Title
The Effects of Uncertainty Frames in Three Science Communication Topics

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Abstract

While uncertainty is central to the nature of science, many fear negative effects of communicating uncertain science to the public, though research results about such effects are inconsistent. Therefore, we test the respective effects of four distinct uncertainty frame types (consensus, deficient, scientific, technical) on three relevant outcomes (claim belief, credibility, behavioral intention) across three science issues (climate change, GMO food labeling, farm machinery hazards). We conducted a survey experiment using a large national sample (N=2247) approximating U.S. census levels of age, education, and gender. Only the consensus uncertainty frame generated a significant pattern of small negative effects on outcome variables.

Topics: science communication, uncertainty frames, climate change, GMO food
Methods: online experiment, MANCOVA

The Effects of Uncertainty Frames in Three Science Communication Topics

Uncertainty is inherent to the very nature of science (Kuhn, 1970; Popper, 1959; Shanteau, 2000), and also even central to the methods of statistical science (Carpenter, 1995). However, public-facing science communicators often shy away from portraying the uncertainties of science. For example, journalists often avoid them by portraying scientific findings as more certain than they truly are (Brechman, Lee, & Cappella, 2009; Jensen, 2008; Retzbach & Maier, 2015), sometimes for the purpose of maximizing simplicity for lay audiences (Ebeling, 2008), and sometimes to avoid possible negative effects (Stocking, 1999).

However, the assumption of detrimental effects from portrayals of uncertainty is tenuous at best—with the experimental evidence indicating negative, positive, and null effects of portrayals of uncertainty (Miles & Frewer, 2003). But these tests have all used *very different* operationalizations of uncertainty, topics of study, and dependent variables—which renders meta-analytic inferences and practical recommendations largely impossible (AUTHOR1). Thus, it is imperative to conduct controlled experiments that can inform the relative effects of different types of uncertainty portrayals on diverse outcome variables across contexts.

This paper presents the results of just such a study—a large survey experiment (N=2,247) that tests the effects of four distinct types of uncertainty frame types (and a control condition) across three separate science issues on three attitude and behavioral intention outcome variables.

Uncertainty Frames in Science Contexts

Generally, uncertainty is "when details of situations are ambiguous, complex, unpredictable, or probabilistic; when information is unavailable or inconsistent; and when people feel insecure in their own state of knowledge or the state of knowledge in general" (Brashers, 2001, p. 478). While uncertainty is an epistemological aspect of the world, it also exists as a person's belief about the certainty of something ("internal certainty"), a person's belief about someone else's certainty ("external certainty"), and also as a feature or characteristic in communication content.

The latter – uncertainty as a message characteristic – often takes the form of descriptive or qualifying information. For example, science journalism often emphasizes incomplete information, controversies, and caveats by means of distinct *uncertainty frames* (AUTHOR2). According to Entman (1993), the process of framing is "to select some aspects of a perceived reality and make them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described" (p. 52).

Uncertainty-framed public science communication is commonplace (e.g., considering climate change alone: AUTHOR2; Antilla, 2005; Bailey, Giangola, & Boykoff, 2014; Boykoff & Boykoff, 2004; Kuha, 2009; Painter & Ashe, 2012; Zehr, 2000), and can arise from diverse causes (Stocking, 2010), including good intentions such as journalistic norms (Bennett, 1996; Boykoff & Boykoff, 2004), or malignant motives such as public disinformation (Jacques, Dunlap, & Freeman, 2008; Oreskes & Conway, 2011), and even the very nature of science itself (Stocking, 1999). These different causes lead to different expressions of uncertainty that have distinct meanings and implications. These are explicated by AUTHOR2 as four distinct types of uncertainty frames.

Types of Uncertainty Frames

Deficient uncertainty. A frame of *deficient uncertainty* emphasizes a lack of knowledge—sometimes due to a lack of research, or because that thing is fundamentally unknowable, or because the problem space has expanded (Hacking, 1975; Kuhn, 2000; Stocking

& Holstein, 1993; Zehr, 2000). While frames of deficient uncertainty are identified in news reporting on prominent science issues such as climate change (AUTHOR2; Zehr, 2000), their effects are rarely studied. The lone experiment (Kuhn, 2000) found that when a probabilistic risk estimate is portrayed as being caused by deficient uncertainty, risk perceptions are no different than the control group (no uncertainty frame).

Technical uncertainty. Most scientific claims are qualified by measurement error, modeling approximations, or imprecision from out-of-sample generalization (Broomell & Kane, 2017). Thus, science communication often consists of projected ranges, confidence intervals, and probabilities. AUTHOR2 terms such portrayals as *technical uncertainty*. Analogous conceptualizations and operationalizations used in prior diverse research are often just termed general "uncertainty" (e.g., Cabantous et al., 2011; Dieckmann, Gregory, Peters, & Hartman, 2017; Johnson & Nakayachi, 2017; Johnson & Slovic, 1998; Morton et al., 2011; Rabinovich & Morton, 2012). In the experimental literature, communicating some technical uncertainty has been associated with positive effects on some outcomes (e.g., higher trustworthiness and behavioral intentions) (Johnson & Slovic, 1995; Morton et al., 2011), though other studies find negative effects on different outcomes (e.g., lower competence perceptions; Johnson & Slovic, 1995).

