



Does etiology matter? Exploring attitudes towards tornado and earthquake hazards

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ARTICLE INFO

Keywords:

Induced seismicity
Techna hazard
Negative emotions
Risk perceptions
Political ideology
Oklahoma

ABSTRACT

While Oklahoma is known as one of the most tornado-prone areas in the U.S., earthquakes are a relatively new hazard for the state. To add a wrinkle to the Oklahoma hazardscape, earthquakes in Oklahoma are a techna hazard, where most geological studies suggest that the earthquakes the state is experiencing are likely a byproduct of oil and gas exploration. While we know most of the state is exposed to and feeling these earthquakes, the scientific community has little information about how individuals are understanding their earthquake exposure and how their views on earthquakes relate to other hazards in the state. This study explores the factors that shape Oklahoman's attitudes toward tornado and earthquake hazards.

Questionnaires were mailed using a stratified random household sample from 27 counties across Oklahoma during the fall of 2019. In total, 866 households responded with a response rate of 17.40%. Findings suggest that Oklahomans believe the earthquake threat is more novel than the tornado threat, and that they have slightly more dread regarding earthquakes than tornadoes on average. Furthermore, respondents who identify as more liberal are more likely to have negative emotions regarding earthquakes, but not tornadoes. Several demographic variables also predict differences in negative emotion toward earthquakes and tornadoes. While a number of demographic variables predict higher feelings of dread for tornadoes and earthquakes, ideology is not a significant predictor of level of dread or risk perception toward either hazard. These findings can help shape risk messaging across the state to encourage households to undertake hazard adjustments.

1. Introduction

Oklahoma is a US state that is exposed to a number of hazards in any given year. Most of these hazards are, on some level, predictable or seasonal. For example, in the spring and fall, Oklahoma experiences a higher risk for supercell thunderstorms that may produce straight line winds, flash flooding, lightning, and tornadoes. In particularly dry seasons, Oklahoma is prone to extensive drought and wildfires. More recently, Oklahoma has been experiencing a new hazard, earthquakes, which do not adhere to a season. Due to the novelty and lack of seasonality of earthquakes, individuals in Oklahoma may not understand this hazard in the same way that they do more historically common, predictable hazards.

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<https://doi.org/10.1016/j.ijdr.2022.103005>

Received 1 November 2021; Received in revised form 1 April 2022; Accepted 25 April 2022

Available online 29 April 2022

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The earthquake hazard in Oklahoma is largely believed by experts to be a result of human activity from the use of wastewater injection wells by the oil and gas industry [1,2]. This issue is fraught with political implications for the state, largely because the oil and gas industry is a large contributor to the local economy [3]. This industry activity, however, is likely affecting the environment by triggering earthquakes that pose a threat to lives and damage infrastructure and personal property.

When individuals encounter a hazard that they lack experience or familiarity with, they often rely on cognitive processes to help them understand that hazard. These cognitive processes include heuristics that help them manage new information and come to conclusions that align with their values, biases, and norms [4–8]. In order to overcome uncertainty about these risks, individuals may rely on heuristics such as cues from trusted elites in the form of politicians or other policy leaders to shape their own perceptions of the risk [9,10]. An example of this is the partisan divide surrounding discussions of climate change and how the associated hazards should be regulated and mitigated [11]. Other hazards with connections to human activity have been polarized as well, including issues with technology polluting the environment and the processes to both create nuclear energy and store its waste [12].

In this paper, we seek to understand how individuals understand and conceptualize tornadoes, a natural hazard, and earthquakes, which are traditionally considered natural but, in this case, are believed to be the result of human activity. To address this question, we analyze data from a survey of households across the state of Oklahoma. We first identify individuals' understanding of the hazards separately, then we examine a broader model to determine how political ideology affects risk perceptions and emotional responses (negative emotions and level of dread) toward the two hazards. Findings suggest that individuals in Oklahoma find the earthquake threat more novel than the tornado threat, and that they do have slightly more dread regarding earthquakes than tornadoes on average. Furthermore, respondents who identify as more liberal are more likely to have negative emotions regarding earthquakes, but not tornadoes. A number of demographic variables also predict differences in negative emotion toward earthquakes and tornadoes. While several demographic variables predict higher feelings of dread for tornadoes and earthquakes, ideology is not a significant predictor of level of dread or risk perception toward either hazard.

