar (see Figure B1 in Appendix B). We interpret this as evidence in support of the assumed instrument being exogenous.

been considering their responses as consequential. The results are also robust to an alternative definition of the dependent variable, where we exclude "not sure" responses, instead of coding them as a choice not to sell, as we do in the main analysis. See Appendix B for details.

Estimating Welfare Effects

With the estimated models, we can simulate expected welfare impacts under various scenarios. The appropriate welfare calculation depends on both what a household decides to do under baseline conditions, as well as in response to the increase in costs due to sea-level rise and saltwater intrusion. An expected welfare framework is needed because we do not know households' selling decisions with certainty, but we can estimate the corresponding household-specific probabilities based on our regression estimates, and then apply them as per equation (12). We use our results to estimate the impacts of sea-level rise under a series of illustrative scenarios where households experience an increase in water and wastewater costs of Δc = \$100, \$250, and \$500 per month, and home prices remain at their current market values (ΔP = \$0) or decrease by ΔP = \$10k and \$50k. Although some may consider these monthly cost increases to be large, they are not implausible when compared to other issues associated with sea-level rise in our study area. For example, ocean-side residents in the city of Avon, NC are facing a proposed 45% increase in their property taxes in order to fund additional infrastructure protections needed to combat sea-level rise. Other NC towns have imposed similar tax increases (Flavelle, 2021).

We use our preferred model (Model 3) for purposes of these welfare illustrations. Model 3 was chosen because it includes household income, which is a theoretically relevant and statistically significant predictor of whether a household sells their home.[9]

Figure 3 displays the distribution of the predicted propensities to sell across households for the baseline and sea-level rise scenarios. The mean baseline propensity to sell is 30.3%. As monthly costs increase (moving from left to right), the distribution shifts right towards households being more likely to sell. For example, if house prices remain constant, the top row of Figure 3 suggests an average increase in the probability of selling of 3.2, 8.2, and 17.1-percentage points for a \$100, \$250, and \$500 increase in monthly costs, respectively. At the same time, as the market value of a home decreases (moving from top to bottom in Figure 3) we see the distribution shifts leftward, suggesting households are less likely to sell. For example, if we hold the increase in monthly costs at \$100, then the probability of a household selling their home is at 33.5%, on average. If the home decreases in value by \$10k, then the average probability of selling decreases to 31.8%. The average probability decreases even further to 25.4% if the market value of the home decreases to \$50k.

Although the posited increases in costs and declines in home values across the illustrative scenarios have opposing effects on the probability of households selling their home, the effects on welfare are clear. Table 6 shows the mean expected welfare losses across households in each of the nine

[9] Model 4 is more comprehensive, but the added sociodemographic variables are statistically insignificant.

scenarios, ranging from a \$14,937 average loss under our most conservative scenario (Δc = \$100, ΔP = \$0), to a \$83,133 average loss under our most extreme scenario (Δc = \$500, ΔP = \$50k).

DISCUSSION

The results of our SP study suggest that residents in coastal communities are more likely to sell their home as they face higher drinking water and wastewater treatment costs due to sea-level rise, but are less likely to sell if the market value of their home decreases. These findings match economic theory, and the magnitude of the estimates seem reasonable given that the inferred discount rate is about 6.4-6.6% . This rate is lower than that generally estimated in other SP studies, which tend to be in the range of 10% to greater than 100% (e.g., Kovacs and Larson, 2008; Bond et al., 2009; Lew, 2018; Howard et al, 2021; West, 2021). But our inferred 6.4-6.6% discount rate is within the range of the 3% to 7% traditionally recommended for US federal regulatory analyses (OMB, 2003).[10]

The results also suggest that wealthier households are more willing to bear the additional water and wastewater costs due to sea-level rise, in order to continue to reside in their current home. This result presents potential environmental justice implications, suggesting that sea-level rise is more is more likely to displace households who have an annual income that is less \$50,000. The potential for further coastal gentrification in response to climate change and sea-level rise has been noted in the literature (Freeman and Cheyne 2008; Colburn and Jepson 2012; Smith and Whitmore 2020; Smith, et al. 2023).

The estimated baseline average probability of a household selling their home is 30.3%. Our illustrative welfare calculations suggest that if households experience a \$100 increase in monthly costs due to sea-level rise, then they are 3-percentage points more likely to sell their home, on average. This average increase in the probability of selling rises to 8.2, and 17.1-percentage points as monthly costs increase by \$250 and \$500, respectively. At the same time, as the market value of a home decreases the probability of selling decreases, all else constant. For example, if we hold the increase in monthly costs at \$100, then the probability of a household selling their home is at 33.5%, on average. If the home declines in value by \$10k, then the average probability of selling decreases to 31.8%. The average probability decreases even further to 25.4% if the market value of the home decreases \$50k. Going the other way, these results provide some insight into how government buyout programs can incentivize homeowners to move out of hazardous, flood-prone areas.

The expected average loss in welfare is about \$15,000 in our most conservative illustrative scenario (posing just a \$100 increase in monthly costs due to sea-level rise and no change in home value). The estimated expected welfare loss becomes greater as the monthly costs and loss in home values increase; with our most extreme scenario of a \$500 increase in monthly costs and \$50,000 loss in home value suggesting an expected welfare loss of over \$83,000 for the average household. Nonetheless, many households in our sample state that they would rather stay in their current home

[10] More recent federal guidance suggests a lower 2% default discount rate (OMB, 2023).

and bear the costs. An important question for local decision-makers is that if households are willing to bear the costs, what are their preferences in *how* to continue to receive clean potable water and adequate wastewater disposal and treatment services. Similarly, if households do decide to move, state and local governments will be interested in whether residents will opt to remain in their jurisdictions. We ask a series of debriefing questions to provide some insight to these questions. Respondents were asked their preferences for averting/mitigating actions if they opted to remain in their current home for at least one of the four choice questions they faced. Similarly, respondents were asked where they would move to if they opted to sell their home in at least one of the choice questions. Among the 348 respondents for whom responses to these questions were elicited, about half (54%) would prefer to pay a public utility to ensure adequate wastewater treatment (i.e., pay to be connected to the public sewer system if they are not already, and/or pay a higher utility bill); compared to only 28% saying they would prefer a private investment like upgrading their septic system. The remaining 16% of respondents said they were not sure what they would prefer, and eight respondents said "other". In contrast, most of the 348 respondents (82%) would prefer to make private investments to ensure clean drinking water (i.e., install a water filter, buy bottled water, or install a deeper well), compared to paying to be connected to the public system and/or paying a higher utility bill. This noticeable difference compared to wastewater treatment could possibly be due to the ease of substitutes (e.g., purchasing bottled water), or perhaps mistrust in public water systems.

Among the 265 respondents who stated that their household would move in at least one of the choice scenarios, 20% said they would relocate to a NC county away from the coast, and 26% said they would leave NC altogether. Other respondents said they would try to remain in the same county (21%), move to another coastal county in NC (14%), or that they were not sure (19%). It is important for decision-makers to recognize that despite access to numerous coastal amenities, the costs associated with sea-level rise may cause some residents to leave these communities.