Scientific uncertainty. Statements of *scientific uncertainty* emphasize that the uncertainty about a claim is a feature of the scientific process (AUTHOR2). For example, a preliminary finding may be accompanied by the statement that further corroborating research is needed (e.g., "more uncertainty" in Broomell & Kane, 2017; "evidentiary balance" in Clarke et al., 2015; "hedging" in Jensen, 2008; "high uncertainty" in Jensen et al., 2017). Experimental evidence indicates that portrayals of scientific uncertainty often result in positive responses, with some null findings—but never negative effects. For example, Jensen and colleagues (2011) found that statements emphasizing scientific uncertainty ("hedging") increased trust in cancer researchers and reduced fatalistic beliefs about cancer.

Consensus uncertainty. Uncertainty can also take the form of portrayed disagreement among relevant parties (e.g., experts, the public) or within the body of evidence itself (Aklin & Urpelainen 2014; Binder, Hillback, & Brossard, 2016; Boykoff & Boykoff, 2004; Broomell & Kane, 2017; Dieckmann, Johnson, Gregory, Mayorga, Han, & Slovic, 2017). This is identified as a frame of *consensus uncertainty* (AUTHOR2). Other terms for similar concepts appear in diverse literature (e.g., "conflict ambiguity" in Cabantous et al., 2011; Smithson, 1999; "conflicting information" in Carpenter et al., 2016). Experimental research that employs consensus uncertainty messages suggests that they negatively affect attitudinal support and credibility perceptions (AUTHOR2; Corner, Whitmarsh, & Xenias, 2012; Koehler, 2016). There is no evidence to suggest that consensus uncertainty frames have positive effects, while much evidence indicates both immediate and downstream positive effects of messages that state *low* consensus uncertainty (high consensus; e.g., van der Linden, Leiserowitz, Rosenthal, & Maibach, 2018).

Distinguishing and testing all four uncertainty frames. Despite these differences in the operationalization and (potentially) effects of these uncertainty frames, the experimental literature has rarely made conceptual distinctions between the types. Rather, most studies operationalize one type of uncertainty, term it "uncertainty," and compare that one type against a control condition. Five studies to date have directly compared the effects of different uncertainty types to each other (Binder, Hillback, & Brossard, 2016; Clarke et al., 2015; Corbett & Durfee, 2004; Kuhn, 2000; Rabinovich & Morton, 2012), but each is limited by methodological and conceptual issues, and none of them assesses all four types. For example, four of the five (excepting Clarke et al.) use small student samples (e.g., Binder et al. had fewer than 20 observations per cell), which render analyses underpowered for detecting the small effects that are typical in framing manipulations. Clarke et al. (2015) and Corbettt and Durfee (2004) both compared high uncertainty of one type against low uncertainty of another type—which disables conclusions about the effect of the manipulation of uncertainty type itself. Binder et al. (2016) and Kuhn (2000) only tested effects on one outcome variable (risk perceptions). Thus, this study explicates and compares all four types of uncertainty frames.

Responses to Uncertainty Frames

As summarized above, the research on the effects of uncertainty frames in science communication identifies three major categories of responses as outcome variables. The first is the extent to which one believes the claim (*claim belief*). In contexts where the claim is about risk or threat, this also often includes risk perceptions such as threat likelihood and threat severity (Han et al., 2007; Hovland, Janis, & Kelly, 1953). The second is an assessment of the credibility of the source (*credibility*) referred to in the science communication (Jensen & Hurley, 2012). The third is the reader's intention to engage in individual or collective behaviors supporting the message claim (*behavioral intention*) (Morton et al., 2011).

Moderators of Responses to Uncertainty Frames

In addition to direct uncertainty framing effects, Kuhn (2000), Binder et al. (2016), and Rabinovich and Morton (2012) found interaction effects with prior issue position, prior opinions about science and scientists, and ideology. Here we consider these moderators, along with the issue being discussed.

Issue contexts. Although most framing effects studies test effects in only one issue context, it is likely that effects of uncertainty frames are issue-specific because uncertainty is more tolerable about some things than about others (Afifi & Weiner, 2004). Indeed, an experiment (Jensen & Hurley, 2012) found that portrayals of consensus uncertainty about toxic sewage sludge had negative effects on credibility perceptions, but uncertainty about reintroduction of gray wolves to populated areas did not.

Prior issue position. Responses to uncertainty frames may be fertile ground for motivated reasoning and confirmation bias (Nickerson, 1998) due to the inherent ambiguity of uncertain information (Dieckmann, Gregory et al., 2017). For example, Nan and Daily (2015) found that portrayals of high consensus uncertainty regarding vaccine safety resulted in *more supportive* attitudes for individuals with a supportive prior issue position, but *less supportive* attitudes for individuals with an opposing position.

Deference to science. An individual's deference to, and trust in, science is a significant influence on responses to science communication in general (Anderson, Scheufele, Brossard, & Corley, 2012; Binder et al., 2016; Lee & Scheufele, 2006), and may also influence the effects of uncertainty portrayals (Aklin & Urpelainen, 2014).

Ideology and worldview. Political ideology and partisan identification often are important influences on individuals' opinions about science issues, and some research has found that political views moderate the effects of uncertainty frames (Broomell & Kane, 2017). However, many scholars instead favor measures that target the ideology roots underlying political opinion, such as worldview, consisting of two dimensions—one of hierarchical to egalitarian values, and one of individualist to collectivist values (e.g., Bolsen & Druckman, 2015; Dieckmann, Johnson et al., 2017; Kahan et al., 2011).

