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Motorists' willingness to drive through flooded roads: Evidence from a stated preference experiment

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ABSTRACT

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Abstract

We conduct a stated-preference choice experiment to reveal motorists' driving-related behavioral responses to different types of signs indicating that the road is flooded and travel costs associated with avoidance of the flooded road. We use three flood-indicating visualization treatments and control group to identify the effects of particular road signs and identify associations between drivers' behavior and their demographic characteristics and the cost (time) of taking an alternate route. Using responses from 714 adult participants, we estimate willingness to drive additional minutes to avoid flooded roads using a random utility framework. Our results suggest that individuals are more likely to avoid flooded roads when shown flood-indicating road signs that do not indicate the exact depth of the water and signs that indicate that the water is relatively deep (more than 12 inches). We further find that individuals tend to persist in their initial choices. They often make risky choices when high risk-indicating information is presented at the beginning of the decision-making process.

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JEL Codes: D12, Q58, R41, R42, R48, R49

Research Highlights:

-Motor vehicle driving on flooded roads is one of the major causes of flood related deaths.
-Despite the government initiatives, such death has been rising over the last few decades.
-Data from a stated preference experiment has been used to understand motorists' behavioral response to visualizing flood indicating road signs.
-The data suggests that motorists respond in desired direction to flood indicating sign that do not convey explicit level of flood risk.
-In case of road signs explicitly indicate water depth, motorists avoid flooded roads only if the water depth is high enough that exceed certain threshold (>12 inches).

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1.Introduction

Flooding is one of the world's most pervasive and destructive natural hazards. Few regions are unaffected by flood events, and, on a global scale, incidents of flooding outnumber all other natural hazards and have been increasing over the past three decades (Berz et al., 2001). Consequently, the economic costs of flooding, arising from damage to human health, property, and assets and from inhibited travel (Grothmann and Ruesswig, 2006; Hallenbeck et al., 2014), are almost unmatched by costs of other hazardous events and have been rising sharply (Berz et al., 2001; Grothmann and Ruesswig, 2006; Ashley and Ashley, 2008). More concerning is the fact that flooding is one of the most common causes of death due to natural hazards (Ashley and Ashley, 2008; Kellar and Schmidlin, 2012; Drobot et al., 2007; Pearson and Hamilton, 2014) and is cited as the most common reason for drowning-related deaths worldwide (Ashley and Ashley, 2008; Hamilton et al., 2016; Ahmed et al., 2018; Hamilton et al., 2018b). In the United States between 1959 and 2005, there was an average of 98 flood-related deaths per year, a truly significant loss of life (Ashley and Ashley, 2008).

What is particularly striking about flood-related mortality in the United States and in other parts of the world, such as Australia and Greece, is the extent to which motor vehicles are involved in flood deaths (Ashley and Ashley, 2008; Diakakis and Deligiannakis, 2013; Haynes et al., 2017). For instance, Ashley and Ashley (2008) found that more than 60% of flood-related deaths in the United States between 1995 and 2005 occurred in motor vehicles. Kellar and Schmidlin (2012) revealed that motor-vehicle-related drownings in floods have been increasing, rising from an average of 55.5 in 2005 to an average of 80 per year in the following decade. The increase in deaths occurred despite establishment of the National Weather Service's "Turn Around, Don't Drown" program in the mid-2000s (Becker et al., 2015). Therefore, developing and testing a mechanism that can prevent motorists from driving through flood waters and therefore reduce flood-related mortality is urgently needed. First, however, we must improve our understanding of factors that motivate motorists to risk their lives by driving through flood waters. We conduct a stated-preference choice experiment to reveal motorists' driving-related behavioral responses to different kinds of road signs warning them about flooding and travel costs associated with avoiding flooded roads. We also analyze associations between participants' driving behaviors, their demographic characteristics, and the cost in terms of time of choosing an alternate route rather than driving over a flooded road. We account for the time difference in the current route and the alternate route that would take to reach destination in the motorists' decision-making as the value of travel time savings is identified a critical parameter in transportation literature (Hensher, 2001; Wardman, 1998). In addition to assessing the efficacy of the road signs in influencing motorists to avoiding flood waters, we use a random-utility model framework to estimate individuals' willingness to drive additional minutes to avoid the floodwater.

Various research papers have sought to identify the reasons behind drivers' voluntary engagement in this dangerous and largely avoidable behavior (Drobot et al., 2007; Pearson and Hamilton, 2014; Becker et al., 2015; Hamilton et al., 2016; Hamilton et al., 2018b). Ahmed et al. (2018), in a systematic review of 24 studies of the act of driving into flood waters, summarizes the current understanding of how people make this decision. The literature on this topic to date has identified seven factors that collectively impact decision-making on such issues: individual preferences, demographic characteristics, environmental views, situational and social factors, their purpose for entering flood waters, and flood-risk indicators (Ahmed et al., 2018). The literature also suggests that individuals' decisions to drive into or avoid flood waters are motivated by their perceptions of the risk and awareness of flood threats.

Ahmed et al.'s (2018) review also pointed to an important gap in our knowledge: the relative impacts of such factors on the decision to drive into flood waters. There is an opportunity, therefore, to contribute to the current literature and to inform policy by determining which elements of the decision-making process are the most significant in motivating motorists to engage in risky, flood-related driving behavior.

Prior research on risky driving associated with flood waters has emphasized the extent to which the decision to enter flood water varies with demographic factors such as age, gender, and geographic location (Ashley and Ashley, 2008; Drobot et al., 2007; Kellar and Schmidlin, 2012; Becker et al., 2015; Haynes et al., 2017; Hamilton et al., 2018a; Hamilton et al., 2018b; Ahmed et al., 2018). Additionally, recent studies have emphasized the importance of conveying proper flood risk information to motivate safe behavior, including structural mechanisms such as road signs that warn of flood risks to promote safe driving (Diakakis and Deligiannakis, 2013; Becker et al., 2015; Hamilton et al., 2016; Ahmed et al., 2018). Several of these studies have found that the effectiveness of flood warnings depends on how they demonstrate the seriousness of the circumstances to drivers (Drobot et al., 2007; Ahmed et al., 2018). Hence, more information is needed about how drivers respond to various kinds of warnings such as road signs. A study integrating demographic factors and drivers' perceptions of different types of flooding-related road signs can reveal the relative extent to which these two factors affect driving behavior.