The next section of this paper examines the literature regarding attitudes toward hazards. Then, we discuss the tornado and earthquake hazards in Oklahoma. Finally, we outline the methodology and results before concluding the paper with a discussion of the findings and their implications for our understanding of attitudes associated with natural and technica hazards.

2. Literature review

2.1. Hazards and uncertainty

A hazard is a threat that can disrupt or harm individuals or society. Kaplan and Garrick [13] define risk as both the likelihood that an event (hazard) will occur and the consequences of said potential event. Risk perceptions are assessments of risk without using the tools of traditional risk assessment, such as measurement techniques [14]. How individuals understand hazards can be affected by a number of variables, including qualitative characteristics (novelty, dread, negative emotion, etc.) and benefits associated with that risk source [4,15–18], hazard exposure [19,20], demographic characteristics [21–23], and experience with a hazard [24–28], as well as other cognitive and situational variables [14,29,30].

Early studies examining risk perceptions focused heavily on differences between expert and public perceptions of technological hazards. For example, for most hazards, laypeople are more likely to estimate the consequences of risks as higher than experts [31,32]. In the United States, much of this early literature and subsequent studies focused on perceptions of the nuclear energy industry [33–40]. The research examined how the 'stigma' of having a nuclear waste repository in a state would affect the local economy or interest in vacationing in the state [34]. This line of literature has increased our understanding of individual perceptions of risks that are imposed upon them by industry or government. This imposition may make the hazard seem uncontrollable and cause a higher degree of dread, or a gut-level reaction of unease, among the population when compared to natural hazards [41–43].

Research has shown that when individuals are faced with uncertainty, they rely on heuristics or cues to help with decision making [44,45]. Heuristics are mental shortcuts that help individuals make decisions or judgments more efficiently [46]. These cognitive heuristics provide individuals with an avenue to make judgments about risks that may not resemble a careful analysis of probabilities and expected consequences, but rather an examination of past experiences, the opinions of trusted experts, or an alignment with thought leaders that they perceive to hold similar values [4,5,47].

Risk research has identified several heuristics that may influence individual risk perceptions. Among those, prior research suggests that when individuals are faced with uncertainty, they may take cues from experts or other elites to shape their perceptions and shortcut their decision-making regarding unknowns [48–50]. When considering hazards, these experts may be scientists, but public access to scientific studies is often limited. Public-facing individuals, such as the media or political figures, may be a proxy for experts when it comes to understanding risks and how they should be controlled [51,52]. This may be especially true with technological or human-induced hazards, where there is often an ideological divide regarding etiology (the cause of a hazard), how a potential hazard (i.e. sea level rise, pollution) will affect society and the economy, or support for interventions such as public policies and regulations [53]. Most individuals in the United States have low information about public policy issues and rely on heuristics to help develop opinions or make voting decisions [54,55], especially as partisan polarization increases among the populace and elites [56]. When individuals understand that their party has a different view of an issue than the "other party", then they are more likely to align their own preferences with their party's preferences [57].

For example, despite scientific consensus about human influence on climate change, the political and partisan nature of the debates surrounding climate change leads to considerable disagreement in both the general population and among politicians [58,59]. This disagreement has turned a debate about the risks associated with climate change and how to address said risks into a policy and political discussion, rather than one centered in scientific consensus and traditional risk assessment. This may also be true about other

hazards attributed to human activity, such as those hazards that are the byproduct of wastewater injection wells.

Individual ideological beliefs have also been found to have an effect on individual perceptions of how technology may affect the environment [60–64]. Slimak and Dietz [4] found that partisanship has a slight effect on environmental worldview, with Democrats more likely to adhere to a pro-ecological worldview than Republicans are. Additionally, liberals were more likely to rate the risk of technology to the environment higher than conservatives, as well as being more risk averse in regards to technology [65,66]. Lachapelle et al. [67] examined ideology as a predictor of believing experts with regards to a number of different types of risks. They found that ideology was a weak predictor for most risks in their study, but that liberal ideology was a strong predictor when trusting scientific experts about the risks associated with shale gas fracking.

Using heuristics to help understand risks, whether that heuristic is the result of hazard experience or taking cues from an expert, can lead individuals to make poor judgments about actual risk [5,44,53,68]. Individuals are more likely to overestimate or underestimate the probability of an event occurring when they rely on heuristics rather than data [42,69]. In particular, uncertainty about technological risks may lead individuals to overestimate risk and consider some technological risk with fear or a belief that it is uncontrollable, developing dread associated with regards to said event [69–71].