CONCLUSIONS

Whether related to the provision of potable water and wastewater services, or other increased infrastructure costs to combat sea-level rise and increased storm surges, coastal residents' welfare will be impacted. In some cases, this welfare loss will be experienced through the increased costs directly, and in other cases it will be due to households having to alter their anticipated housing consumption decisions. Either way, with the predicted annual sea-level rise rates of 2.01 to 4.55 mm/year for NC (NOAA, 2018), and stories like that in Avon, NC where ocean-side residents are facing a proposed 45% increase in their property taxes to combat sea-level rise (Flavelle, 2021), coastal communities will have to grapple with these tradeoffs for decades to come. Our results can inform local communities about the potential emigration of residents facing these costs. The results and framework for calculating expected welfare impacts can also inform benefit-cost analyses of future adaptation strategies and infrastructure investments, such as providing alternative water sources, updating desalinization capabilities, and installing centralized wastewater treatment facilities.

A critical gap in applying our results to policy analysis, however, is that a quantitative link must be made between projected rates of septic system failures, increased salinity in public and private groundwater wells, and the costs of taking actions to mitigate or avert these adverse impacts. Once such cost estimates have been obtained, the results and framework from this SP study can be applied to formal benefit-cost analyses. It would also be beneficial to extend our study by administering the survey to a larger sample, ideally drawing from a sample frame based on data of residential parcels along the coast. It would be advantageous to supplement such a survey with tax assessor parcel and location-specific GIS data.

Nonetheless, our current study contributes to the literature by examining an understudied threat from sea-level rise – impacts on the provision of clean potable water and wastewater treatment. Environmental economic studies to date have focused primarily on a subset of threats from sea-level rise, namely flooding and coastal erosion (e.g., Whitehead et al., 2009; Gopalakrishnan et al., 2016; Landry et al., 2003; Walsh et al., 2019). We also illustrate a context where researchers can circumvent the difficulties in measuring and communicating environmental attributes, and instead estimate welfare effects by focusing on financial tradeoffs. Such a focus is not applicable in all settings, but in some cases, it may provide a useful alternative for welfare estimation. Finally, we illustrate a novel theoretical framework that allows for the estimation of welfare effects using data on households' decisions to sell their home, even in the absence of information of where selling households move to. Although we use SP data in this application, our approach could be applied to revealed preference data of residential parcels and transactions. Such efforts would provide a welfare extension to a limited body of revealed preference studies that have found that the probability of households selling their home are impacted by environmental disamenities (Depro and Palmquist, 2012; Guignet and Martinez-Cruz, 2018; Irwin and Wolf, 2022). Hedonic pricing methods and locational sorting models provide means of estimating welfare effects using such data; but perhaps our framework can serve as yet another approach for estimating welfare impacts in this context.

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FIGURES AND TABLES

Figure 1. Map of Study Area: North Carolina (NC) Coastal Counties.

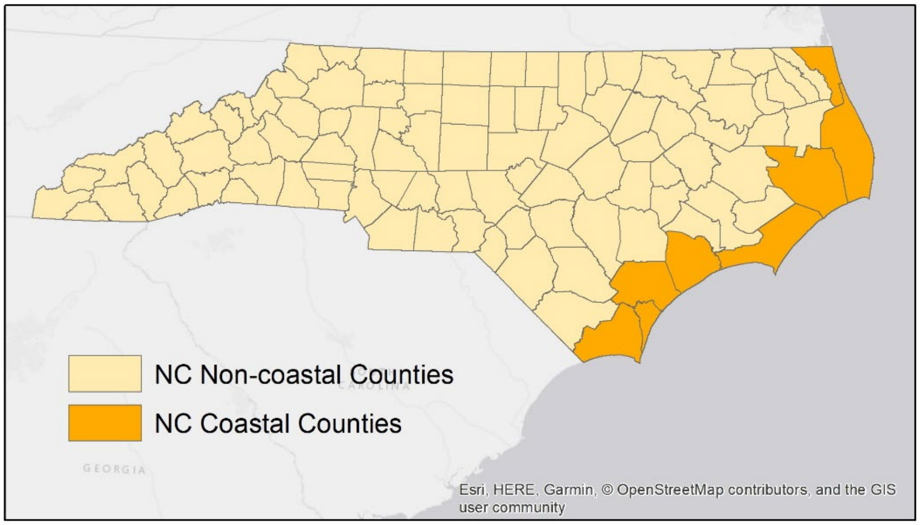


Figure 2. Example choice question of whether to keep or sell home.

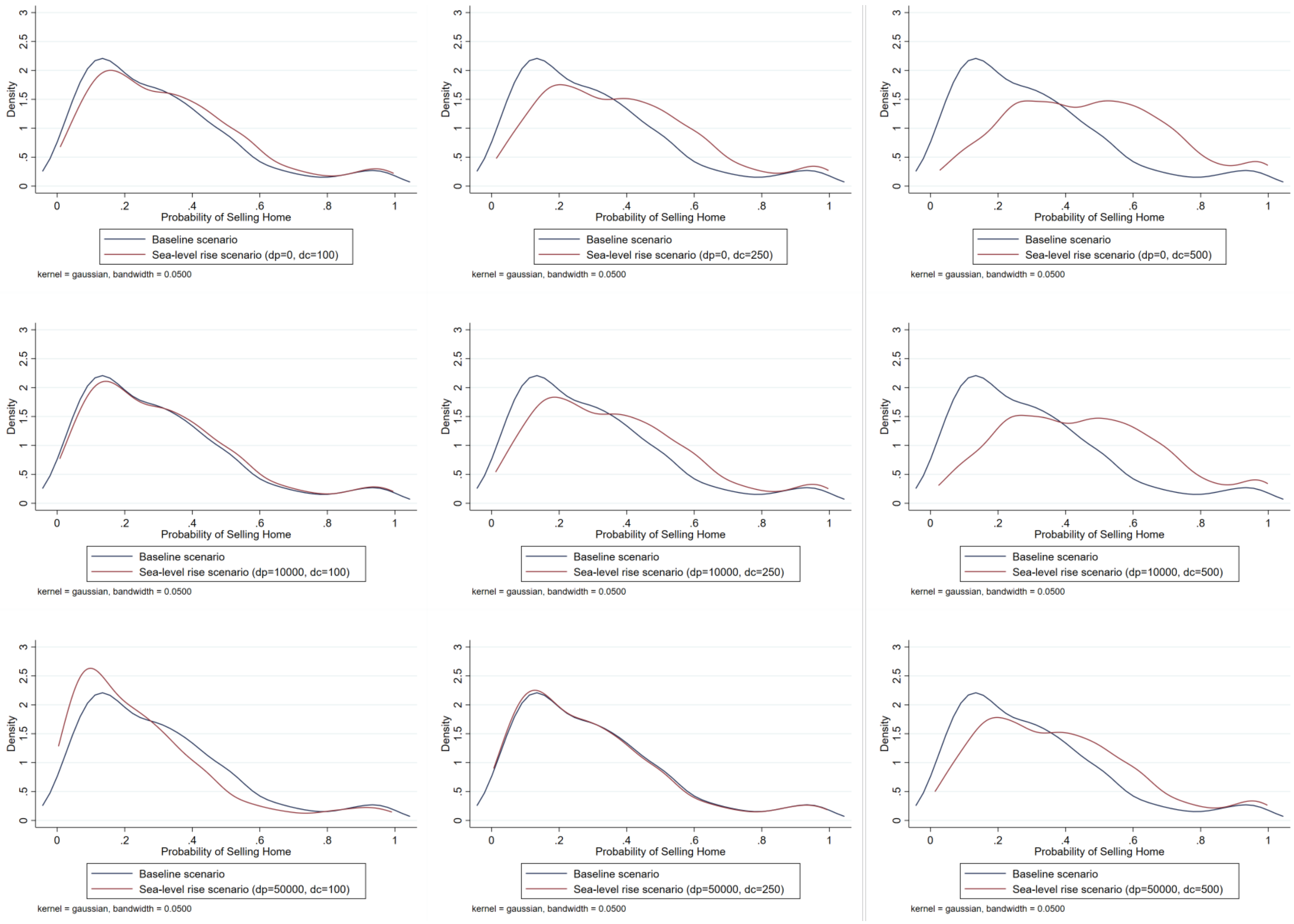
Suppose that the monthly costs for your drinking water and wastewater treatment increase by **$75 per month**. In other words, you would have to pay an additional **$900 each year**. Which of the following options would you choose?