Hypotheses and Research Question

The review indicates that consensus uncertainty is the frame type with the most experimental evidence supporting causal effects. This is corroborated by the theoretical interpretation that consensus uncertainty not only portrays an absence of an identifiable answer or verdict, but *even provides evidence to the contrary* in the form of oppositional expert support.

H1a: A claim of scientific research containing a consensus uncertainty frame will correspond with lower claim belief, credibility, and behavioral intentions, compared to claims portrayed without any uncertainty frame.

While the literature does not provide an overall conclusion about whether scientific and technical uncertainty frames have clear *positive* effects on attitudinal responses, the extant evidence seems to indicate that they do not have significant *negative* effects as have been observed with consensus uncertainty.

H1b: A claim of scientific research containing a consensus uncertainty frame will correspond with lower claim belief, credibility, and behavioral intentions compared to claims containing a technical or scientific uncertainty frame.

Experimental evidence and theory suggest that *technical uncertainty* and *scientific uncertainty frames* can be associated with responses of heightened credibility perceptions, and confidence in the findings, while one focus group study found that participants rated *deficient uncertainty* as the lest preferred type for expects to have (Miles & Frewer, 2003). However, there is limited experimental and theoretical justification for specific hypotheses.

RQ1: How do individuals' responses to uncertain science (by way of claim belief, credibility, and behavioral intentions) compare across claims containing different types of uncertainty frames (four types and a control)?

We are aware of just one experimental test of the effects of uncertainty frames that compared effects across issues (Jensen & Hurley, 2012). This test found that effects vary across issues. Thus, we expect that the relative effects of different uncertainty frames will vary across issues. However, because of the nascent and exploratory nature of this research, we do not offer hypotheses regarding the pattern of differences across issues. Instead, we ask:

RQ2: How do individuals' responses to uncertainty frames compare across issue contexts?

Methods

Design

This study consisted of a between-subjects survey experiment with conditions varying by three issues (climate change, GMO food labeling, occupational hazards of operating vibrating machinery) and five uncertainty frame conditions (deficient, technical, consensus, scientific, and a control condition). Participants completed pre-test measures of general issue opinions, then were randomly assigned to one experimental condition, then viewed a corresponding stimulus (a simulated news article), and then completed post-test survey measures—all within the Qualtrics online survey platform.

Issue Contexts

In selecting the three issue contexts, our goal was to choose a range of issues that differ in their level of popularization and partisan polarization, but would also all still be comparable in their target of risk and the scientific consensus about that risk. The first selected issue, *climate change* (CC), has wide recognition and is deeply divided along American political views (Hart & Feldman, 2016; Kahan et al., 2011; Leiserowitz et al., 2019) as a consequent of ideological tenets and also through partisan politicizing of the issue.

The second issue used in this study, *labeling of genetically modified foods* (GMO), also is popularized and large segments of the population hold polarized prior opinions (Kennedy &

Funk, 2016; McFadden & Lusk, 2017). However, opinions about GMO foods are not correlated with political ideology, but rather are (positively) correlated with (lower) education, (female) gender, and (higher) perceptions that genetic engineering is unethical or immoral (Elder, Greene, & Lizotte, 2018; Lusk et al., 2004).

For a vast majority of the population, the third issue used in this study, *occupational hazards in farming associated with exposure to vibrating machinery* (VM), is not associated with strong, pre-existing, polarized attitudes, or any particular ideology. While scientists themselves are confident that extended contact with vibrating machinery (tractors, power tools, etc.) is extremely damaging to musculoskeletal health (e.g., Langer, Ebbesen, & Kordestani, 2015; Lings & Leboeuf-Yde, 2000), there is no indication that the general public has pre-existing opinions about this issue. In fact, even occupational health and safety professionals are largely unaware of the evidence regarding this hazard (Paschold & Sergeev, 2009).

Sample

Participants were recruited using Qualtrics, an online survey platform that offers a "Panels" product that assembles custom-ordered samples for survey research by selecting the participants recruited by a large assortment of other, traditional market research panels to fill desired sample quotas (e.g., education, political opinion, age). After eliminating participants who failed attention-check items, exhibited speeding or straight-lining, or did not agree to the consent form, the pilot study consisted of 622 participants, and the main study sample consisted of about 150 participants per each of the 15 conditions (n=2247). The main study recruited the sample to satisfy a 50% split of male and female, an approximated match of U.S. census proportions of educational attainment (28% high school or less; 34% some university or two-year degree; and 38% four-year degree or higher) and age (14% 18-30; 25% 31-50; 39% 51-70; 12% 71+), and a 50% split of self-identified conservatives and liberals (to ensure varied worldviews and because online opt-in samples tend to skew toward being more liberal). The main sample was 83% white.