To understand the relationship between ideology, risk perceptions, and emotional responses to hazards, we examine how individuals view a common natural hazard (tornadoes) and an emerging hazard linked to human activity (earthquakes). The next section of this paper discusses the hazard context in Oklahoma and what may cause individuals in the state view the risks associated with tornadoes and earthquakes differently.

2.2. Hazards in Oklahoma

The State of Oklahoma has a lengthy history with a number of hazards, including wildfire, drought, flood, high winds, hail, lightning, ice storms, and tornadoes. Earthquakes are an emerging hazard in Oklahoma and therefore come with some level of uncertainty. While earthquakes are usually considered a natural hazard in most contexts, experts generally agree that earthquakes in Oklahoma are caused by the use of waste-water injection wells in oil and gas exploration [72–78]. This makes this hazard, which experts have traditionally defined as “natural”, a consequence of human activity, referred to as a techn hazard or a techn event [79].

While limited, a handful of prior studies have explored how individuals perceive the earthquake risk in Oklahoma based on prior research. When considering how experience with the earthquakes shapes public perception, researchers have found that experience with earthquakes increases risk perceptions [80], opposition to oil and gas [81], and anxiety [82] across the state. Researchers have also explored what leads households to undertake mitigation measures or support government intervention to reduce risks. Choi and Wehde [83] found that elevated risk perceptions were an important predictor for mitigation measures, and Wu et al. [84] found that individuals in Oklahoma are most likely to adopt earthquake hazard adjustments that they believe will also reduce the risks associated with other hazards. Some research hints that etiology matters when considering interventions. Residents have mixed views on whether state and local agencies can mitigate the earthquake hazard in the state, or whether these agencies are willing to do so [85]. Researchers have also found a connection between believing earthquakes were the result of human activity and support for state interventions to reduce earthquake risk [83].

Other research has explored how identity, ideology, and party affiliation shape perceptions of earthquakes in Oklahoma. In a series of interviews with Oklahoman residents, Drummond and Grubert [3] noted the prevalence of narratives regarding the history of oil and gas exploration in Oklahoma and economic ties to that industry across the state. They found a fundamental tension between concern about earthquakes and long held ties to oil and gas. Likewise, they found that private fears about oil and gas may not be shared in public venues due to concerns about the social acceptability of such a belief. In a series of interviews across the states of Oklahoma and Colorado, Campbell et al. [81] also found that issues such as how rural Oklahomans tied their identity to the extraction industry (and a conservative ideology) influenced support for oil and gas exploration in Oklahoma. Using two statewide surveys, Gray et al. [63] found that party affiliation and ideology correlated with perceptions of risk, with respondents that identified as Republicans and more conservative rating risk from earthquakes as lower than their more liberal counterparts. They also found that Republicans and more conservative respondents were more likely to suggest that the earthquakes were of natural origin than their more liberal counterparts. Additional research in Oklahoma found that ideology indirectly affects risk perception regarding earthquakes [86].

There is less research regarding individual perceptions of and preparedness for tornadoes, but there is evidence that individuals from Great Plains states (TX, OK, NE, IA), which have a high occurrence of tornadoes, have a higher level of knowledge about tornado hazards than those individuals from non-Great Plains states [87]. More specifically, individuals in Oklahoma have a high level of knowledge about tornado threats and low likelihood of believing myths about tornado threats [88]. While there is little specific information about the relationship between ideology and perception of tornado hazards, Choi and Wehde [89] found that ideology is a significant predictor of trust in local and federal emergency management agencies, but it is not a significant predictor in preparedness for tornado hazards across the states that comprise “tornado alley” in the United States.

The research presented above shows that ideology is often related to risk perceptions and shapes other emotional responses to hazards, with differences found between natural and technological hazards. Gray et al. [63] specifically examined the effect of ideology on risk perception of two techn hazards in Oklahoma. They establish that there are ideological differences in risk perceptions with conservatives having, on average, lower risk perceptions for both global warming and human induced seismicity, pushing forward our understanding of risk perception regarding techn hazards. In this study, we employ a similar methodology to understand differences in emotional responses to the novel techn earthquake hazard and the more common tornado hazard in Oklahoma.