OPTION A: Keep my home and pay an **additional $75 every month**.

OPTION B: Sell my home for **$25,000 less than its current market value.**

- ○ I Choose Option A
- ○ I Choose Option B
- ○ I am not sure

Figure 3. Distributions of predicted propensities to sell across households.



Presented sea-level rise scenarios have increasing monthly costs moving from left to right (Δc = \$100, \$250, and \$500 per month) ΔP = \$0), and increasing losses in home values moving from top to bottom (ΔP = \$0, \$10k and \$50k).

Table 1. Descriptive statistics: Home characteristics.

Variable	Obs	Mean	Std. dev.	Min	Max
Home value (2020$ USD)[a]	404	292,822	163,090	50,000	950,000
Monthly water/wastewater costs[b]	409	80.13	59.32	0	300
Square footage[c]	414	2,699	4,729	2	45,000
# of bathrooms[d]	415	2.42	0.83	0.5	5
Dummy: 5+ bathrooms[d]	415	0.01	-	0	1
Home Quality (1-5)[e]	415	3.94	0.91	1	5
Dummy: Single-family home	415	0.84	-	0	1
Dummy: Duplex, twin or town/row home	415	0.07	-	0	1
Dummy: Mobile home	415	0.03	-	0	1
Dummy: Condo	415	0.07	-	0	1
Miles to Coast	415	22.20	23.69	0	100

(a) Six respondents are not included here because they report a home value greater than $1 million, and five are excluded because they were not sure of their home value. (b) Six respondents did not provide information on their baseline water and wastewater costs. (c) One respondent did not report the interior square footage of their home. (d) The number of bathrooms variable is censored from above at five due to the survey question format. Six respondents who selected "5 or more" bathrooms are coded as having five bathrooms. To account for this censoring, an indicator denoting those responses is also included in the subsequent models. (e) Likert scale variable describing quality of home, ranging from 1=Below average to 5=Above average.

Table 2. Descriptive statistics: Sociodemographic characteristics.

Variable	Obs	Mean	Std. dev.	Min	Max
Years of age	415	52.81	17.40	0	100
Dummy: Has children	415	0.26	-	0	1
Number of children[a]	109	1.82	1.02	1	7
Dummy: Male	415	0.50	-	0	1
Dummy: Hispanic	415	0.07	-	0	1
Dummy: Employed	415	0.53	-	0	1
Dummy: Retired	415	0.34	-	0	1
Dummy: Income $50k-$75k	415	0.21	-	0	1
Dummy: Income $75k-$100k	415	0.20	-	0	1
Dummy: Income $100k-$150k	415	0.19	-	0	1
Dummy: Income $150k or more	415	0.14	-	0	1
Dummy: Income not reported	415	0.02	-	0	1
Dummy: Fulltime resident	415	0.87	-	0	1
Dummy: Have mortgage	415	0.56	-	0	1

(a) Summary statistics for the number of children presented for only the 109 respondents who have at least one child under the age of 18 living at their home.

Table 3. Regression Results for Model of Probability of Selling Home.

Variables	Probit (1)	IV Probit (2)	IV Probit (3)	IV Probit (4)
Home value	-1.1276e-07	5.9048e-06***	6.0434e-06***	6.1173e-06***
	(3.2658e-07)	(6.7800e-07)	(7.1915e-07)	(7.1272e-07)
Annual Water/Sewage Costs	1.4997e-04***	8.9277e-05***	9.3685e-05***	9.5732e-05***
	(1.2625e-05)	(1.9322e-05)	(1.9254e-05)	(1.9379e-05)
Square footage	-3.0384e-05**	-3.6906e-05***	-3.7503e-05***	-3.6624e-05***
	(1.3278e-05)	(1.1029e-05)	(1.0494e-05)	(1.0254e-05)
# of bathrooms	-0.0491	-0.5401***	-0.4740***	-0.4656***
	(0.0689)	(0.1025)	(0.1027)	(0.1012)
Dummy: 5+ bathrooms	0.8393	1.4301	1.6292*	1.5984*
	(0.5228)	(1.1008)	(0.8944)	(0.8865)
Home Quality (1-5)	0.0075	-0.2127***	-0.1923**	-0.1877**
	(0.0574)	(0.0751)	(0.0761)	(0.0758)
Dummy: Mobile home	0.1769	0.7702***	0.5614**	0.5545**
	(0.3427)	(0.2391)	(0.2512)	(0.2672)
Dummy: Condo	0.0298	0.3779**	0.3735**	0.3991**
	(0.1561)	(0.1860)	(0.1855)	(0.1943)
Miles to coast	-0.0041**	0.0013	0.0010	0.0019
	(0.0020)	(0.0024)	(0.0024)	(0.0026)
Dummy: Agree, do not plan to move	-0.3267***	-0.1522	-0.1491	-0.1581
	(0.1143)	(0.1294)	(0.1313)	(0.1319)
Dummy: Strongly agree, do not plan to move	-0.7083***	-0.5949***	-0.6210***	-0.6446***
	(0.1081)	(0.1396)	(0.1359)	(0.1387)
Dummy: Income \$50k to \$150k[a]			-0.3914***	-0.4071***
			(0.1171)	(0.1242)
Dummy: Income \$150k or more[a]			-0.8017***	-0.8117***
			(0.1971)	(0.2035)
Dummy: Income not reported			-1.3729**	-1.3320**
			(0.6251)	(0.6120)
Dummy: Fulltime resident				0.2296
				(0.1870)
Dummy: Retired				-0.1343
				(0.1092)
Dummy: Has Mortgage				0.1023
				(0.1035)
Dummy: Has children				-0.2033
				(0.1388)
Constant	-0.6335***	0.0704	0.1461	-0.0846
	(0.2373)	(0.2691)	(0.2706)	(0.3373)
Log-likelihood	-881.0900	-21826.1979	-21737.8720	-21725.9256

Standard errors in parentheses, clustered at the respondent-level. * p<0.10, ** p<0.05, *** p<0.01. Regression models estimated using sample of 1,588 choice observations across 397 respondents. (a) The omitted income category is respondents with an annual income of less than \$50k.

Table 4. Regression results for first-stage model of home values.