We conduct a stated-preference experiment in which motorists reveal their driving-related behaviors in response to viewing three flooding-related road signs, and we compare their subsequent driving choices to choices made by drivers in a control group who are not shown any flooding-related signs. The three visualization treatments differ in what flooding-related information is presented in the road signs – an indication of the depth of the water versus no indication of the water depth – and how the information is conveyed – water depth indicated by exact inches versus images that imply different water depths by depicting how high the water is relative to a car's exterior.

By prompting behavioral responses to each road sign, this experiment design induces participants to make decisions about what they would do if they saw the signs. Thus, the experiment can reveal whether flood-risk-related road signs affect driving behavior and, if so, how effective the different methods of conveying the flood-risk information (explicit water depth vs. water depth through images) are. Using demographic information in the systematic analysis allows us to demonstrate whether drivers engaging in risky behavior during a flood event is related solely to their demographic characteristics, solely to their perceptions of specific street signs, or a combination of both factors. Our novel approach, which integrates experimental methods with data visualization techniques, allows us to (1) determine the relative importance of demographic factors and flood risk indicators in motivating driving behavior and (2) identify how best to convey flooding-related information in road signs.

Our results suggest that motorists are more likely to avoid flooded roads when shown flood-indicating road signs that do not indicate the exact depth of the water relative to the control group where no road flooding sign is shown. In case of exact depth, on the other hand, motorists are more likely to avoid flooded roads when they are shown the signs that indicate that the water is relatively deep (more than 12 inches). We further find that individuals tend to persist in their initial choices. They often make risky choices when high risk-indicating information is presented at the beginning of the decision-making process.

2. Research Design and Procedure

We conduct a stated-preference choice experiment to elicit motorists' behavioral responses in terms of crossing certain flooded roads after seeing different types of road signs warning of flooding ahead and travel costs (time) associated with avoidance of the flooded roads. The experiment was conducted in a laboratory-type setting using adult participants in a university-organized annual event, which takes place on a certain day each year. The event attracts both students and non-students who live nearby and historically has attracted a few thousand people each year, allowing us to recruit a sufficient number of representative adult participants. Administrators recruited participants who were 18 years of age or older.

Prior to the experiment session, participants signed a consent form approved by the university's Institutional Review Board. The experiment was conducted on iPads using the program set on the SoPHIELabs platform. It required 10 to 15 minutes to complete, and participants were paid $6 as compensation at the end of the experiment, which was disclosed to them prior to participating (see Appendix A for the experiment roadmap).

The experiment presented flood-like scenarios in which participants were asked what they would have done if they had faced such flood-indicating road signs while driving. There were four between-subject treatments (Table 1) in which each participant made yes/no type choices in the given scenarios indicating whether they would continue driving the current route through flood water or would take an alternate route to avoid the flood water. Participants in the treatment groups and control group first saw a general message that portrayed the driving conditions, such as ongoing heavy rain while driving a two-wheel sedan car such as a Toyota Camry, Honda Accord, Nissan Altima, or Chevy Malibu, which could be a risky choice when the road was flooded (see appendix A). In each decision scenario, participants were given the information that, if they wanted to take an alternate route, it would take additional time determined by a random draw from 0 to 60 minutes and were shown the associated additional fuel cost.

For all of the decision settings, participants evaluated the road conditions based on a common message describing them, information regarding flooding contained on a road sign in the treatment groups, and information about the additional time and cost required to use the alternate route to reach their destination. They then chose whether to continue driving on the current route or take the alternate route to avoid the potentially risky flooded road.

Participants in the control group (T1) were shown no road signs. The road signs presented in the treatments displayed text and illustrations: (T2) Road Flooded; (T3) Road Flooded and text identifying four water depths expressed in inches; and (T4) Road Flooded and four water depths indicated by symbols of water waves next to a symbol of a car. Table 1 presents details of the treatments used, and Table 2 presents the road signs presented to participants. The four variations in the road signs in T3 and T4 were presented to the participants in a random order to attempt to account for order effects. The between-subject design allowed us to estimate differential driving-related behavior in response to the road signs. In addition, the within-treatment variation in the road signs in T3 and T4 allowed us to estimate individuals' responses to similar risk-related road signs shown in different orders. For example, motorists might, on average, decide not to continue on the flooded road when shown that the water depth is greater than 12 inches, but their responses could depend on how many other water depths they had

[3]The total cost of driving the alternate route was calculated under the assumption that a 60-minute drive in a city/suburb area would require 2.0 to 2.5 gallons of gas at a given market price of $2.40 per gallon at the time of the experiment.

already viewed. In the process of eliciting participants' behavioral responses to data visualization, we did not provide any feedback to the participants about the choice(s) they made. This ensures that our design and implementation did not have any influence on the participants' subsequent decisions when applicable.

In each decision, participants were presented with a statement of the additional time required to use the alternate route to reach the destination. The times presented were randomly drawn from a distribution of 0 to 60 minutes, and the average additional time required was 30 minutes.

After making their driving decisions, participants completed a short demographic survey before receiving their compensation. In total, 714 participants completed the experiment with 178 participants assigned to treatment groups T1 (control) and T2 and 179 participants assigned to the treatment groups T3 and T4 (Table 1). In the control group (T1) and T2, each of the participants made a single decision. Each participant in treatment groups T3 and T4, on the other hand, made four decisions comprising total 10 decisions (9 treatment (road signs) and a control group). Thus, the experiment generated 1,782 choice observations. Table 2 presents the hypotheses tested in the study. There are 9 hypotheses to be tested associated with decisions made by 9 treatment (road signs) groups and compare them with the behavior of the control group (no road sign).

3. Empirical Strategy

We use a single-bounded dichotomous-choice model to estimate motorists' behavioral responses to viewing flooding-related road signs in the experiment and the travel cost in terms of additional time required to take the alternate route as the price variable (McKean et al., 1996; Randall, 1994). Each respondent was shown flooding-related road sign j and chose whether to continue driving the current route or take the alternate route, resulting in the following discrete outcomes for road sign j:

$$D_j = \begin{cases} 0 \quad if\ Benefit < TC_i \\ 1\ if\ Benefit \geq TC_j \end{cases} \tag{1}$$

in which D = 1 indicates that the participant chose to continue driving the current route at travel cost TC_j and D = 0 indicates that the participant chose to take the alternate route and incur a greater travel cost based on the additional time needed to reach the destination. Thus, participants would choose to take the alternate route only when their benefit from it was greater than or equal to the associated cost of taking it. The probability of each outcome for individual i can be expressed as

$$\Pi_i = \Pr(Y = D) = \begin{cases} F\left(V_i(TC_j, \mathbf{X}_i, \mathbf{Z}_j)\right) \\ 1 - F\left(V_i(TC_j, \mathbf{X}_i, \mathbf{Z}_j)\right) \end{cases} \quad \text{for } D = \begin{cases} 0 \\ 1 \end{cases} \tag{2}$$

where F(·) is a cumulative distribution function, V_i is the difference in indirect utility of individual i between continuing and not continuing to drive the flooded road given the additional travel cost associated with alternate route j, X_i' represents the set of individual i's socio-economic characteristics, and Z_j is the set of treatments to which individual i is exposed.