Measures

The pilot study was used to guide preliminary scale development through analyses of reliability and dimensionality, resulting in a rewording only of the items in the measure of prior issue position on vibrating machinery hazards. In the main study, we also assessed scale reliability (using Cronbach's α) and dimensionality (using exploratory factor analysis), and these analyses guided decisions on which items to retain in each mean scale. EFAs were performed within each scale (via Mplus v.7.11; Muthen & Muthen, 2013), using maximum likelihood estimation and oblique (goemin) rotation, because emerging factors are likely to be correlated. Decisions about dimensionality were guided by Kaiser's eigenvalue criteria, Catell's scree plot, and parallel analysis (i.e., eigenvalue Monte Carlo analysis with 50 iterations). Appendix A displays descriptive statistics, eigenvalues, factor loadings, and reliabilities for each item and their mean scales, as well as full text of each item.

Prior issue position. This measure was necessarily different for each of the three issues, but similar in structure and style. In the *climate change* conditions, prior issue position was assessed with a five-item measure adapted from Dieckmann, Gregory et al. (2017). For the *GMO foods labeling* conditions, it was assessed with a five-item measure adapted from Frewer and colleagues (1998, 2002). For the *occupational hazards of farming* (vibrating machinery) conditions, prior issue position was assessed with a five-item measure styled to resemble its counterpart measures in the climate change and GMO conditions.

Deference to science. *Deference to science*—used as a covariate in the analyses—was assessed with a four-item measure developed by Binder et al. (2016).

Hierarchical-egalitarian and individualist-collectivist worldview. Ideology/worldview was measured with the short form of the cultural cognition measure (Bolsen & Druckman, 2015; Kahan et al., 2011) which contains six items measuring egalitarian worldview attitudes and six items measuring collectivist worldview attitudes. A full measurement model EFA was conducted using all 12 items simultaneously, showing that one item in each of these dimensions crossloaded with the other dimension. Thus only the five non-cross-loading items of each scale are used in the two mean scales.

Claim belief. *Internal certainty* is an individual's own opinion of the degree to which a claim or research finding is (un)certain (e.g., Binder et al., 2016; Chang, 2015), and has most commonly been measured with self-report Likert-style measures that often contain only one item (e.g., "I am certain that...") (e.g., Clarke et al., 2015; Corbett & Durfee, 2004; Dixon & Clarke, 2013). Our measure expanded on that form by including three different phrasings of internal certainty. *Perceived risk* was assessed with a three-item measure (adapted from Binder & colleagues, and Bolsen & Druckman, 2015) referring to the severity of the threat posed to farmers and agriculture workers—which was the scientific finding presented in the stimuli. Since the stimulus message was a claim about risk, internal certainty about the claim and risk perception are very similar. The items on the internal certainty scale represent the *likelihood* of the threat (to farmers), and items on the perceived risk (to farmers) represent *severity* of the threat. These are commonly used as the two dimensions of risk perception (e.g., Han et al., 2007). The measurement model EFA showed that *internal uncertainty* and *perceived risk* loaded on the same factor. Thus, they are combined into one mean scale and labeled *claim belief*.

Perceived credibility. *Credibility* refers to an individual's perception of the trustworthiness/honesty and the expertise/competence of the source advancing the claim or research finding. This was assessed using a measure constructed from semantic differential items from foundational (e.g., Berlo, Lemert, & Merta, 1969; Hovland, Janis, & Kelly, 1953; McCroskey, 1966) and contemporary (e.g., Jensen & Hurley, 2012) credibility scales, with four response items measuring expertise and four items measuring trustworthiness.

Behavioral intentions. *Behavioral intentions* were measured with three items representing an intention toward participating in collective action movements that support the claim made by the article.

Manipulation check: External certainty (by uncertainty frame type). *External certainty* refers to an opinion about what someone else's opinion is; here, an individual's perception of the degree of certainty that scientists hold about a claim or research finding (e.g., Dixon & Clarke, 2013; Lewandowsky, Gignac, & Vaughan, 2013). This manipulation check assesses whether or not participants correctly distinguished between each type of uncertainty, so we administered four distinct individual external certainty items—one for each of the four uncertainty types.

Experimental Conditions Stimuli

Each participant viewed a one-page simulated news article reporting that new scientific research has found that [one of the three issues] is having negative effects on farmers and agriculture workers (see Table 1 for text and placement, Appendix B for an example). The language of the news article was held constant across all 15 conditions, except for necessary references to the issue and the clauses that were the uncertainty frame manipulation (which varied accordingly across the four uncertainty and one control conditions). The content and style of the uncertainty frame manipulations was taken from actual uncertainty-framed science news published in *The New York Times*, *The Washington Post*, and *The Wall Street Journal* between

2009 and 2015, as coded in a content analysis by AUTHOR2. However, the stimuli did not display the name of any newspaper, so as to not trigger biases toward the issues based on attitudes toward those publications. The online survey platform required participants to spend at least 15 seconds viewing the news article before moving on.

-- Table 1 Here --

Results

Manipulation Check

To assess whether the uncertainty frame manipulations (portrayals of different kinds of scientists' uncertainty) were noticed and distinguishable from each other, analyses of covariance (ANCOVAs) tested for differences in the four external certainty items (each referencing a particular external certainty type) across frame type and control conditions. This analysis combined the three issues (CC, GMO, VM) because the uncertainty clauses and the manipulation check measures were constant across all three issues. These tests controlled for age, individualist worldview, hierarchical worldview, and deference to science because, despite random assignment, a one-way analysis of variance (ANOVA) indicated that the means on these four variables differed significantly across the frame type conditions (omnibus: age $F(4, 2242) = 5.44$, $p < .001$; individualism $F(4, 2242) = 3.34$, $p = .010$; hierarchical $F(4,2242) = 6.87$, $p < .000$; deference to science $F(4, 2242) = 2.74$, $p = .027$) (see Table 2).