We do not know how individuals in Oklahoma perceive the new earthquake hazard in relation to the historically present tornado hazard in the state. Based on past exposure and experience, individuals in Oklahoma likely perceive tornadoes and earthquakes differently. Oklahoma is in the territory of the United States known as “tornado alley” and has a high seasonal risk of tornadoes in the

spring and fall, when weather patterns are changing from winter to summer and vice versa [90]. While the tornado risk is similar across the state, when a tornado touches down, damage is typically confined to a narrow path of less than one mile wide. Given that Oklahoma has low population levels and large swaths of rural land, many of these tornadoes do not affect lives or property. In contrast, earthquake risk is not uniform across the state. The highest earthquake risk lies around the Arbuckle Aquifer in Central and North Central Oklahoma [91]. Unlike tornadoes, however, which most often have a smaller damage footprint, earthquake shaking is often felt tens to hundreds of miles away, depending on the characteristics of the earthquake, such as magnitude, focal depth, and surrounding rock type [92].

As discussed above, the earthquake hazard in Oklahoma is largely considered by experts to be a technica hazard, or a natural hazard that is triggered by human activity [1,2]. This is widely discussed in media and by politicians in the state, particularly after an earthquake. The human activity causing the earthquakes is linked to the oil and gas industry, which is a major contributor to the economy and provides numerous jobs in the state [3]. The technological nature of the hazard may cause some individuals—primarily liberal leaning based on prior research discussed above—to have a more negative emotional response regarding the hazard than those who lean conservative. Furthermore, regulation of the oil and gas industry is a political and policy question that may lead individuals to align their positions with political elites in the state, in which case we would expect more liberal leaning individuals to have elevated negative emotions due to the potential risk to the environment.

Based on the above understanding of the factors affecting hazard attitudes, we propose the following research questions addressing a natural hazard (tornado) and a technica hazard (earthquake).

RH1: Respondents will identify earthquakes as more novel than tornadoes.

RH2: Respondents will report more negative emotion for earthquakes when compared to tornadoes.

RH3: Respondents will report higher dread for earthquakes when compared to tornadoes.

RH4: Respondents will report lower risk perceptions for earthquakes when compared to tornadoes.

RH5: Political ideology will be a significant predictor of negative emotion for earthquakes after controlling for demographic variables.

RH6: Political ideology will not be a significant predictor of negative emotion for tornadoes after controlling for demographic variables.

RH7: Political ideology will be a significant predictor of dread for earthquakes after controlling for demographic variables.

RH8: Political ideology will not be a significant predictor of dread for tornadoes after controlling for demographic variables.

RH9: Political ideology will be a significant predictor of earthquake risk perceptions after controlling for demographic variables.

RH10: Political ideology will not be a significant predictor of tornado risk perceptions after controlling for demographic variables.

We are also interested in whether the effects of political ideology are different across hazards. Thus, we test the following three hypotheses:

RH11: The magnitude of the effects of political ideology on the negative emotion of earthquakes will be larger than the magnitude of the effects of political ideology on the negative emotion for tornadoes.

RH12: The magnitude of the effects of political ideology on the dread of earthquakes will be larger than the magnitude of the effects of political ideology on the dread of tornadoes.

RH13: The magnitude of the effects of political ideology on earthquake risk perception will be larger than the magnitude of the effects of political ideology on tornado risk perception.

The following section will describe the sampling process, measurement coding, and the results of the hypothesis testing.

3. Methods

3.1. Sample

This study used a disproportionate stratified random sampling procedure to identify household samples from 27 counties in Oklahoma that are located within the earthquake hazard map [93]. This project also oversampled minority groups (non-white households). In each risk area, 480 household addresses were randomly selected from each African American, Asian, Hispanic, Native American, and White household. Therefore, in total, 7200 household addresses were randomly selected for the study. The study follows Dillman, Smyth, & Christian's [94] survey procedures. Each household was sent as many as three survey packages (waves 1, 3, and 4) and one reminder postcard (wave 2). The households also received a pre-incentive (5-dollar Amazon gift codes) in one of their survey mail packages. The mailing list was obtained from *Experian Information Solutions Inc.* using a random selection process. This list was used to match with a survey company, *Oklahoma Direct's* mailing address data. The matching results showed that 129 survey receivers had moved to other areas. Therefore, 129 addresses were removed from the original mailing list. The questionnaires were sent by *Oklahoma Direct* from August to November of 2019. In total, 866 households responded, 44 households refused, and 2179 survey packages were undeliverable. The final response rate is 17.86%

3.2. Variables

The survey instrument included 49 questions¹, largely modeled on previous surveys conducted in Oklahoma [84,95] and in California and Washington [96] with additional modules included regarding attitudinal variables, political views, and tornadoes.