The participant's decision is based on random utility:

$$V_i(TC_{ij}, \mathbf{X}_i, \mathbf{Z}_{ij}) = \alpha + \gamma TC_{ij} + \mathbf{X}_i'\beta + \delta \mathbf{Z}_j + \eta_i + \epsilon_{ij} \quad (3)$$

where γ, β, and δ are the parameters of interest and represent changes in utility associated with one-unit changes in travel time using the alternate route, the individual's demographic characteristics, and the type of road signs viewed, respectively. The set of treatments (Z) includes the information treatments (Road Flooded; Road Flooded plus depth in inches; Road Flooded plus number of waves indicating depth of flooding). The demographic characteristics included in X are age, highest level of education, income level, gender, frequency of driving in a week, exposure to flooding, and past decisions when facing road flooding. Finally η_i represents individual specific random effects and E_{ij} is the the idiosyncratic disturbance term that has standard logistic distribution.

Using a sample of η independent observations, the log-likelihood function for estimating the parameters of interest in equation 3 (α, γ,β,and δ) can be expressed as

$$lnL = \sum_{i=1}^{n}\{I_{D=0} \ln F\left(\alpha + \gamma TC_{ij} + X_i'\boldsymbol{\beta}_1 + \boldsymbol{\beta}_2 Z_j\right) + I_{D=1} \ln\left[1 - F(\alpha + \gamma TC_{ij} + X_i'\boldsymbol{\beta}_1 + \boldsymbol{\beta}_2 Z_j)\right\} \quad (4)$$

where $I_{(D=\{0,1\})}$ is an indicator variable representing individual i's driving decision associated with a detour time for route j in response to road sign Z_j (yes, D = 1; no, D = 0) and F(·) represents a standard logistic distribution.

4. Data and Results

Table 3 reports the summary statistics for all variables for the 714 participants and resulting 1,782 choices. Overall, participants chose to drive the flooded road in 25% of the scenarios on average. They were least likely to choose to drive the flooded road when shown the sign stating Road Flooded and a symbol of a car with no water waves in front of it (T4 1), followed by the sign that showed only Road Flooded (T2).

On average, the participants in the study were 31 years old and 31 percent were male. Participants reported driving 2.62 times per week on average. In terms of education, 51% of the participants had at least a bachelor's degree, 38% had an associate degree or some college with no degree earned, and the remaining 11% had at most a high school education. The participants' annual incomes were relatively high; 29% earned between $75,000 and $99,999 and 42% earned between $100,000 and $149,999 per year. The majority of the participants (80%) in the study identified themselves as white, 10% identified themselves as Asian, and 5% identified themselves as Black. Half (51%) of the participants had been exposed to flooding in the past and 37% had taken an alternate route when confronted with a flood road while driving.

To estimate participants' likelihood of driving through the flooded road in response to road signs conveying information about the flooding conditions, we estimate equation 4 using the mixed effect logit model (Train 1997; 1999) estimating participants specific random effects. The random effects that capture unobserved heterogeneity such as taste differences that is randomly distributed can induce correlation among the utilities of each alternative in the choice set (Hensher, 2001; Bhat, 1997; McFadden and Train, 1997; Revelt and Train, 1999).

In order to check the sensitivity of the results, we estimate equation 4 with and without the demographic characteristics as covariates in the model. We interpret, however, the coefficients from the model with explanatory variables included.

In the data matrix that was used to estimate equation 4, we stack four observations for each participant in T3 and T4 groups on top of other where each of the four corresponding road sign is represented by an indicator variable (T3-j, j=1,…4; and T4-j, j=1,…,4) that are included in Z in equation 4. Also, we account for potential the order effect in treatment groups T3 and T4 by adding dummy variables indicating the order of each of the road signs in T3 and T4 that was presented to the participants. In particular, the natural order of road sign from least to most risky road condition are as follows: <4 inches, 4-8 inches, 9-12 inches, and >12 inches (for T3) and just a car, a single wave in front of a car, 2 waves in front of a car, and 3 waves in front of a car (for T4). We included dummy variables indicating if the sequence of each road sign was shown in different order (higher order for first two signs and lower orders for the last two signs) or not with reference to the natural order indicating risk. Table 4 reports the resulting estimated logit coefficients, corresponding robust standard errors, and marginal effects (ME) that describe the change in probability of driving through the flooded road for any change in corresponding variables.

We use additional driving time required by the alternate route as a travel cost that factors into participants' driving decisions since it involves both direct (fuel) and indirect (the opportunity cost of time spent driving that potentially captures both the labor and leisure value of time) costs. As shown in Table 4, the likelihood of a motorist continuing to driving the flooded road increases with the time required for the alternate route. This is logical as it implies that motorists intend to avoid alternate routes to avoid costs associated with driving extra miles.

We next compare the results of motorists viewing the road signs warning of flooding compared to motorists who were not shown any road signs (T1). The Road Flooded sign (T2) reduced the likelihood of motorists continuing on the flooded route (by 9%) compared to no presentation of a road sign (T1) under similar conditions. The results also show that the depth of the flood water influenced drivers' decisions. The marginal effects (last column in Table 5) indicate that participants' likelihood of driving the flooded road rose 22% in response to the Road Flooded sign that indicated that the flood waters were less than 4 inches deep (T3 1) and declined 21% in response to the Road Flooded sign that indicated that the flood waters were greater than 12 inches deep (T3 4).

To examine the effectiveness of our two methods of conveying information about the depth of the flood water, we compare the results from T3 and T4 in which the signs in T3 explicitly stated the depth of the water in inches and the signs in T4 expressed water depth as one or more wave symbols depicted in front of a car symbol. The variations in depth in T3 were less than 4 inches, 4 to 8 inches, 9 to 12 inches, and greater than 12 inches. Equivalent expressions of depth in T4 were the car symbol with no wave, one wave, two wave, and three wave symbols in front of it. Higher water levels indicated greater risk to the driver in choosing to cross the flood water.