The manipulation check ANCOVAs demonstrated that, as expected, perceptions of each external certainty type (consensus, technical, deficient, scientific) held by the scientists quoted in the stimulus news articles were significantly higher in each corresponding treatment condition (consensus, technical, deficient, scientific) compared to the control condition ($p<.001$). The main effects of uncertainty frame type on external certainty were moderate to large (η^2 from .05 to .21).

The marginal means of each external certainty item indicated that participants not only distinguished uncertainty frame conditions from the control conditions, but also distinguished uncertainty frame types *from each other*. The lone exception was that scores on the technical uncertainty item in the technical uncertainty conditions did not (quite) differ significantly from that item's scores in the scientific uncertainty condition. These results support confidence that these particular operationalizations of each of these four uncertainty types were sufficiently noticeable in strength, recognizably distinct in nature, and conceptually valid in operationalization.

-- Table 2 Here --

Tests of the Hypotheses and Research Question

Analyses. H1a, H1b, RQ1, and RQ2 investigate the extent to (and ways in) which individuals' reported claim belief, credibility perceptions, and behavioral intentions vary across uncertainty frame type and control conditions, and across issues. This was done within each issue separately by testing mean differences in these three outcome variables across the four uncertainty frame types and the control condition while controlling for prior issue positions and also any demographic variables that happened to be unequally distributed across frame type conditions (i.e., MANCOVA with LSD post-hoc comparisons). In addition to controlling for prior position, the MANCOVAs in the CC issue conditions (n=743) included covariates of age, individualist worldview, hierarchical worldview, and deference to science because a one-way ANOVA indicated their means were different across CC frame conditions (omnibus: age $F(4, 738) = 2.38$, $p < .001$; individualism $F(4, 738) = 5.63$, $p < .000$; hierarchical $F(4, 738) = 6.07$, $p < .000$; deference $F(4, 738) = 3.01$, $p < .018$). In addition to prior issue position, the analyses in the GMO labeling conditions (*n*=749) controlled for age, individualist worldview, and hierarchical worldview because these three demographic variables differed across GMO frame conditions (omnibus: age $F(4, 744) = 2.11$, $p < .078$; individualism $F(4, 744) = 2.92$, $p = .020$; hierarchical $F(4, 744)=6.05$, $p < .000$). In the VM issue analyses (*n*=755), only education differed across frame type conditions ($F(4, 750) = 2.41$, $p = .048$) so it was used as a covariate alongside prior position. All of these analyses used standardized z-scores (M=0; SD=1) of the covariates and dependent variables, calculated within each issue's five conditions.

Comparisons of outcome means across conditions. Figure 1 plots the marginal means of the three outcome variables (claim belief, credibility, behavioral intentions) across the four frame type and the one control conditions, with a separate figure for each of the three issues. Table 3 provides the analysis results for each issue.

-- Figure 1 Here --

-- Table 3 Here --

Climate change. LSD post-hoc comparisons revealed that claim belief was significantly lower in the consensus uncertainty condition ($M_{z\text{-}score} = -0.13$) compared to the control condition ($M_z = 0.07$; $p = .000$) as well as compared to deficient ($M_z = 0.00$; $p = .019$), scientific ($M_z = 0.00$; $p = .024$), and technical uncertainty ($M_z = 0.06$; $p = .001$). Similarly, credibility was lowest in the consensus uncertainty condition ($M_z = -0.16$) – significantly lower than in the control condition ($M_z = 0.09$; $p = .006$), and deficient ($M_z = 0.05$; $p = .022$) and scientific ($M_z = 0.06$; $p = .014$) uncertainty. Pairwise comparisons show that compared to the control condition ($M_z = 0.14$), behavioral intentions were significantly lower in the consensus ($M_z = -0.07$; $p = .029$) and deficient uncertainty ($M_z = -0.07$; $p = .029$) conditions compared to the control condition, but the omnibus test was not significant and as such these small differences in behavioral intent are tenuous (Table 3).

GMO labeling. The omnibus test of differences by frame type was not significant for any outcome in the GMO labeling conditions. Thus, the results of the following pairwise comparisons should be seen as tenuous. Compared to the control condition ($M_z = -0.16$), claim belief was higher in the technical ($M_z = 0.07$; $p = .031$) and scientific uncertainty ($M_z = 0.08$; $p = .031$) conditions. Similarly, credibility was higher in the technical uncertainty condition $M_z = 0.14$) than in the control condition ($M_z = -0.14$; $p = .011$).

Vibrating machinery**.** Credibility was lower in the consensus uncertainty condition ($M_z = 0.22$) than in the deficient ($M_z = 0.19$; $p = .000$) or scientific ($M_z = 0.01$; $p = .040$) or technical uncertainty ($M_z = 0.12$; $p = .003$) conditions, with a significant omnibus effect of frame type. Claim belief was also lower in the consensus uncertainty condition ($M_z = -0.18$) than in the scientific ($M_z = 0.06$; $p = .030$) or technical uncertainty ($M_z = 0.08$; $p = .020$) conditions. However, the omnibus test was not significant, adding uncertainty to these small differences. Behavioral intentions did not differ significantly across any frame type conditions.