The dependent variables of interest for this study include risk perceptions, novelty, negative emotions, and level of dread regarding both the tornado and earthquake hazards. In the survey, five questions ask respondents to report their hazard risk perceptions regarding potential damage to their homes or properties, injuries, job disruptions, and daily activity disruptions (1=*not at all likely* to 5=*Almost a certainty*) for each hazard. These risk perception questions were used in several other natural hazard risk studies [97–101]. To further ensure the reliability of these risk perception measures, Cronbach Alpha analyses were used to test the reliability of the risk perception variable. Based on previous studies [102,103], a variable with an alpha value greater than 0.80 is considered highly reliable. The average values of these variables were recoded as tornado risk perceptions (Cronbach's $\alpha = 0.86$) and earthquake risk perceptions (Cronbach's $\alpha = 0.93$). Next, respondents were asked to report the perceived newness or novelty (1=*old* to 5=*new*) for each hazard. Respondents were also asked to rate how much negative emotion (such as anger, fear, and disgust) they feel when thinking about tornadoes and earthquakes (1=*no negative emotion* to 5=*high negative emotion*). Finally, respondents were asked, "Is earthquake/tornado risk a risk that people have learned to live with and can think about reasonably calmly, or is it one that people have great dread for (on the level of a gut reaction)?" (1=*common* to 5=*dread*) [104]. Since these three dependent variables are generally straightforward [105,106], similar to other studies [107], these variables are measured using individual items. Our independent variable of interest is ideology (1=*strongly liberal* to 5=*strongly conservative*) [108].

The models include a number of control variables including age (year), education level (1=*Less than high school*, 2=*High school graduate*, 3=*Some college/vocational school*, 4=*College graduate*, 5=*Graduate school*), annual income level in USD (1=*Less than \$30,000*; 2=*\$30,000 to \$54,999*; 3=*\$55,000 to \$79,000*; 4=*\$80,000 to \$104,999*; 5=*\$105,000 to \$129,999*, 6=*More than \$130,000*), duration of living in the state of Oklahoma (years), female sex (1=*Female* and 0=*Male*), marital status (1=*Married* and 0=*Unmarried*), White (1=*Yes* and 0=*No*), African American (1=*Yes* and 0=*No*), Hispanic (1=*Yes* and 0=*No*), Asian (1=*Yes* and 0=*No*), and Native American (1=*Yes* and 0=*No*). Finally, respondents were asked about their knowledge level of wastewater injection awareness (1=*Not at all knowledgeable* to 5=*Very knowledgeable*) which is also included as a control variable in models examining earthquakes due to their connection with wastewater injection activities.

4. Results

Table 1 shows the central tendency measures (or percentage where appropriate) and standard deviation (S.D.) for each demographic variable. These descriptive statistics show that, while the survey response rate is 17.86%, the sample is similar to the US Census data for the state with some noticeable differences in the age group, education level, and household income. The median age of survey respondents is older than the US Census data. Survey respondents are all over the age of 18, which likely contributed to differences between the respondents and the general population. Differences in education level and household income are likely because two major Oklahoma university towns were included in the sampling area (earthquake hazard zones). In addition, while an over-sampling procedure was employed, the racial distribution is close to the US Census data. This result is due to the uneven response rate from racial groups. Therefore, a weighting system was not used when analyze the data. Other demographic characteristics such as the percentage of sex and marital status are also fairly similar to US Census data.

Paired sample t-tests were used to test RH1 to RH4 (Table 2). The test results support RH1. Respondents' median rating of novelty level for earthquakes is higher than the median rating of novelty level for tornadoes and statistically significant ($t_{(845)} = -30.23, p < .01$). As far as respondents' emotions toward these two different hazards, the results supported RH3 but not RH2. The t-test result for RH2 is significant ($t_{(848)} = 5.53, p < .01$), but Oklahomans have a stronger negative emotional reaction to tornadoes when compared to earthquakes, which contradicts RH2. As for RH3, the test result found statistically significant differences in the respondent's median levels of dread for tornadoes and earthquakes ($t_{(851)} = -6.16, p < .01$). Consistent with RH3, Oklahomans reported having more dread regarding earthquakes when compared to tornadoes. The test result also supported RH4 ($t_{(850)} = 17.80, p < .01$). Earthquake risk perception is lower than tornado risk perception.