Variables	Linear MLE (2)	Linear MLE (3)	Linear MLE (4)
Annual Water/Sewage Costs	0.62	0.56	0.44
	(1.16)	(1.11)	(1.09)
Square footage	3.10	3.00	2.97
	(2.54)	(2.36)	(2.39)
# of bathrooms	84550.82***	70917.21***	69512.86***
	(12706.49)	(13004.71)	(12771.84)
Dummy: 5+ bathrooms	-153676.60	-175043.83	-168990.56
	(144598.64)	(112838.98)	(112850.72)
Home Quality (1-5)	36134.60***	31700.48***	30451.40***
	(9661.29)	(9487.54)	(9553.67)
Dummy: Mobile home	-111143.64***	-70622.43***	-69877.33***
	(28951.17)	(24103.62)	(23446.17)
Dummy: Condo	-59056.33*	-55859.63*	-56903.95*
	(30621.54)	(29022.12)	(30054.58)
Miles to coast	-634.71*	-582.48*	-606.96*
	(347.62)	(328.64)	(360.30)
Dummy: Agree, do not plan to move	-7831.73	-10152.12	-10258.02
	(15299.23)	(14909.48)	(14825.74)
Dummy: Strongly agree, do not plan to move	27083.92	28191.88*	28873.10*
	(17533.32)	(16181.97)	(16472.16)
Change in home value	0.83***	0.85***	0.84***
	(0.12)	(0.11)	(0.11)
Dummy: Income \$50k to \$150k[a]		70695.91***	71558.22***
		(14681.71)	(15371.51)
Dummy: Income \$150k or more[a]		136970.36***	138223.55***
		(25121.38)	(25399.55)
Dummy: Income not reported		217201.82***	205730.08***
		(67293.09)	(66246.59)
Dummy: Fulltime resident			-21360.48
			(26709.05)
Dummy: Retired			21090.00*
			(12133.71)
Dummy: Has Mortgage			-5815.08
			(12975.01)
Dummy: Has children			16643.55
			(19749.93)
Constant	-58037.85*	-73292.29**	-54070.44
	(34901.59)	(32634.67)	(42778.08)
Log-likelihood	-21826.1979	-21737.8720	-21725.9256

Standard errors in parentheses, clustered at the respondent-level. * p<0.10, ** p<0.05, *** p<0.01. Regression models estimated using sample of 1,588 choice observations across 397 respondents. (a) The omitted income category is respondents with an annual income of less than \$50k.

Table 5. Inferred discount rates from probability of sale model results.

Variables	Probit (1)	IV Probit (2)	IV Probit (3)	IV Probit (4)
Discount Rate	-0.0752	6.6140***	6.4508***	6.3900***
	(0.2178)	(2.0456)	(1.9587)	(1.9104)

Standard errors in parentheses, clustered at the respondent-level. * p<0.10, ** p<0.05, *** p<0.01.

Table 6. Average household loss in welfare: Expected compensating variation.

Decrease in home value	Increase in monthly costs Δc = \$100	Δc = \$250	Δc = \$500
ΔP = \$0	\$14,937	\$35,599	\$64,817
ΔP = \$10k	\$17,016	\$38,447	\$69,117
ΔP = \$50k	\$22,955	\$47,099	\$83,133

APPENDICES

Appendix A. Supplemental Descriptive Statistics.

Figure A1. Reported importance of attribute when responding to choice questions.

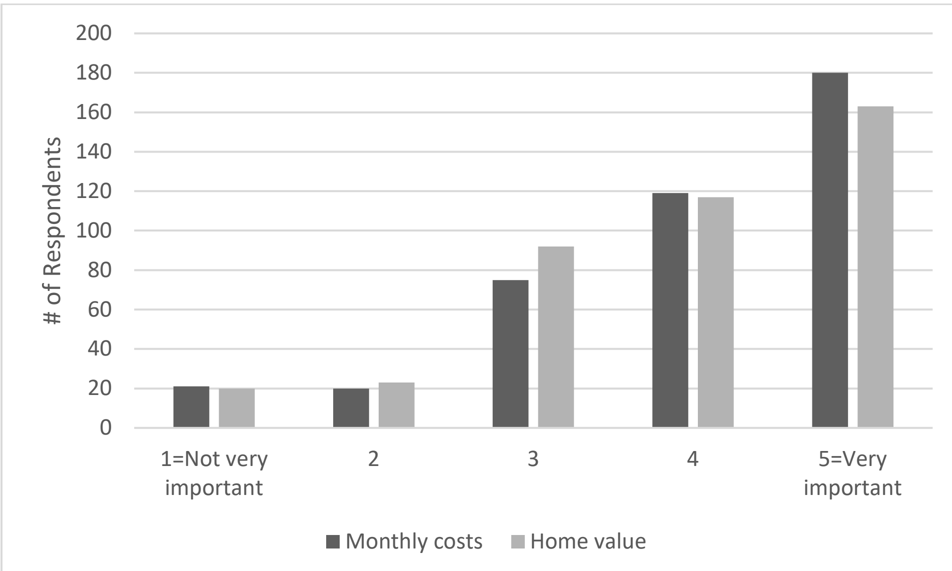
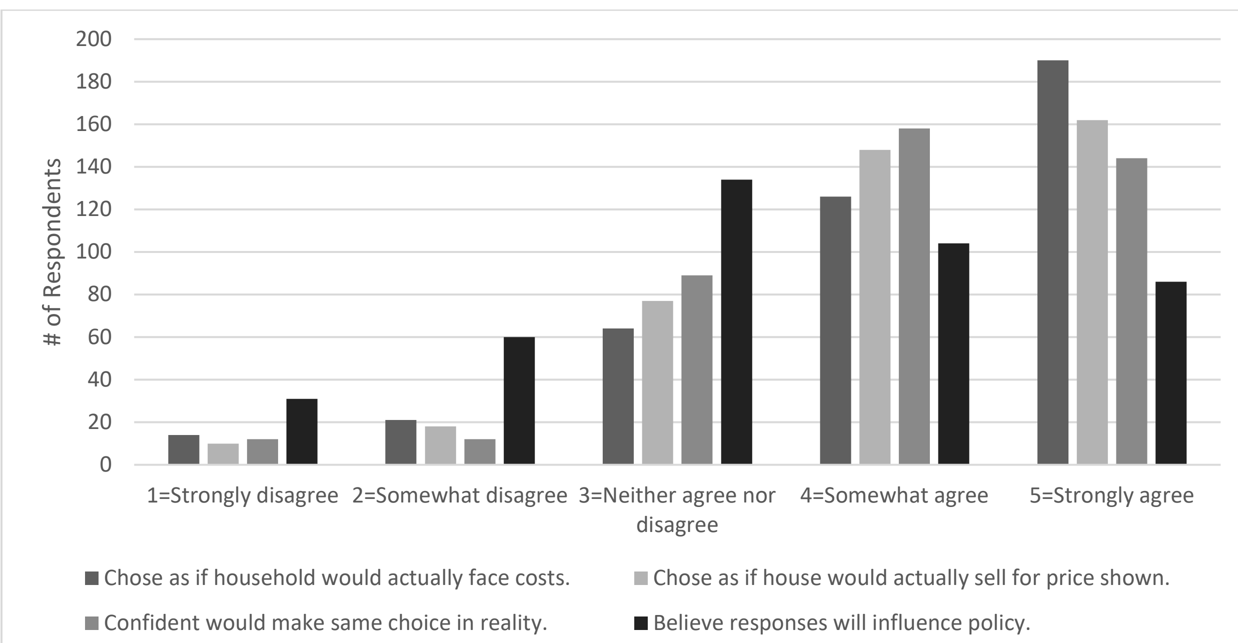


Figure A2. Debriefing responses assessing consequentiality and hypothetical bias.