The motorists were less likely to drive the flooded road in T4 only when the road flooding information was conveyed by adding the car with no waves (T4 1) and with three waves (T4 4) to the Road Flooded sign relative to the baseline of no road sign. Thus, we find that how information conveys the depth of flood waters can have an impact on drivers' behaviors. We find that explicit statements of relatively low water levels (less than 4 inches, T3 1) increase the likelihood of motorists continuing and explicit statements of relatively high water levels (more than 12 inches, T3 4) reduce the likelihood of their driving the flooded road. Likewise, the symbol of the car with the symbol with three waves indicating that the water is relatively deep (T4 4) decreases their likelihood of driving through the flood water. More importantly, however, the participants were more cautious and less likely to drive the flooded route when the signs provided only vague information about the severity of the flooding: Road Flooded (T2) and Road Flooded plus the car symbol (T4 1).

Each of four different roads signs in treatment group T3 are intended to imply a similar flood risk to the four road signs in T4. In particular, the order of the severity of flood-indicating road signs and the expected behavioral responses to the corresponding road signs, from lowest to highest, is as follows: T3-1=T4-1; T3-2=T4=2; T3-3=T4-3; T3-4=T4-4. As a result, comparison of the corresponding pairs of coefficients in Table 4 tests whether a road sign in T3 is equally effective in inducing motorists' responses in a certain direction relative to its counterparts in T4. In other words, the equality of coefficients is tested for each pair (T3-1=T4-1; T3-2=T4=2; T3-3=T4-3; T3-4=T4-4). Table 5 shows that both types of road signs conveying a similar flood risk are equally effective at changing participants' reported behavior except when the water depth is very shallow (T3-1 and T4-1). For the latter case, T4-1 that uses just a car image to indicate the least flood risk is more effective in inducing responses to desired direction (taking an alternate route) compared to the road sign (T3-1) that conveyed a similar flood risk. In sum, motorists respond in the desired direction to both types of road signs when road signs indicate medium to high-water depth. Road sign using the just a car-image (T4-1) is more effective in generating desired outcomes compared to the road sign explicitly indicating shallow water depth (<4 inches: T3-1).

In terms of the influence of participants' demographic characteristics, the results show that male drivers and more-frequent driving are associated with continuing on the flooded roads despite the presence of the road-flooding warning signs. Age is associated with a reduced likelihood of driving the flooded road. Of particular interest is the effect of prior experience with taking an alternate route in this type of road flooding, which reduces the likelihood of driving the flooded road by 10%. Thus, motorists who have experienced taking a detour to avoid a flooded road on their daily commute in the past are less likely to drive the flooded road than motorists with no such experience.

There were four road signs that were shown to participants in T3 and T4 treatment groups at random order. We accounted for potential order effects, if any, of those road signs by including dummy variables indicating if the corresponding road sign was shown at order that is different from natural order. The results show that, for T3, altering the order in which the signs are shown from natural to random decreases (increase) the participants' likelihood of staying on the flooded route if the shallow (deep) water depth-indicating road signs are shown later (earlier) than their natural order (see Table 4). Such conclusion in case of T4 holds only for the road signs indicating two deepest flood water (T3-3 and T3-4).

Marginal rate of substitution: Willingness to drive additional minutes

Following Hanemann (1999), we estimate individuals' willingness to pay (WTP) a premium for certain characteristics when valuing environmental and environmentally friendly goods and services such as food (Li et al., 2020) and when estimating travelers' variations in required compensation (contingent value) when valuing characteristics associated with beaches (Legget et al., 2017). These valuations are estimated using the ratio of the marginal rate of substitution (MRS) of characteristic k over characteristic m, which is expressed as

$$MRS = \frac{\frac{\delta UV}{\delta x_k}}{\frac{\delta UV}{\delta x_m}}. \quad (5)$$

Since one of the explanatory variables in our model is the cost of additional minutes required to take the alternate route, the marginal willingness to avoid driving (WTAD) additional minutes associated with other attributes can be estimated using the ratio of the coefficient of the corresponding attribute to the coefficient of the additional-minutes variable. For example, WTAD for individual i in response to the road signs relative to the baseline of no road sign can be estimated as

$$WTAD_i = \frac{\delta}{\gamma} \qquad (6)$$

where δ is the coefficient associated with road sign j and γ is the coefficient associated with the additional minutes required to use the alternate route to reach the destination. The estimates in equation 6 can be interpreted as a participant's willingness to avoid the extra driving time by continuing the current route given the road conditions. A negative value indicates willingness to take the alternate route and drive the additional minutes; a positive value indicates unwillingness to spend the additional minutes. Therefore, WTAD is the number of minutes saved the driver requires as compensation for taking the alternate route due to flooding to maintain the level of welfare gained by continuing on the flooded route (the reference level).

We use equation 6 to estimate motorists' preferences for time saving (WTAD) by not driving additional minutes and hence choosing to travel the flooded road. Positive values indicate that motorists are unwilling to drive additional minutes in response to changes in corresponding characteristics, while negative values indicate that motorists are willing to drive the additional minutes. The results of this analysis are reported in Table 6. Since these measures are based on point estimates reported in Table 4, we check the robustness of the statistical significance of the results in Table 6 by constructing bias-corrected confidence intervals using bootstrapped standard errors. We use 500 iterations to construct the confidence intervals and report the results in Table 7. We once again interpret the results from the full model that includes the demographic characteristics as variables.

We find that participants were willing to drive an additional 18.47 minutes to avoid flooded roads in response to the Road Flooded (T2) sign (Table 6). However, in response to the Road Flooded sign with information about the water being less than 4 inches deep (T3 1), they preferred to remain on the flooded route and save the equivalent of 43.37 minutes. They were much more cautious in response to the Road Flooded sign stating that the water was more than 12 inches deep (T3 4) and were willing to drive approximately 40.63 additional minutes to avoid the risk. In response to road signs showing Road Flooded plus the car symbol with no wave symbol (T4 1, equivalent to T3 1) and with three wave symbols (T4 4, equivalent to T3 4), participants were willing to drive an additional 27.13 minutes and 35.55 minutes, respectively, to avoid the corresponding flooded road.

The results show some differences associated with participants' demographic characteristics. A one-year increase in age leads to a 0.87 minute increase in willingness to drive (WTD) additional minutes to avoid the flooded road. Extrapolating from this estimate, this suggests that a 50-year-old motorist would be willing to drive 16.4 minutes more than a 30-year-old motorist to avoid a flooded road. Experience with road flooding also affected WTD. Participants who have past experience taking an alternate route to avoid flooding and view a flood warning sign are willing to drive approximately 20 (19.91) minutes more than participants without such experience.