Summary. The results indicate partial support for H1a and H1b, such that claim belief and credibility perceptions were slightly lower in response to a consensus uncertainty frame compared to the control and compared to some other uncertainty frame types. This effect is observed in CC and VM conditions but not in the GMO condition. However, effect sizes were very small (η^2=.00-.02). Concerning RQ1, in every instance of a significant difference, it is consensus uncertainty (low) compared to some other frame type condition (high). Regarding RQ2, the climate change and vibrating machinery conditions had very similar patterns of results across the uncertainty frame types (Figure 1) such that the consensus uncertainty condition produced the lowest claim belief and credibility. However, the GMO condition diverged from this pattern, with the control condition (portraying no uncertainty) being associated with the lowest claim belief and credibility.

Discussion, Limitations, and Future Research Directions

Discussion

This study provides a robust experimental test – across three diverse issue contexts – of whether there are effects of different types of real-world uncertainty frames, relative to a control condition and relative to each other. Importantly, the manipulation check found that respondents noticed and accurately distinguished the operationalized differences in frame type.

In the CC and VM issue conditions, claim belief was slightly but significantly lower in the consensus uncertainty conditions than in the control conditions. For climate change only, credibility is also lower in the consensus uncertainty condition than the control condition. Considering that these effects are small and not ubiquitous across issues, it is important to look for evidence of a cohesive pattern of effects and, second, to apply relevant theoretical reasoning to those findings and patterns.

Portrayals of consensus uncertainty likely have negative effects because they introduce the possibility of expert support for both sides, thereby legitimizing (and even providing evidence for) positions of dissent or denial. While these observed effects are small, it is important to keep in mind that they capture a snapshot of attitudes in response to just one message—a message that integrated the uncertainty frame subtly into an authentic news article. It is likely that overtime effects of repeated exposure to aggregate framing trends in broader discourse can have large and lasting effects that are not captured by normative social-scientific experimental methods.

We emphasize two main implications. The first is the apparent (small) negative effect of consensus uncertainty frames in some circumstances, which corroborates AUTHOR1's review. The second implication is that even though participants recognized the presence of the uncertainty frames (and distinguished between them), these data indicate—in this snapshot—no pattern of significant effects of scientific, technical, or deficient uncertainty compared to the control condition on these attitudinal outcome variables. This is of great importance because science communicators often *do not have the option of* communicating with no uncertainty. Perhaps these findings of no effects of these uncertainty frames in a realistic news article can provide science communicators reassurance that some uncertainty types do not have negative effects—even when participants specifically recognize that those uncertainties were stated. As a reminder, because distinctions between these uncertainty types were clearly made in the manipulation check, this observed lack of effect on outcome variables is *not* likely because participants failed to see a difference between any of these frame types (or lack thereof). Rather, it is more likely that these different frames just do not have significantly different effects (on these attitudes, in this one-shot method, on these issues, in this sample).

One interesting result is that while effects on beliefs and credibility perceptions emerged, behavioral intentions were no different across any frame type conditions within any issue or combinations of issues. One explanation that is well-supported by theory is that changing behaviors is more difficult than changing beliefs (e.g., McGuire, 2012). It is also possible that behavioral intentions are further down the causal chain, such that behavioral intentions change is predicated on changes in beliefs and attitudes. As a supplemental analysis exploring this idea, we used the data from the climate change conditions and ran a parallel mediation analysis using the PROCESS macro in SPSS and 5000 bootstrapped samples (Hayes, 2013; Model 4) found that the effect of the consensus uncertainty condition (X=1) compared to the control condition (X=0) significantly lowered behavioral intentions (Y) via decreases in claim belief (M1; standardized indirect effect = -.067; LLCI = -.136; ULCI = -.012; bootstrapped SE = .031) and credibility perceptions (M2; standardized indirect effect = -.038; LLCI = -.094; ULCI = -.001; bootstrapped SE = .024). These results support the idea that even when uncertainty frames do not have significant direct effects on behavioral intentions, they still might have significant and important effects via indirect routes.

Another intriguing finding is that no significant effects were observed in the GMO conditions—not even with consensus uncertainty. One possible explanation is that participants already thought that scientists disagreed on GMO foods (which is corroborated by the relatively low prior issue position; Appendix A) and thus frames of uncertainty are seen as more credible and believable in uncertainty frame conditions than in the control condition (Figure 1). This implies that "acceptable" levels of uncertainty vary across issues—which is consistent with prior findings (Jensen & Hurley, 2012), and is a valuable question for future research.

Limitations

Although this study is carefully designed to avoid plausible alternate explanations and confounds, there are some limitations that should guide interpretations of these findings. First, there may be other valid types and typologies of uncertainty frames, providing more or different nuances. Second, while a prior content analysis (AUTHOR 2) and the present manipulation check give confidence in the theoretical and ecological validity of the current operationalizations, there are many alternative, different, and equally-valid operationalizations. These myriad alternative portrayals of these uncertainty types might result in more, less, or different patterns of, effects. It is important that future research tests how diverse uncertainty type operationalization—and diverse message media, genres, and sources—affect observed effects.