Appendix B. Sensitivity Analyses.

First, to further assess the exogeneity of our assumed instrument, we estimate a series of regressions where the dependent variable is the randomly assigned change in price $\Delta\bar{P}_{ij}$. This is estimated as a function of the baseline home value $\bar{P}_i$ and baseline monthly water and wastewater costs c_i, as well as other home and household characteristics. As shown in Table B1, the corresponding coefficients are statistically insignificant, demonstrating that the randomly assigned $\Delta\bar{P}_{ij}$ is uncorrelated with observable characteristics. This finding is consistent with the assumed exogeneity of $\Delta\bar{P}_{ij}$. The one exception is that the number of bathrooms appears to be associated with lower losses in price. The \$1,268 to \$1,297 increase in $\Delta\bar{P}_{ij}$ associated with each additional bathroom, as suggested by models (2) through (4) in Table B1, is surprising given that $\Delta\bar{P}_{ij}$ was randomly assigned as part of the experimental design. Such spurious correlations are possible, however, and it is reassuring that the magnitude of these estimates are small relative to the \$0 to \$50,000 loss imposed under the experimental design. In Figure B1 we graph the sample distribution of the number of bathrooms for each randomly imposed price level. The distributions are similar. In aggregate, we interpret this as evidence that the assumed exogeneity of $\Delta\bar{P}_{ij}$ and use of it as an instrument for our instrumental variables approach is reasonable.

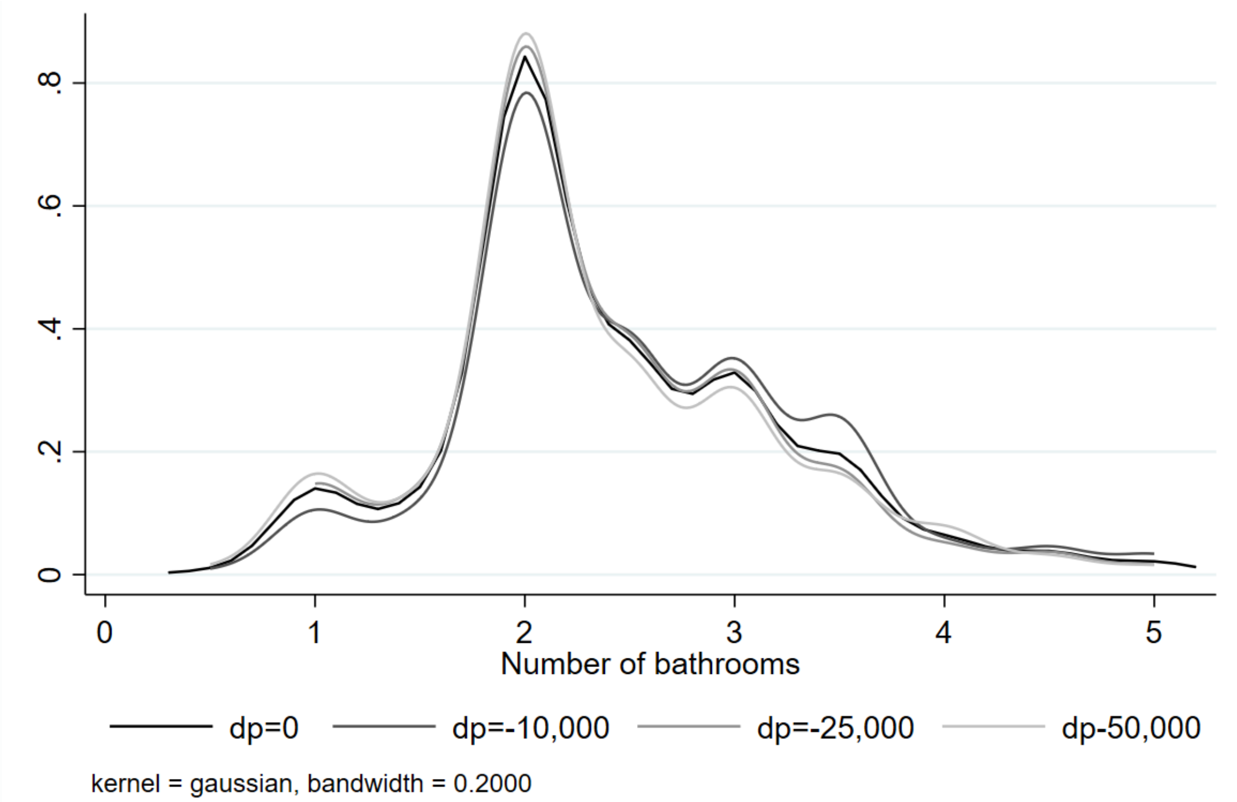
Table B1. Regression model to confirm the randomly assigned ΔP is uncorrelated with other observed variables. Dependent variable is ΔP.

Variables	(1)	(2)	(3)	(4)
Home value (2020$ USD)	0.0006	-0.0035	-0.0034	-0.0035
	(0.0020)	(0.0026)	(0.0027)	(0.0027)
Monthly water/wastewater costs	-1.8083	-4.0089	-4.3443	-4.6719
	(6.6764)	(6.5822)	(6.6131)	(6.5429)
Square footage		0.0961	0.0949	0.0962
		(0.0780)	(0.0792)	(0.0804)
# of bathrooms		1268.1358**	1297.2821**	1288.9031**
		(543.3561)	(540.7111)	(541.7959)
Dummy: 5+ bathrooms		919.0539	499.3375	472.0391
		(4478.5948)	(4089.3257)	(4037.7028)
Home Quality (1-5)		418.3895	438.6411	422.9701
		(410.3635)	(410.5936)	(422.1054)
Dummy: Mobile home		702.1235	476.2680	477.9593
		(2598.8039)	(2642.8779)	(2646.2858)
Dummy: Condo		-886.7968	-975.8227	-903.1942
		(1176.7574)	(1191.6352)	(1279.4779)
Miles to coast		-6.7446	-6.1027	-6.5091
		(14.9877)	(14.9482)	(16.3757)
Dummy: Agree, do not plan to move		-271.3156	-221.2574	-216.4110

		(844.1859)	(841.1242)	(844.1524)
Dummy: Strongly agree, do not plan to move		-997.9769	-1045.4478	-1029.2353
		(768.9619)	(775.0226)	(796.1930)
Dummy: Income \$50k to \$150k[a]			-504.3710	-507.7490
			(853.5839)	(872.0696)
Dummy: Income \$150k or more[a]			-182.7418	-161.6076
			(1290.9359)	(1298.5599)
Dummy: Income not reported			1324.2226	1201.4103
			(2084.0449)	(2143.3199)
Dummy: Fulltime resident				-63.7052
				(1080.9387)
Dummy: Retired				261.9977
				(816.2884)
Dummy: Has Mortgage				-13.1365
				(680.6716)
Dummy: Has children				312.9040
				(848.1974)
Constant	-21782.6113***	-24694.0347***	-24495.8857***	-24476.1575***
	(730.7102)	(1713.6068)	(1741.5575)	(1912.7883)
Observations	1588	1588	1588	1588
Log-likelihood	-17899.4917	-17896.1413	-17895.9591	-17895.9148

Standard errors in parentheses, clustered at the respondent-level. * $p<0.10$, ** $p<0.05$, *** $p<0.01$. (a) The omitted category is respondents with an annual income of less than \$50k

Figure B1. Distribution of number of bathrooms across each randomly assigned *ΔP*.