The objective of the study is to identify the road sign(s) or the style of the road sign(s) that induce motorists to avoid risky driving on flooded roads so that associated damages of lives and livelihoods can be averted. An important policy implication of our findings is that the road sign to use for achieving the desirable outcome depends on the type of rood flooding. If the desired outcome is to induce motorists to avoid flooded roads even with as shallow as 4 inches of water, use of road sign without explicit water depth might be more effective. As the flood water level rises, it is always desirable that motorists avoid flooded road and avert damages to lives and/or livelihoods that are more likely to occur. Though using both explicit statement of water depth and image indicating deep water on the road are effective, the former generates a higher likelihood of desired outcome. Therefore, applying evidence-based policy on road sign might avert damages that are associated with driving motor vehicles on flooded roads and save lives and livelihoods.

5. Conclusion

Floods are highly destructive natural disasters that have severe economic consequences in terms of damage to property and assets, inhibited travel, and significant losses of human life. Over the past three decades, the number of flooding events and their severity have increased significantly. Flooding is one of the most common causes of death due to natural hazards, and a substantial number of the deaths occur while driving. Unfortunately, the frequency of driving-related deaths has been gradually rising over time despite establishment of the National Weather Service's "Turn Around, Don't Drown" program in the mid-2000s (Becker et al., 2015). These trends to make clear that we need a better understanding of why individuals choose to drive into flood waters despite the significant risk to their health and survival and programs aimed to make them aware of the risk.

We conducted a stated-preference choice experiment to reveal motorists' driving-related behavioral responses to road signs indicating road flooding ahead by presenting three types of warning messages and comparing their choice to drive the flooded road anyway or take a longer alternate route to choices made by participants who viewed no road signs. By using two road sign treatments that differed in how the severity of the flooding was communicated, we identified thresholds of depth of the water that induced participants to avoid driving the flooded road. Our results indicate that participants are less likely to continue down a flooded road when shown either a simple sign stating Road Flooded (no information about the severity of the flooding) and when shown a sign stating Road Flooded and displaying information indicating that the flood water is relatively deep at greater than 12 inches.

We find that they are more likely to remain on the flooded route when shown a sign stating Road Flooded and displaying information indicating that the flood water is shallow at less than 4 inches. Drivers avoid the flooded road and take the alternate route when shown a simple Road Flooded sign and when shown a sign stating Road Flooded and showing the car symbol with no wave symbols (no information on depth) and the car symbol with three wave symbols indicating deep water. The significance of the responses to the simple Road Flooded sign and to the sign stating Road Flooded and displaying only a car symbol suggests that drivers will tend to be more cautious when warned by signs that do not provide information about the severity of the flooding and therefore of the risk they face in choosing to drive through the flood water.

In terms of demographic characteristics, we find that older drivers report that they are less likely to drive through flood waters than younger drivers and that experience with having to take a detour around a flooded section of road is associated with a greater willingness to take the additional time needed for the alternate route to avoid flooding-related risk. The results also suggest that the order in which drivers are confronted with warning signs about flooding can affect their decisions because they tend to persist in making the same choice in subsequent decisions despite changes in the severity of the risk.

The findings from this study have significant policy implications for efforts to induce motorists to avoid flooded roads and other flood waters. We find that the most effective signs do not provide information about the depth of the water (and severity of the risk) unless the flood water is quite deep. When the flood water is deep (more than 12 inches in this study), signs that explicitly inform drivers of the severity of the flooding convince many drivers to avoid the flooded road and take the alternate route despite the time cost required to do so.

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Table 1: Experimental design and road signage

	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)	Treatment 4 (T4)
	No flood-related road signage		 (T3-1)  (T3-2)  (T3-3)  (T3-4)	 (T4-1)  (T4-2)  (T4-3)  (T4-4)
# of participants	179	179	178	178
# of observations	179	179	712	712

Notes: a: number of observations in Treatment groups T3 and T4 are different from the number of participants as each participant in those groups made four decisions associated with four different road signs.

Table 2: Hypotheses tested

Hypotheses	Results
H_0: Motorists are equally likely to drive on a road with flood-related road signs and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and without any flood-related road sign.	Reject H_0 $p \leq 0.05$
H_0: Motorists are equally likely to drive on a road with flood-related road signs and showing <4 inches of water and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and showing less than 4 inches of water and without any flood-related road sign.	Reject H_0 $p \leq 0.01$
H_0: Motorists are equally likely to drive on a road with flood-related road signs and showing 4 to 8 inches of water and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and showing 4 to 8 inches of water and without any flood-related road sign.	Fail to reject H_0 $p > 0.1$
H_0: Motorists are equally likely to drive on a road with flood-related road signs and showing 9 to 12 inches of water and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and showing 9 to 12 inches of water and without any flood-related road sign.	Fail to reject H_0 $p > 0.1$
H_0: Motorists are equally likely to drive on a road with flood-related road signs and showing greater than 12 inches of water and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and showing greater than 12 inches of water and without any flood-related road sign.	Reject H_0 $p \leq 0.05$
H_0: Motorists are equally likely to drive on a road with flood-related road signs and showing a car and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and showing a car and without any flood-related road sign.	Reject H_0 $p \leq 0.1$
H_0: Motorists are equally likely to drive on a road with flood-related road signs and showing a single water wave under a car and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and showing a single water wave under a car and without any flood-related road sign.	Fail to reject H_0 $p > 0.1$
H_0: Motorists are equally likely to drive on a road with flood-related road signs and showing two water waves under a car and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and showing two water waves under a car and without any flood-related road sign.	Fail to reject H_0 $p > 0.1$
H_0: Motorists are equally likely to drive on a road with flood-related road signs and showing three water waves under a car and without any flood-related road sign. H_1: Motorists are not equally likely to drive on a road with flood-related road signs and showing three water waves under a car and without any flood-related road sign.	Fail to reject H_0 $p > 0.1$