Seemingly Unrelated Regression (SUR) analyses were used to test RH5 to RH10. SUR uses a set of linear regressions to account for cross-equation error correlations, which allows for the comparison of coefficients across models [109,110]. When accessing the significance of the differences between coefficients across regressions, Wald Chi-square statistic is used to test the independence [111, 112]. The results supported RH5. Political ideology is a significant predictor of negative emotion for earthquakes after controlling for demographic variables ($b = -0.20, p < .01$). As the respondents' reported level of conservativeness increases, the level of negative emotions regarding earthquakes declines. In other words, more conservative Oklahomans are less likely to have negative emotions toward earthquake hazards when compared with their less conservative counterparts. RH6 is also supported. The results suggest that political ideology is not a significant predictor of the level of negative emotion for tornadoes even after controlling for demographic variables ($b = -0.08, ns$). As for the level of dread toward each hazard, RH7 was not supported but RH8 was. The test results show that political ideology is not a significant predictor of earthquake dread level ($b = 0.01, ns$) or the level of dread toward tornadoes ($b = -0.00, ns$). Similar to the previous results, RH9 was not supported but RH10 was. The findings suggest political ideology is not a significant predictor of earthquake risk perception ($b = 0.00, ns$) or tornado risk perception ($b = -0.02, ns$).

¹ Since this paper only focuses on participants' attitude towards tornado and earthquake risks and its factors, not all the questions were analyzed in this paper. The survey instrument is available upon request.

Table 1
Demographic characteristics.

Demographic Variables	Survey Sample	Oklahoma Data ^a
Age (Median)	57.17 years old (S.D. = 16.82)	37 years old
Sex (Percentage)	48.3% Female	50.5% Female
	48.3% Male (SD = .50)	49.5% Male
Race Group (Percentage)	4.5% Black/African American	7.8% Black/African American
	11.0% American Indian	9.4% American Indian
	9.4% Asian American	2.4% Asian American
	8.2% Hispanic	11.1% Hispanic
Marital Status (Percentage)	62.1% White (S.D. = 1.26)	74.0% White
	34.2% Not Married	N/A
	62.0% Married (S.D. = .48)	
Education Level (Percentage)	1.4% Less than high school	88.0% High school graduate
	10.7% High school graduate	25.5% Bachelors' degree or higher
	29.4% Some College/vocational school	
	28.1% College graduate	
	27.8% Graduate school (S.D. = 1.03)	
Income Level (Percentage and Median)	15.9% Less than 30K	\$52,919 (Median)
	19.4% 30K to 54,999	
	17.6% 55K to 79,999	
	14.9% 80K to 104,999	
	7.6% 105K to 129,999	
	14.0% More than 130K (S.D. = 1.67)	

^a Data source: US Census Bureau QuickFacts Oklahoma 2019 <https://www.census.gov/quickfacts/OK>.

Table 2
Mean ratings of participants' attitudes toward tornadoes and earthquakes.

Attitude	Hazard	Mean	S.D.	Test Result
Novelty	Tornado	1.55	.03	$p < .01$,
	Earthquake	3.22	.05	$t_{(845)} = -30.23$
Negative Emotion	Tornado	2.75	.04	$p < .01$,
	Earthquake	2.50	.04	$t_{(848)} = 5.53$
Dreadfulness	Tornado	2.60	.04	$p < .01$,
	Earthquake	2.90	.04	$t_{(851)} = -6.16$
Risk Perception	Tornado	2.59	.03	$p < .01$,
	Earthquake	1.98	.03	$t_{(850)} = 17.80$

Table 3 includes the results of the Seemingly Unrelated Regression analyses. RH11 was supported, such that the effects of political ideology on negative emotions toward earthquakes in Oklahoma is larger than the effects of political ideology on negative emotions toward tornadoes in Oklahoma ($Wald \chi^2 = 6.69, p < .01$). The effect of political ideology is stronger in the earthquakes model (where the larger b absolute value is located). On the other hand, RH12 and RH13 were not supported. The effects of political ideology on the level of dreadfulness and hazard risk perceptions are not statistically different between the earthquake and tornado models ($Wald \chi^2 = 0.10, ns$; $Wald \chi^2 = 0.44, ns$).