To examine the sensitivity of our results, we re-estimate our preferred specification (IV probit model 3 in Table 3) under alternative definitions of the dependent variable and sample screening criteria based on responses to debriefing questions. Model 3A in Tables B2 through B4 excludes "not sure" responses to the choice questions, instead of coding them as a choice to not sell, as we do in the main analysis. The remaining models in Tables B2 through B4 are estimated using the original dependent variable definition, but apply increasingly comprehensive criteria for eliminating respondents that may potentially have exhibited hypothetical bias, protest votes, or who may not have been considering their responses as consequential. Model 3B is estimated using a sample that excludes respondents who somewhat or strongly disagreed with the statement that they made their choices as if they would actually face the change in costs and home values posited in the choice scenarios. Model 3C further excludes observations pertaining to respondents who somewhat or strongly disagreed that they would make the same choices in reality. In addition to the previous criteria, model 3D also excludes an additional 67 respondents who somewhat or strongly disagreed that their responses would affect policy (see Figure A2). These criteria are meant to exclude observations pertaining to respondents who may have exhibited hypothetical bias and/or did not perceive their responses as consequential. The sample used to estimate model 3E is further restricted by excluding respondents who strongly agreed that they value the provision of potable water and wastewater services, but do not believe they should have to pay an increased cost for such services. We meant this as a way to exclude respondents who may have put forth potential protest responses. Similarly, model 3F excludes an additional 91 respondents who only somewhat agreed with the above statement. This left a comparably smaller estimating sample of just 139 respondents (556 observations).

As can be seen in Tables B2 through B4 the results are robust to the alternative dependent variable definition and alternative criteria to restrict the estimating sample. First looking to the IV probit model results of households' decisions to sell their home (Table B2), across all models we see positive and statistically significant coefficients corresponding to home values and water and wastewater costs, again suggesting that people are more likely to sell their home if they receive a higher price from doing so, and as the costs of remaining at their current home increase. Similar to our earlier models, we also see people are less likely to sell their home if it has more desirable features (e.g., greater interior square footage, more bathrooms, etc.) and is of better quality. The results also again suggest that wealthier households are less likely to sell.

The inferred discount rates shown in Table B3 are also very similar across all models, generally ranging from a statistically significant 3.4% to 6.9%. The one exception is under model 3F where we apply our most stringent sample screening criteria. There we estimate a statistically insignificant 3.0% discount rate. Although the magnitude of this point estimate is smaller, the insignificant result may also be partly driven by the much smaller sample size (n=556 compared to the original sample size of 1,588 choice occasions).

The first-stage results of home values are also robust (Table B4), with many of the coefficients continuing to be statistically significant and of the expected sign. Most importantly, this remains true for the change in home value variable, which is the randomly assigned value that provides the necessary exclusion restriction for our IV approach.

Table B2. Probability of selling home: Sensitivity analysis of IV probit model 3.

Variables	(3A)	(3B)	(3C)	(3D)	(3E)	(3F)
Home value	6.1329e-06***	6.2538e-06***	6.4724e-06***	5.8393e-06***	4.3765e-06***	4.2303e-06**
	(6.6918e-07)	(6.6615e-07)	(6.3172e-07)	(8.7841e-07)	(1.5486e-06)	(2.0506e-06)
Annual Water/Sewage Costs	1.0347e-04***	9.5749e-05***	9.3502e-05***	9.6516e-05***	1.2725e-04***	1.4288e-04***
	(2.4837e-05)	(1.9276e-05)	(1.9409e-05)	(2.4606e-05)	(2.3838e-05)	(2.5664e-05)
Square footage	-3.7818e-05***	-4.4406e-05***	-4.4024e-05***	-4.1929e-05***	-3.5970e-05***	-2.9174e-05**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
# of bathrooms	-0.4485***	-0.5340***	-0.5661***	-0.4806***	-0.3644**	-0.2557
	(0.1041)	(0.1049)	(0.1063)	(0.1153)	(0.1565)	(0.1734)
Dummy: 5+ bathrooms	1.4568*	1.4047	1.4546	1.2502	0.0970	0.1641
	(0.8592)	(1.2031)	(1.2120)	(1.1810)	(1.1772)	(1.0989)
Home Quality (1-5)	-0.2060**	-0.2283***	-0.2375***	-0.1962**	-0.1324	-0.3699*
	(0.0840)	(0.0840)	(0.0851)	(0.0988)	(0.1159)	(0.1957)
Dummy: Mobile home	0.7668***	0.2819	0.5466***	0.6088***	0.4064*	0.7092***
	(0.2021)	(0.3053)	(0.1923)	(0.2173)	(0.2112)	(0.2496)
Dummy: Condo	0.3222	0.2748	0.3947**	0.4752**	0.5886**	1.0407**
	(0.2057)	(0.2100)	(0.1944)	(0.2273)	(0.2921)	(0.4419)
Miles to coast	-0.0014	0.0023	0.0022	0.0012	-0.0022	-0.0028
	(0.0027)	(0.0026)	(0.0027)	(0.0028)	(0.0031)	(0.0042)
Dummy: Agree, do not plan to move	-0.1818	-0.2252*	-0.2219	-0.2441	-0.3287*	-0.0306
	(0.1369)	(0.1366)	(0.1384)	(0.1638)	(0.1896)	(0.2586)
Dummy: Strongly agree, do not plan to move	-0.6256***	-0.6807***	-0.6775***	-0.7374***	-0.7983***	-0.7700***
	(0.1421)	(0.1405)	(0.1419)	(0.1629)	(0.1797)	(0.2508)
Dummy: Income \$50k to \$150k[a]	-0.3910***	-0.3433***	-0.3566***	-0.3680***	-0.4320***	-0.2856
	(0.1248)	(0.1200)	(0.1203)	(0.1336)	(0.1611)	(0.2452)
Dummy: Income \$150k or more[a]	-0.8599***	-0.6984***	-0.7304***	-0.6720***	-0.6741**	-0.2713
	(0.2039)	(0.2085)	(0.2126)	(0.2258)	(0.2800)	(0.4179)
Dummy: Income not reported	-1.6310**	-1.2557**	-1.3090**	-0.9935	-0.6077	-0.9567

	(0.6921)	(0.5960)	(0.6007)	(0.7580)	(0.6209)	(1.0912)
Constant	0.2899	0.3863	0.4709*	0.2483	-0.0676	0.1829
	(0.2701)	(0.2832)	(0.2837)	(0.3364)	(0.3738)	(0.6661)
Observations	1311	1416	1384	1124	912	556
Log-likelihood	-17998.1568	-19373.2588	-18917.2506	-15407.9386	-12471.0880	-7537.8205

Standard errors in parentheses, clustered at the respondent-level. * p<0.10, ** p<0.05, *** p<0.01. (a) The omitted category is respondents with an annual income of less than $50k.

Table B3. Inferred discount rates: Sensitivity analysis of IV probit model 3.