Table 3: Summary statistics of the key variables

Variable	Mean	Std. Dev.	Min	Max
Decision to continue (dependent variable):				
Control (No road sign control)	0.28	0.45	0	1
T2 (Only road flooded sign)	0.20	0.40	0	1
T3-1 (T2+ <4 inches water level)	0.29	0.45	0	1
T3-2 (T2+ 4-8 inches water level)	0.29	0.46	0	1
T3-3 (T2+ 9-12 inches water level)	0.30	0.46	0	1
T3-4 (T2+ >12 inches water level)	0.33	0.47	0	1
T4-1 (T2+ just car)	0.15	0.36	0	1
T4-2 (T2+ single wave of water under car)	0.25	0.44	0	1
T4-3 (T2+ two waves of water under car)	0.29	0.46	0	1
T4-4 (T2+ >2 waves of water under car)	0.23	0.42	0	1
Additional Time in alternate route (minutes)	30.31	17.67	0	60
Driving frequency (week)	2.62	1.47	0	4
Age (years)	31.15	15.03	18	77
Sex (1=male)	0.37	0.48	0	1
Education level:				
Less than high school	0.004	0.06	0	1
High school	0.11	0.31	0	1
Associate and Some college, no degree	0.38	0.49	0	1
Bachelor degree	0.28	0.45	0	1
Graduate/professional degree	0.23	0.42	0	1
Income level:				
Less than 25,000	0.16	0.36	0	1
25,000-49,999	0.13	0.34	0	1
50,000-74,999	0.13	0.34	0	1
75,000-99,999	0.16	0.37	0	1
100,000-149,999	0.20	0.40	0	1
150,000-199,999	0.11	0.32	0	1
200,000-249,999	0.06	0.24	0	1
250,000 and above	0.05	0.22	0	1
White (1=yes; 0=no)	0.80	0.40	0	1
Black (1=yes; 0=no)	0.05	0.23	0	1
Asian (1=yes; 0=no)	0.10	0.30	0	1
Flood exposure (1=yes; 0=no)	0.51	0.50	0	1
Generally take detour (1=yes; 0=no)	0.37	0.48	0	1
N	714			

Table 4: Logit estimation of decision to drive through the flooded road

	Without demographics			With demographics		
Variables	Coef.	Std. Err.	ME	Coef.	Std. Err.	ME
Time in alternate route	0.04***	0.00	0.01	0.04***	0.00	0.01
Treatments:						
Only road flooded (T2)	-0.64*	0.34	-0.08	-0.71**	0.26	-0.09
T3-1 (<4 inches)	1.73***	0.43	0.23	1.67***	0.34	0.22
T3-2 (4–8 inches)	0.37	0.39	0.05	0.35	0.30	0.05
T3-3 (9–12 inches)	-0.30	0.40	-0.04	-0.37	0.40	-0.05
T3-4 (>12inches)	-1.57**	0.66	-0.21	-1.56**	0.60	-0.21
T4-1 (just car)	-1.02*	0.54	-0.14	-1.04*	0.45	-0.14
T4-2 (single wave +car)	-0.18	0.39	-0.02	-0.24	0.29	-0.03
T4-3 (double-wave +car)	-0.29	0.39	-0.04	-0.34	0.29	-0.04
T4-4 (>2 waves +car)	-1.31*	0.70	-0.17	-1.37**	0.56	-0.18
Order of road signs in T3:						
<4 inches in 2-4[a]	-2.42***	0.47	-0.32	-2.43***	0.38	-0.32
4–8 inches in 3–4[b]	-0.31	0.42	-0.04	-0.39	0.35	-0.05
9–12 inches in 1–2[c]	0.87**	0.43	0.12	0.89**	0.36	0.12
>12 inches in 1–3[d]	2.33***	0.66	0.31	2.24***	0.61	0.30
Order of road signs in T4:						
No wave in 2–4[a]	-0.00	0.56	-0.01	-0.02	0.48	-0.00
1 wave in 3–4[b]	-0.02	0.45	-0.01	-0.04	0.35	-0.01
2 waves in 1–2[c]	0.85**	0.44	0.11	0.88**	0.34	0.12
3 waves in 1–3[d]	1.14*	0.70	0.15	1.17*	0.57	0.15
Demographic variables:						
Driving frequency				0.11*	0.04	0.01
Age (year)				-0.03***	0.01	0.00
Sex (1=male)				0.39**	0.12	0.05
Education				0.04	0.08	0.00
Income				-0.01	0.03	0.00
White				0.37	0.27	0.056
Black				0.72	0.35	0.10
Asian				0.46	0.33	0.06
Flood exposure (1=Yes; 0=No)				0.15	0.17	0.02
Detour habit (1=Yes; 0=No)				-0.77***	0.18	-0.10
Constant	-2.56***	0.29		-2.18***	0.42	
Random effect-variance	2.10	0.44		1.83	0.40	
N		1,782			1,782	

***, **, and * indicate statistically significant at 1, 5, and 10 percent respectively.
a: the order of this sign was from 2 to 4; b: the order of this sign was between 3 and 4; c: the order of this sign was between 1 and 2; d: the order of this sign was from 1 to 3.

Table 5: Testing the equality of coefficients of treatment groups T3 and T4

Null hypothesis	Z-val.	p-val.	Decision
T3-1=T4-1	4.43	0.000	T3-1 and T4-1 do not have same effects
T3-2=T4-2	1.32	0.19	T3-2 and T4-2 do not have differential effects
T3-3=T4-3	-0.08	0.93	T3-3 and T4-3 do not have differential effects
T3-4=T4-4	-0.22	0.83	T3-4 and T4-4 do not have differential effects

Table 6: Compensating variation for driving through flooded road associated with characteristics