5. Discussion and conclusions

This study explored the influence of ideology on emotional responses and risk perceptions to hazards. Study findings suggest that respondents have different emotional responses when considering tornadoes (natural hazard) and earthquakes (techna hazard) in Oklahoma. As expected, due to their more recent onset, respondents do consider the earthquake hazard in Oklahoma novel when compared to the more common tornado hazard. Emotional responses to the hazards are mixed, with higher median negative emotions toward the tornado hazard and higher median dread ratings for the earthquake hazard. While hypothesized that respondents would have higher negative emotions toward earthquakes due to their novelty and existing literature [69–71], this discrepancy may be due to both direct and indirect experiences with earthquakes and tornadoes as a state. Tornadoes are not new for Oklahomans, and their consequences are broadly understood across the state. Likewise, residents are familiar with the protective behaviors that reduce the risks associated with tornadoes. Earthquakes, in contrast, are novel, lack seasonality, have no watches or warnings issued, and people are unfamiliar with both the type of damage that may occur to infrastructure that was built to sustain winds and available protective behaviors. This higher level of uncertainty regarding earthquakes likely leads to a higher level of dread when compared to tornadoes.

With regards to negative emotional reactions, multiple tornadoes in Oklahoma history have broken wind-speed, size, and damage records. For example, the 2013 Moore tornado had wind speeds estimated at 210 mph, was 1.1 miles wide, and resulted in 24 deaths, 10 of which were children [113]. Even if respondents have not been directly affected by tornadoes, they may know individuals or have family members with direct economic or physical experience with tornadoes or are at least familiar with their history in the area. While several earthquakes have caused minor damage, fewer than five earthquakes have caused moderate to major physical damage in Oklahoma, and that damage has been in less densely populated areas.

Table 3

Seemingly unrelated regression coefficients (*b*), robust standard errors (*SE*) and Wald test for determinants of “earthquake hazard” and “tornado hazard”, negative emotion and dread.

	Negative Emotion			Dread		
	Earthquake <i>b SE</i>	Tornado <i>b SE</i>	Wald χ^2	Earthquake <i>b SE</i>	Tornado <i>b SE</i>	Wald χ^2
IVs						
Conservativeness	-.20** (.04)	-.08 (.04)	6.69**	.01 (.04)	-.00 (.04)	.10
Age	.01* (.00)	-.00 (.00)	4.50*	-.00 (.00)	.00 (.00)	1.68
Education Level	.07 (.05)	-.05 (.05)	4.89*	.07 (.04)	-.03 (.05)	3.49
Income Level	-.05 (.03)	-.02 (.03)	.37	-.02 (.03)	-.04 (.03)	0.16
OK Living Duration	-.00 (.00)	.00 (.00)	.22	-.00 (.00)	-.00 (.00)	.00
Household Size	-.00 (.02)	.01 (.02)	.10	-.01 (.02)	-.00 (.02)	.46
Female	.35** (.10)	.42** (.10)	.46	.14 (.09)	.27** (.09)	1.39
Marital Status	.09 (.11)	.02 (.11)	.30	-.13 (.10)	-.10 (.10)	.06
White	.45 (.47)	-.22 (.45)	1.96	.58 (.42)	-.71 (.41)	5.97*
African American	1.07* (.52)	.31 (.50)	1.99	.84 (.46)	-.43 (.45)	4.73*
Hispanic	.77 (.49)	.16 (.48)	1.45	.80 (.44)	-.45 (.43)	5.09*
Asian	.80 (.49)	-.20 (.46)	3.92*	.48 (.44)	-.69 (.42)	4.63*
Native American	.57 (.04)	-.21 (.47)	2.45	.88* (.44)	-.58 (.43)	7.12**
WIA	.15** (.04)			-.00 (.03)		
N	653	653		655	655	
R ²	.08	.06		.03	.04	
χ^2	72.25**	43.33**		23.44	31.24**	
Risk Perception						
	Earthquake <i>b SE</i>	Tornado <i>b SE</i>	Wald χ^2			
IVs						
Conservativeness	.00 (.03)	-.02 (.03)	.44			
Age	.01* (.00)	-.00 (.00)	8.53**			
Education Level	.04 (.04)	-.04 (.04)	.03			
Income Level	-.04 (.03)	-.01 (.02)	2.59			
OK Living Duration	-.00 (.00)	-.00 (.00)	.48			
Household Size	-.00 (.02)	.01 (.02)	.14			
Female	.17** (.07)	.14* (.07)	.10			
Marital Status	.01 (.08)	-.09 (.08)	1.20			
White	.40 (.34)	-.51 (.32)	6.49*			
African American	.68* (.38)	-.27 (.36)	5.78*			
Hispanic	.52 (.36)	-.28 (.34)	4.57*			
Asian	.82* (.36)	-.35 (.33)	9.93**			
Native American	.32 (.36)	-.54 (.34)	7.95**			
WIA	.06* (.03)					
N	655	655				
R ²	.06	.03				
χ^2	40.61**	18.71				