Third, the online experimental survey is not a truly ecologically valid context. As with many similar studies, a one-time message stimulus is not likely to generate large or long-lasting effects. Longitudinal studies and/or studies using a diversified mix of media sources and platforms are difficult and costly, but they are often necessary for understanding the true effects of phenomena like framing. Fourth, the three issues used in this study likely differ in terms of public understanding of the science, public awareness and understanding of the issue, scientific consensus, threat severity, threat salience, and the degree to which a particular degree of scientists' uncertainty is perceived as acceptable. It is yet unclear to what extent these contextual characteristics determine the effects of uncertainty frames—but it is likely that they are non-negligible forces.

Future Research Directions

Future research should explore and expand on whether there are functional differences in cognitive responses to these different uncertainty frame types. The degree to which, and the manner in which, these different frames spark different schema or emotions is a fundamental explanatory mechanism for why there would be (or not be) different effects (e.g., Nabi, Gustafson, & Jensen, 2018).

It may be the case that (say, consensus) uncertainty frames about Claim A in Issue 1 may *not only* have negative effects on attitudes about Claim A in Issue 1, but *also* about Claim B in Issue 1. An example is if scientists are portrayed as having consensus uncertainty about the effects of climate change (which would *not* be inaccurate), this portrayal may also increase perceptions that scientists have consensus uncertainty about *the existence or causes* of climate change (which *would* be inaccurate). This "uncertainty transfer" might also be another effect of motivated reasoning.

Research should also explore the extent to which variations in message source (e.g., politicians, stakeholders, media; see AUTHOR2) may moderate the effects of some uncertainty frames. Another consideration for future research is to conceptualize and test for interactions of uncertainty frame type with the covariates used in these analyses.

Finally, appropriate and relevant uncertainty frames could be a strategic tool used to mitigate psychological reactance. That is, it may be that the right portrayals of (say, scientific or deficient) uncertainty could reduce the severity or frequency of instances where oppositional audiences perceive scientists (or others) as being elitist, domineering, or dogmatic. It may be that individuals—particularly those with prior oppositional issue beliefs—would respond more positively to behavioral recommendations (and the sources of them) if they were presented with full disclosure of the (deficient, technical, or scientific) uncertainties of science.

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Table 1

The Four Uncertainty Statements Positioned in Each News Article

	Uncertainty Type (Message Condition)			
Position	**Deficient**	**Technical**	**Consensus**	**Scientific**
Sub-heading	New evidence says the effects of __ are a threat to millions of agriculture workers, although much is still unknown.	New evidence says the effects of __ are a threat to millions of agriculture workers, __ somewhere between 5% and 22%.	New evidence says the effects of __ are a threat to millions of agriculture workers, although some experts disagree.	New evidence says the effects of __ are a threat to millions of agriculture workers, although future research may change this.
Body text, 3rd par.	The impact of __ appears to include damage to …. although much remains unknown and more research is still needed.	The impact of __ appears to include damage to …. with estimated decreases in __ varying between 5% and 22%.	The impact of __ appears to include damage to … although this is in contrast to the research of some other scientists.	The impact of __ appears to include damage to … although—like with all science—we expect further research to clarify, or even change, these preliminary findings.
Breakout box	Same as 3rd paragraph.	Same as 3rd paragraph.	Same as 3rd paragraph.	Same as 3rd paragraph.
Conclusion	… it is important to note that scientists' understanding of the effects of __ on agriculture workers remains limited because, so far, very little research has been conducted on this issue.	… it is important to note that the effect of __ on agriculture workers can vary widely, and that researchers use their data to form an estimated range of possible amounts.	… it is important to note that there is continued controversy in the scientific community about the effects of __ on agriculture workers, with some scientists contending that __ is not causing the observed pattern of __ for farmers and laborers.	… it is important to note that the effects of __ on agriculture workers is a highly complex process that requires repeated study before any strong conclusions. Therefore, scientists fully expect that future research could cause their current understanding of this issue to change as more data become available.

Table 2

Manipulation Check: External Uncertainty Type Means across Uncertainty Frame Type Conditions

External Uncertainty Outcome Variable *(stimulus condition)*	**Omnibus**			**LSD post-hoc comparisons**		
	F	*p*	η^2	est. marginal means	[ULCI, LLCI]	*p* vs. control
Consensus	85.90	.000	.133			
(*Control*)				4.67	[4.53, 4.82]	--
(*Consensus*)				**2.98**	**[2.84, 3.13]**	**.000**
(*Deficient*)				4.37	[4.23, 4.51]	.003
(*Scientific*)				4.41	[4.27, 4.55]	.010
(*Technical*)				4.38	[4.24, 4.52]	.004
Deficient	139.05	.000	.199			
(*Control*)				4.19	[4.06, 4.33]	--
(*Consensus*)				3.48	[3.35, 3.62]	.000
(*Deficient*)				**2.15**	**[2.02, 2.28]**	**.000**
(*Scientific*)				2.71	[2.58, 2.84]	.000
(*Technical*)				3.62	[3.48, 3.75]	.000
Scientific	43.61	.000	.072			
(*Control*)				3.60	[3.46, 3.73]	--
(*Consensus*)				3.34	[3.20, 3.48]	.010
(*Deficient*)				3.21	[3.07, 3.35]	.000
(*Scientific*)				**2.42**	**[2.28, 2.56]**	**.000**
(*Technical*)				3.45	[3.31, 3.59]	.142
Technical	54.77	.000	.089			
(*Control*)				4.20	[4.06, 4.34]	---
(*Consensus*)				3.71	[3.57, 3.85]	.000
(*Deficient*)				3.23	[3.10, 3.37]	.000
(*Scientific*)				3.11	[2.97, 3.25]	.000
(*Technical*)				**2.89**	**[2.75, 3.03]**	**.000**

Note. η^2=partial eta squared; ULCI = upper limit 95% confidence interval; LLCI = lower limit 95% confidence interval. Bold text represents each uncertainty type outcome variable's corresponding uncertainty type stimulus condition.