	Model without demographics			Model with demographics		
Variable	WTD	Upper	Lower	WTD	Upper	Lower
Treatments:						
Only road flooded (T2)	-16.54	0.94	-34.03	-18.47	-0.92	-36.02
T3-1 (<4 inches)	44.78	67.50	22.07	43.37	65.93	20.81
T3-2 (4–8 inches)	9.54	29.24	-10.16	9.09	28.70	-10.52
T3-3 (9–12 inches)	-7.76	12.80	-28.31	-9.70	10.77	-30.17
T3-4 (>12inches)	-40.61	-6.34	-74.87	-40.63	-6.19	-75.10
T4-1 (just car)	-26.46	118	-54.11	-27.13	0.54	-54.81
T4-2 (single wave +car)	-4.53	15.33	-24.39	-6.16	13.78	-26.10
T4-3 (double-wave +car)	-7.38	12.23	-69.98	-8.72	10.98	-28.43
T4-4 (>2 waves +car)	-33.91	1.93	-69.74	-35.55	0.29	-71.39
Order of road sign in T3:						
<4 inches in 2–4	-62.74	-37.09	-88.39	-63.24	-37.53	-88.94
4-8 inches in 3–4	-8.13	13. 52	-29.52	-10.11	11.33	-31.55
9–12 in 1–2	22.52	45.08	0.05	23.24	45.93	0.54
>12 in 1–3	60.27	95.35	25.20	58.25	93.46	23.04
Order of road signs in T4:						
No wave in 2–4	-0.04	28.62	-28.69	-0.51	28.15	-29.17
1 wave in 3–4	-0.64	22.19	-23.47	1.12	23.95	-21.70
2 waves in 1–2	22.11	44.98	0.76	22.82	45.81	-0.16
>2 waves in 1–3	29.41	65.12	-6.31	30.31	65.99	-5.36
Demographic characteristics:						
Driving frequency				2.90	6.49	-0.70
Age (year)				-0.87	-0.42	-1.32
Sex (1=male)				10.24	19.80	0.68
Education				0.94	6.81	-4.93
Income				-0.23	2.10	-2.56
White				9.52	30.13	-11.09
Black				18.71	46.98	-9.56
Asian				11.82	36.34	-12.70
Flood exposure (1=Yes; 0=No)				3.90	17.07	-9.27
Detour habit (1=Yes; 0=No)				-19.91	-5.37	-34.45

Table 7: Bootstrapped standard errors and bias-corrected confidence intervals for compensating variation										
	Excludes demographic variables					Excludes demographic variables				
Variable	WTD	Bias	Std. Err	Lower	Upper	WTD	Bias	Std. Err	Lower	Upper
Treatments:										
Only road flooded (T2)	-16.54	0.82	9.35	-0.94	35.42	-18.47	0.55	9.40	0.55	37.39
T3-1 (<4 inches)	44.78	0.65	12.84	4.38	57.51	43.37	-0.01	12.41	9.79	56.29
T3-2 (4–8 inches)	9.54	0.08	10.43	-11.38	31.22	9.09	-0.43	10.99	-13.11	28.96
T3-3 (9–12 inches)	-7.76	0.45	11.36	-38.19	8.32	-9.70	-1.12	11.21	-35.85	7.75
T3-4 (>12inches)	-40.61	-11.21	67.09	-100.11	-11.87	-40.63	-7.99	59.00	-110.42	-12.85
T4-1 (just car)	-26.46	-1.32	16.51	-62.02	2.24	-27.13	0.04	16.61	-75.38	-3.03
T4-2 (single wave +car)	-4.53	-0.74	10.16	-21.64	18.20	-6.16	-0.59	10.40	-26.30	15.62
T4-3 (double-wave +car)	-7.38	0.03	10.63	-31.11	10.15	-8.72	0.13	10.82	-38.73	8.04
T4-4 (>2 waves +car)	-33.91	-14.09	71.98	-93.49	-1.04	-35.55	-13.04	76.32	-114.05	-4.60
Order of road signs in T3:										
<4 inches in 2–4	-62.74	-0.71	13.99	-76.16	-22.61	-63.24	0.14	15.88	-85.95	-21.91
4-8 inches in 3–4	-8.13	-0.62	12.60	-27.65	23.42	-10.11	-0.46	12.84	-35.48	15.86
9–12 in 1–2	22.52	0.47	13.66	4.16	58.62	23.24	2.19	13.76	8.33	61.16
>12 in 1–3	60.27	15.12	77.02	29.48	130.48	58.25	9.80	65.94	21.89	119.77
Order of road signs in T4:										
No wave in 2–4	-0.04	-0.11	18.26	-34.21	39.30	-0.51	1.04	18.10	-32.57	40.06
1 wave in 3–4	-0.64	0.54	13.29	-36.22	18.20	1.12	-0.52	12.72	-26.23	21.85
2 waves in 1–2	22.11	0.53	11.67	3.62	51.30	22.82	-0.43	12.96	5.45	57.45
>2 waves in 1–3	29.41	11.83	75.22	-0.20	108.91	30.31	16.35	84.91	-0.75	436.69
Demographic characteristics:										
Driving frequency						2.90	0.02	1.66	-0.36	6.10
Age (year)						-0.87	0.00	0.21	-1.33	-0.50
Sex (1=male)						10.24	0.08	4.35	1.45	18.14
Education						0.94	-0.02	2.88	-5.15	6.27
Income						-0.23	0.00	1.11	-2.85	1.55
White						9.52	0.86	10.13	-7.60	33.07
Black						18.71	1.40	13.53	-5.71	46.04
Asian						11.82	0.81	12.35	-9.02	37.01
Flood exposure (1=Yes; 0=No)						3.90	-0.03	5.95	-4.89	18.41
Detour habit (1=Yes; 0=No)						-19.91	0.49	6.64	-35.92	-8.93

Note: Bootstrapped standard errors have been estimated using 500 iterations. Bias-corrected standard errors have been used to construct 95% confidence intervals.

Appendix A

Appendix A – Experiment Design Roadmap

Step 1. Experimental questions design. This step included experts' input, such as academic scholars contributing to policy related to road-signs in Delaware.

Step 2. Developing program for running the experiment. Testing in experiment-like sessions prior to the actual session.

Step 3. Design Implementation using dichotomous choice experiments. 714 Participants responded either *yes* or *no* to at least one dichotomous choice question.

a. Participants were set up with $6.

b. Participants made at least one dichotomous choice decision.

c. Participants filled out a survey (Appendix B)

Step 4. Data analysis and preparation of manuscript, outreach activities.

Driving through a flooded road can be risky. Suppose there has been heavy rain and you are driving on a road to a destination in a 2-wheel drive sedan car (such as a Toyota Camry, Honda Accord, Nissan Altima, Chevy Malibu, etc.)

If you avoid your current route, the alternate route will:

- take an additional 7 minutes compared to the travel time using the current route.
- cost approximately an additional $0.85.

What would you do to reach your destination?

- **Continue on the current route**
- **Take the alternate route**

Submit ...

Figure A1: Screenshot of the general message about road condition shown to all

Driving through a flooded road can be risky. Suppose there has been heavy rain and you are driving on a road to a destination in a 2-wheel drive sedan car (such as a Toyota Camry, Honda Accord, Nissan Altima, Chevy Malibu, etc.)

The street sign resembles the following photo.