* Significant at 0.05 level.

**Significant at 0.01 level.

WIA=Wastewater Injection Awareness.

Risk perceptions captures respondents' expectations about damages to their property, community, and disruption of their daily lives due to hazards. Similar to negative emotions, respondents' tornado risk perception is higher than earthquake risk perception. Although the literature suggests recent hazard events could increase individual risk perceptions [114–116], the recent minor earthquakes have not produced considerable damage and might not be intense enough to boost earthquake risk perceptions across the state.

We do find some evidence in our SUR analyses that ideology influences negative emotions regarding the emerging, techna, earthquake hazard in Oklahoma. More conservative respondents in our sample were more likely to report lower levels of negative emotion in response to earthquakes than their more liberal counterparts. This is likely tied to the association of earthquakes with the oil and gas industry. Liberal individuals have long seen the oil and gas industry as a potential risk to the environment [117] and a large contributor to climate change and likely see the earthquakes as an extension of the industry's effect on the overall environment. Conservative individuals, in contrast, have been found in previous studies to be more likely to support extraction industry operations than their liberal counterparts [117,118]. On the other hand, ideology does not have a significant effect on dread or risk perceptions for earthquakes. This mixed result, while reflecting the literature, deserves further attention in future research. Interestingly, we found key differences when comparing our earthquake results to questions regarding tornadoes and political ideology. Finding no significance across the board on these research hypotheses suggests that there is a difference in the perception of earthquakes and tornadoes. Put another way, our findings suggest that earthquakes are political in a way that tornadoes are not, and that this techna event is inducing a different type of affective response in our survey respondents.

Several of the control variables in the larger model have interesting results. Female respondents are more likely to rate higher levels of negative emotion toward both earthquakes and tornadoes. This is generally in line with prior literature on risk perception, which

shows female respondents rating a higher perception of risks for many types of hazards [119,120]. They are also more likely, however, to rate a higher dread of tornadoes when compared to male respondents, but they do not rate a higher dread toward earthquakes. As noted above, this may be due to the historical damage and loss of life caused by significant tornadoes in Oklahoma's history. In previous scholarship, findings have conflicted regarding how minority groups perceive hazards. In this study, we found that African American respondents rated higher levels of negative emotion toward earthquakes than other ethnic groups, but not tornadoes. Respondents who identify as Native American do not have statistically significant differences in negative emotion toward earthquakes or tornadoes, but they do rate a higher dread emotion toward earthquakes. Asian respondents are more likely than other ethnic groups to have higher earthquake risk perceptions. Finally, while we do not have a direct measure of knowledge-level regarding the two hazards, we did ask respondents to identify their level of knowledge about wastewater injection activities. As respondent's knowledge about wastewater activities increases, they are more likely to report higher negative emotion about earthquakes, but not a higher level of dread emotion.

There are a few weaknesses with this study that should be addressed. First, we do not measure level of interest in the topic. Those who are more interested in hazards may have stronger emotions about the issues associated with said hazards [121]. Furthermore, we do not measure actual level of knowledge about either earthquakes or tornadoes, which may also influence emotional reactions to hazards. Despite these weaknesses, we believe that the results of this study add to our understanding of how society may perceive risk associated with hazards, particularly those that are triggered by human activity.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research was supported by the National Science Foundation Humans, Disasters, and the Built Environment Program under grant number 1827851. Any opinions, findings, and conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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