Variables	(3A)	(3B)	(3C)	(3D)	(3E)	(3F)
Discount Rate	5.9271***	6.5314***	6.9222***	6.0502***	3.4392*	2.9607
	(1.9380)	(1.8613)	(1.9463)	(2.3214)	(1.7580)	(1.8212)

Standard errors in parentheses, clustered at the respondent-level. * p<0.10, ** p<0.05, *** p<0.01.

Table B4. First-stage model of home values: Sensitivity analysis of IV probit model 3.

Variables	(3A)	(3B)	(3C)	(3D)	(3E)	(3F)
Annual Water/Sewage Costs	0.96	0.10	-0.10	-0.16	-1.22	-1.33
	(1.27)	(1.07)	(1.08)	(1.25)	(1.35)	(1.64)
Square footage	2.82	4.43	4.52	4.55	5.30*	4.84*
	(2.52)	(2.86)	(2.81)	(2.79)	(2.84)	(2.68)
# of bathrooms	63605.05***	75302.32***	78146.12***	70828.93***	74512.19***	55811.63***
	(14184.63)	(13699.47)	(13803.04)	(15352.54)	(16059.78)	(16845.53)
Dummy: 5+ bathrooms	-165966.83	-135293.18	-141771.74	-107992.78	53519.79	33044.05
	(110291.46)	(142597.14)	(141193.90)	(148323.39)	(100458.68)	(79915.84)
Home Quality (1-5)	33080.92***	35448.26***	34728.62***	35222.98***	34200.36**	77235.54***

	(10701.10)	(10270.39)	(10207.97)	(12510.13)	(14568.70)	(12904.66)
Dummy: Mobile home	-80745.91***	-39383.05*	-45850.75**	-49042.30*	-54937.08	3540.40
	(26584.27)	(21499.89)	(22764.88)	(25360.00)	(34700.38)	(46994.80)
Dummy: Condo	-54378.61*	-41935.72	-61271.63**	-65280.35*	-105568.94***	-162798.69***
	(31770.62)	(31845.39)	(26453.34)	(33926.38)	(27564.01)	(42807.75)
Miles to coast	-444.16	-683.17*	-702.36*	-583.17	-462.48	-271.52
	(356.45)	(357.98)	(368.56)	(407.62)	(437.00)	(504.10)
Dummy: Agree, do not plan to move	-9953.84	-734.37	1541.80	-4094.95	-11018.49	-36916.00
	(15541.20)	(15318.59)	(15279.57)	(18196.02)	(20138.79)	(26906.39)
Dummy: Strongly agree, do not plan to move	32927.59*	38651.39**	41406.86**	50560.14**	40057.79*	18547.16
	(17786.76)	(16882.38)	(16784.79)	(20801.87)	(23778.74)	(29096.22)
Change in home value	0.83***	0.88***	0.86***	0.78***	0.90***	0.98***
	(0.14)	(0.12)	(0.12)	(0.14)	(0.15)	(0.20)
Dummy: Income \$50k to \$150k[a]	71880.97***	60999.06***	58939.03***	60281.73***	63333.24***	69210.44***
	(16640.17)	(15281.81)	(15293.47)	(18012.94)	(19889.54)	(20800.95)
Dummy: Income \$150k or more[a]	141799.72***	121762.19***	120231.35***	115996.81***	126382.14***	138593.23***
	(27770.85)	(27826.45)	(28422.54)	(31624.73)	(37658.50)	(36070.50)
Dummy: Income not reported	245295.71***	192579.34***	193025.97***	160855.28*	128334.05**	247522.51***
	(72859.56)	(63309.02)	(63179.77)	(84252.39)	(63383.88)	(81449.76)
Constant	-69198.12*	-96087.76***	-99802.49***	-93001.87**	-83749.58*	-192955.72***
	(35548.21)	(33867.24)	(34222.21)	(40818.76)	(43679.73)	(51616.34)
Observations	1311	1416	1384	1124	912	556
Log-likelihood	-17998.1568	-19373.2588	-18917.2506	-15407.9386	-12471.0880	-7537.8205

Standard errors in parentheses, clustered at the respondent-level. * p<0.10, ** p<0.05, *** p<0.01. Regression models estimated using sample of 1,588 choice observations across 397 respondents. (a) The omitted category is respondents with an annual income of less than $50k.

Appendix C. Case-by-case Theoretical Derivations of Compensating Variation.

In this appendix we lay out the details of the theoretical and empirical derivation for estimating the welfare effects under four cases. The cases vary based on whether a household would sell their home or not under baseline conditions, versus a projected sea-level rise scenario where water costs increase, and the market value of their home may be affected.

Case 1: Does not sell in baseline, and does not sell in response to increased costs.

In the somewhat trivial case where a household decides not to sell and pay Δc_{ij} each year, the welfare measure is simply the present value of that additional cost, $\Delta C_{ij} = \sum_{t=1}^{\infty}\{(1+r)^{-t}\Delta c_{ij}\}$. Note that the survey scenarios impose that the housing bundle $\overline{\boldsymbol{q}}_i$ otherwise remains the same. For example, any adverse effects on water quality or wastewater disposal are completely mitigated upon paying Δc_{ij} each year. As shown below, in this "no sell / no sell" case the compensating variation (CV_{NN}) is simply equal to the exogenous shift in costs, i.e., $CV_{NN} = \Delta C_{ij} = \frac{\Delta c_{ij}}{r}$.

By definition of this case, a household does not sell under the baseline and sea-level rise scenarios, and so we compare the "no sell" states for both of these scenarios. The following inequality holds because utility is assumed to be strictly increasing in numeraire consumption, and the fact that each survey scenario imposes an increase in cost. The first inequality expresses that a household's initial utility from not selling and staying in their home, is greater than their utility from remaining in the same housing bundle, but then incurring additional costs equal to ΔC_{ij}.

$$v\left(Y_i - C_i, \bar{h}(\overline{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right) > v\left(Y_i - C_i - \Delta C_{ij}, \bar{h}(\overline{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right)$$

We implicitly define CV_{NN} in this case as:

$$v\left(Y_i - C_i, \bar{h}(\overline{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right) = v\left(Y_i - C_i - \Delta C_{ij} + CV_{NN}, \bar{h}(\overline{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right)$$

Plugging in the assumed functional form and parameters from the empirical model (equations (3) and (4)), allows us to explicitly solve for CV_{NN} as:

$$CV_{NN} = \Delta C_{ij} = \frac{\Delta c_{ij}}{\beta_1 / \beta_2} \qquad \text{(C1)}$$

This is the welfare loss only among those who do not sell in the baseline and sea-level rise scenarios. We next solve for the corresponding compensating variation (CV) for the other three cases.

Case 2: Does not sell in baseline, but does sell in response to increased costs.