If you avoid your current route, the alternate route will:

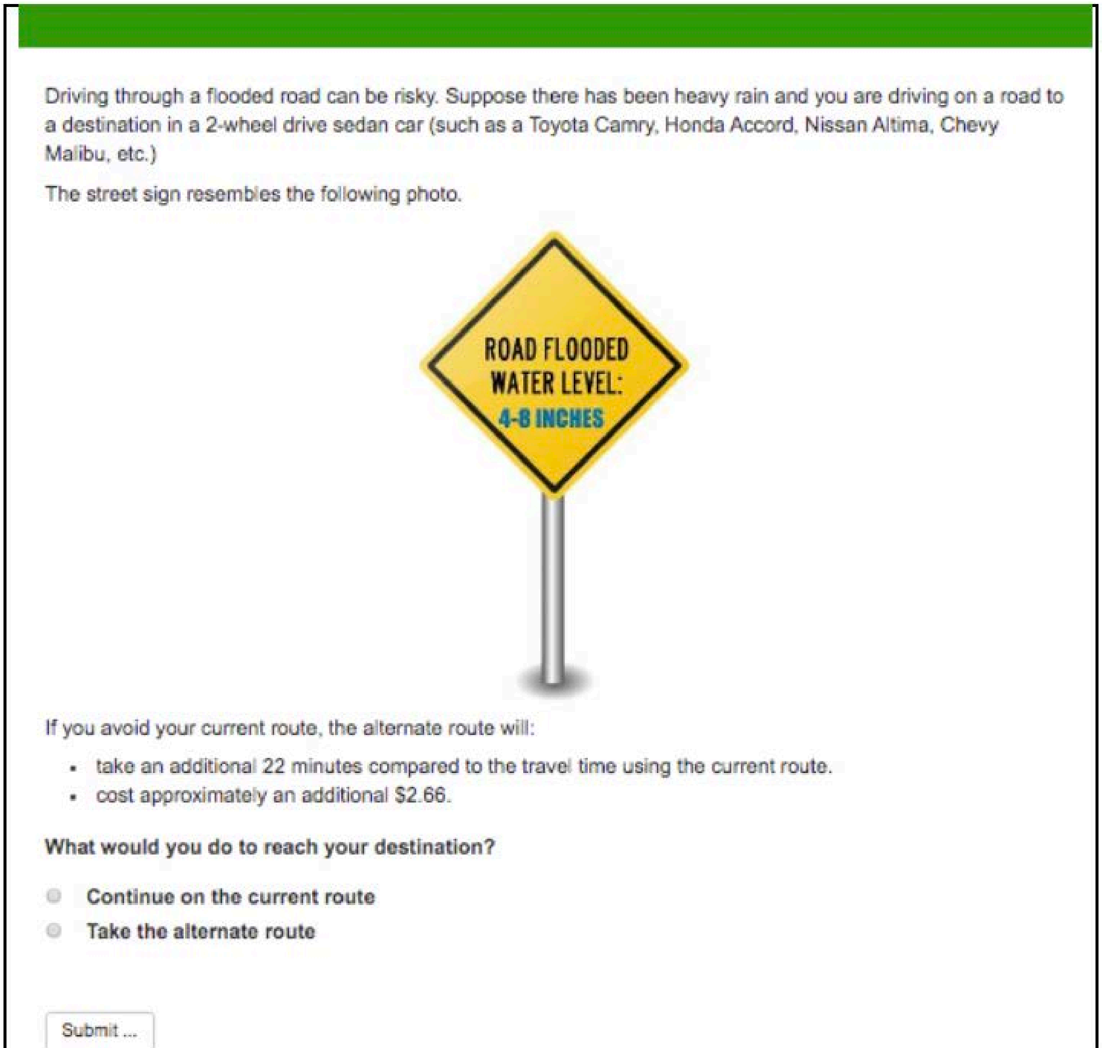
- take an additional 16 minutes compared to the travel time using the current route.
- cost approximately an additional $1.93.

What would you do to reach your destination?

- **Continue on the current route**
- **Take the alternate route**

Submit ...

Figure A2: Decision-screen of treatment group 2 (T2)


Driving through a flooded road can be risky. Suppose there has been heavy rain and you are driving on a road to a destination in a 2-wheel drive sedan car (such as a Toyota Camry, Honda Accord, Nissan Altima, Chevy Malibu, etc.)

The street sign resembles the following photo.

If you avoid your current route, the alternate route will:

- take an additional 22 minutes compared to the travel time using the current route.
- cost approximately an additional $2.66.

What would you do to reach your destination?

- **Continue on the current route**
- **Take the alternate route**

Submit ...

Figure A3: Decision-screen of the second choices for treatment group 3 (T3-2)

Driving through a flooded road can be risky. Suppose there has been heavy rain and you are driving on a road to a destination in a 2-wheel drive sedan car (such as a Toyota Camry, Honda Accord, Nissan Altima, Chevy Malibu, etc.)

The street sign resembles the following photo.

If you avoid your current route, the alternate route will:

- take an additional 3 minutes compared to the travel time using the current route.
- cost approximately an additional $0.36.

What would you do to reach your destination?

- **Continue on the current route**
- **Take the alternate route**

Submit ...

Figure A4: Decision-screen of the second choice of treatment group 4 (T4-2)

Appendix: B - ***Survey***

1. What is your age (in years):

2. What is your sex?
    - Male
    - Female

3. Are you Hispanic?
    - Yes
    - No

4. How would you identify your race?
    - White
    - Middle Eastern or Arab
    - Black
    - East Asian
    - South Asian
    - Pacific Islander
    - Native American
    - Other (please specify)

5. What is the highest level of education that you have completed?
    - Less than high school
    - High school graduate or equivalent (i.e. GED)
    - Some college, but no degree
    - Associate degree
    - Bachelor degree
    - Graduate degree or professional degree

6. Which category best describes your <u>household</u> income (before taxes) in 2018
    - Less than $25,000
    - $25,000-$49,999
    - $50,000-$74,999
    - $75,000-$99,999
    - $100,000-$149,999
    - $150,000-$199,999
    - $200,000-$249,999
    - $250,000 and above

7. How many days a week do you drive on average?
- 1 day/ week or less
- 2-3 days/week
- 4-5 days/week
- 6-7 days/week

---

8. How frequently does your daily commute route ever get flooded?
- Never
- Once/year
- Twice/year
- Once/month
- Once/week

---

9. Have you ever taken a detour due to flooding in your daily commute route?
- Yes
- No

The Department of Applied Economics and Statistics
College of Agriculture and Natural Resources
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The Department of Applied Economics and Statistics carries on an extensive and coordinated program of teaching, organized research, and public service in a wide variety of the following professional subject matter areas:

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