Some respondents will optimally decide to sell when faced with Δc_{ij}, which essentially gives them an opportunity to minimize their loss by moving to a new home. Consider the case where the respondent is not initially going to sell, but decides to sell after being faced with having to pay more for the provision of water and wastewater disposal. By definition of this case, we compare the "no sell" and "sell" states across the baseline and sea-level rise scenarios, respectively. The inequality below presumes that households were better off in the baseline, compared to the posited survey scenario.

$$v\left(Y_i - C_i, \bar{h}(\bar{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right) > v\left(Y_i + \bar{P}_i + \Delta\bar{P}_{ij}, \bar{h} = 0\right)$$

In this "no sell" / "sell" case, some amount of compensating variation for individuals that sell their home (CV_{NS}) is required to get the respondent back to the initial utility level, because now they no longer benefit from the services provided by their initial housing bundle (i.e., $\bar{h} = 0$). We can implicitly define CV in this "no sell / sell" case as:

$$v\left(Y_i - C_i, \bar{h}(\bar{\boldsymbol{q}}_i, \boldsymbol{x}_i)\right) = v\left(Y_i + \bar{P}_i + \Delta\bar{P}_{ij} + CV_{NS}, \bar{h} = 0\right)$$

Given our assumed linear-in-parameters functional form from equation (3), we can then solve for CV_{NS} as follows:

$$\alpha_N + \gamma(Y_i - C_i) + \bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta} = \alpha_S + \gamma\left(Y_i + \bar{P}_i + \Delta\bar{P}_{ij} + CV_{NS}\right)$$

$$\alpha_N + \gamma(Y_i - C_i) + \bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta} = \alpha_S + \gamma\left(Y_i + \bar{P}_i + \Delta\bar{P}_{ij}\right) + \gamma CV_{NS}$$

$$\gamma CV_{NS} = \alpha_N + \gamma(Y_i - C_i) + \bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta} - \left(\alpha_S + \gamma\left(Y_i + \bar{P}_i + \Delta\bar{P}_{ij}\right)\right)$$

$$\gamma CV_{NS} = \alpha_N - \alpha_S - \gamma C_i + \bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta} - \gamma\left(\bar{P}_i + \Delta\bar{P}_{ij}\right)$$

$$\gamma CV_{NS} = \alpha_N - \alpha_S + \bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta} - \gamma\left(C_i + \bar{P}_i + \Delta\bar{P}_{ij}\right)$$

$$CV_{NS} = \frac{-(\alpha_S - \alpha_N) + \bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta}}{\gamma} - \left(\frac{c_i}{r} + \bar{P}_i + \Delta\bar{P}_{ij}\right)$$

The intuition is that for those who optimally decide to sell (but would not in the baseline), their welfare loss is the monetized value of the net loss in utility due to having to give up their current home (first term in the above equation), but this is partially offset by the present value of the savings from not having to incur baseline water and wastewater costs, plus the gain in numeraire consumption due to the proceeds from selling one's current home. Such numeraire consumption in our setting can include the purchase of a new home.

Plugging in the coefficients from the empirical model (equation (4)) illustrates that CV can be estimated as:

$$CV_{NS} = \frac{-(\beta_0+\bar{q}_i\boldsymbol{\beta_3}+x_i\boldsymbol{\beta_4})}{\beta_1} - \left(\frac{c_i}{\beta_1/\beta_2} + \bar{P}_i + \Delta\bar{P}_{ij}\right) \tag{C2}$$

Case 3: Does sell in baseline, and does sell in response to increased costs.

Under this case, we compare the "sell" states across both the baseline and sea-level rise scenarios. The initial inequality is based on the premise that utility is greater in the baseline, compared to a sea-level rise scenario that imposes additional costs and lower home values.

$$v\big(Y_i + \bar{P}_i, \bar{h} = 0\,\big) > v\big(Y_i + \bar{P}_i + \Delta\bar{P}_{ij}, \bar{h} = 0\,\big)$$

We implicitly define the CV under this "sell / sell" situation (CV_{SS}) as:

$$v\big(Y_i + \bar{P}_i, \bar{h} = 0\,\big) = v\big(Y_i + \bar{P}_i + \Delta\bar{P}_{ij} + CV_{SS}, \bar{h} = 0\,\big)$$

It can easily be seen that for this equality to hold we must have:

$$CV_{SS} = -\Delta\bar{P}_{ij}. \tag{C3}$$

In our framework, it is only in this "sell/sell" case that the change in price equals the non-marginal change in welfare.

Case 4: Does sell in baseline, but does not sell in response to increased costs.

Under this case, we compare the "sell" and "no sell" states across the baseline and sea-level rise scenarios, respectively. The baseline utility is defined as $v\big(Y_i + \bar{P}_i, \bar{h} = 0\big)$. In this case, an increase in water and wastewater costs alone would make a household even more prone to sell their home, but the corresponding decrease in the market price of their home $\Delta\bar{P}_{ij}$ may make a household better off by not selling. More formally, this case can be expressed by the below inequalities:

$$v\big(Y_i + \bar{P}_i, \bar{h} = 0\,\big) > v\big(Y_i - C_i - \Delta C_{ij}, \bar{h}(\bar{\boldsymbol{q}}_i, \boldsymbol{x}_i)\,\big) > v\big(Y_i + \bar{P}_i + \Delta\bar{P}_{ij}, \bar{h} = 0\,\big)$$

The latter inequality and comparison of the first and third terms holds because baseline utility is higher compared to the posited survey scenario that imposes increased costs and a lower home value. The third term represents utility if a household would still decide to sell in the posited survey scenario. But by definition of this "sell / no sell" case, a household can minimize their loss by opting to not sell and stay at their current home, as reflected by the middle utility term. We therefore focus on the leftmost inequality and comparison of the first and second terms when implicitly defining compensating variation (CV_{SN}). In this case, CV_{SN} is implicitly defined as:

$$v\big(Y_i + \bar{P}_i, \bar{h} = 0\big) = v\big(Y_i - C_i - \Delta C_{ij} + CV_{SN}, \bar{h}(\bar{\boldsymbol{q}}_i, \boldsymbol{x}_i)\,\big)$$

Assuming the same linear-in-parameters functional form based on equation (3), and then some further simplification, allows us to explicitly define CV_{SN} as follows:

$$\alpha_S + \gamma(Y_i + \bar{P}_i) = \alpha_N + \gamma\big(Y_i - C_i - \Delta C_{ij} + CV_{SN}\big) + \bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta}$$

$$\alpha_S + \gamma\bar{P}_i = \alpha_N - \gamma\big(C_i + \Delta C_{ij}\big) + \gamma CV_{SN} + \bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta}$$

$$\alpha_S - \alpha_N + \gamma\bar{P}_i + \gamma\big(C_i + \Delta C_{ij}\big) - (\bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta}) = \gamma CV_{SN}$$

$$CV_{SN} = \bar{P}_i + \big(C_i + \Delta C_{ij}\big) + \frac{\alpha_S - \alpha_N - (\bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta})}{\gamma}$$

$$CV_{SN} = \bar{P}_i + \frac{c_i + \Delta c_{ij}}{r} + \frac{\alpha_S - \alpha_N - (\bar{\boldsymbol{q}}_i\boldsymbol{\varphi} + \boldsymbol{x}_i\boldsymbol{\theta})}{\gamma}$$

The intuition is that the welfare loss in this case is the loss in numeraire consumption because the household is no longer selling their current home (first term in the above equation), plus the present value of the additional costs for potable water and wastewater services one must now incur (second term). This loss is partially offset, however, by the monetized value of the utility differential from getting to continue to experience the housing services derived from the current home (third term).

Plugging in the coefficients from the empirical model (equation (4)) illustrates that CV can be estimated as:

$$CV_{SN} = \bar{P}_i + \frac{c_i + \Delta c_{ij}}{\beta_1/\beta_2} + \frac{\beta_0 + \bar{\boldsymbol{q}}_i\boldsymbol{\beta_3} + \boldsymbol{x}_i\boldsymbol{\beta_4}}{\beta_1} \qquad \text{(C4)}$$