Table 3

Omnibus Test of the Effect of Frame Type on Outcomes for Three Issues

	Climate Change		GMO Labeling		Vibrating Machinery	
DV	***F*** *(df=4.733)*	η^2	***F*** *(df=4,740)*	η^2	***F*** *(df=4,748)*	η^2
Belief	3.96*	.02	1.56	.01	1.79	.01
Cred	2.55**	.01	1.71	.01	4.33**	.02
BI	1.60	.01	0.59	.00	1.15	.01

Note. Values report the effect of frame type in MANCOVA omnibus test results on each outcome variable (Belief=claim belief; Cred=credibility; BI=behavioral intentions.); *p<.05; **p<.005; η^2=partial eta-squared.

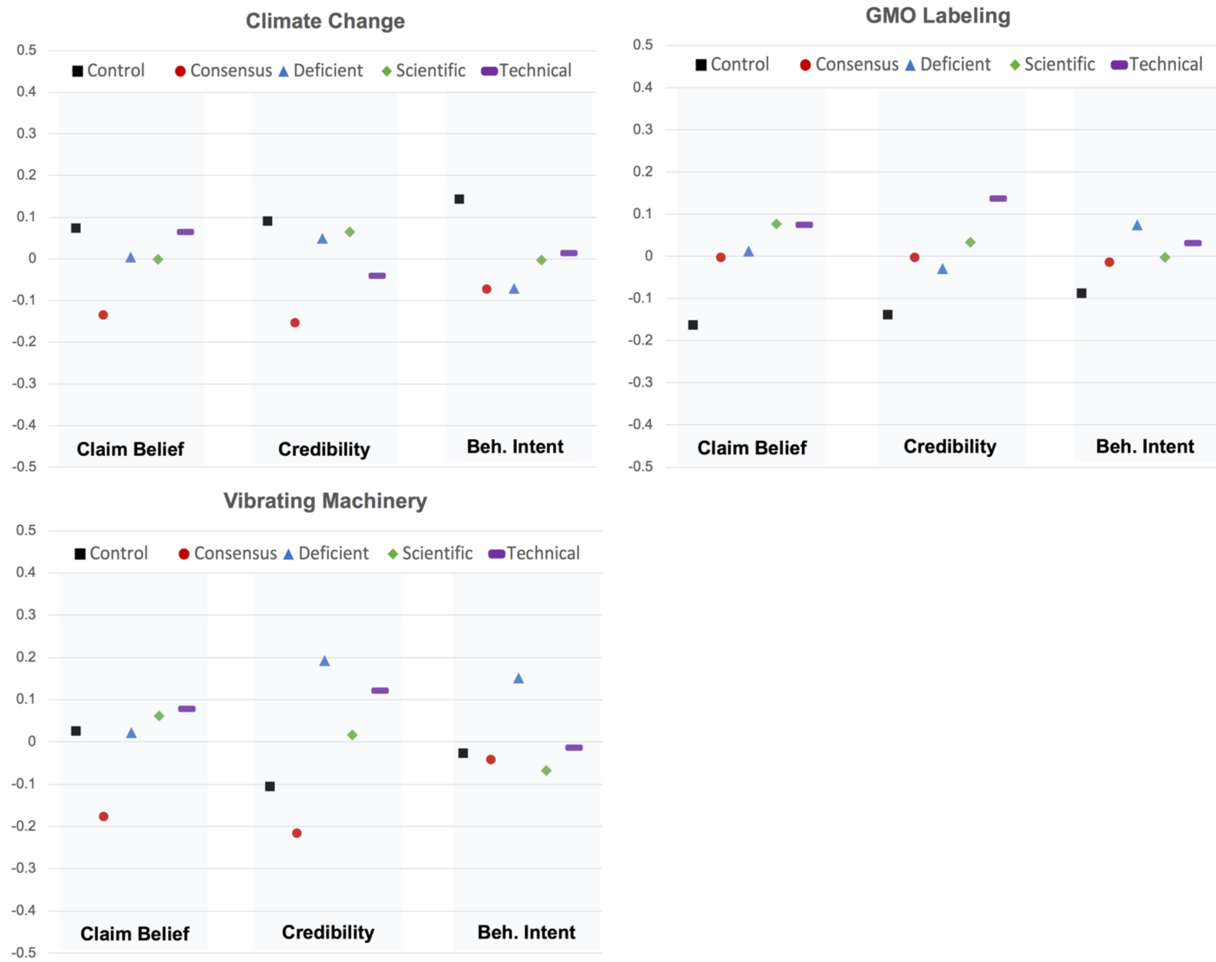

Figure 1. Comparing the marginal means (z-scores) of the three dependent variables (y-axis), for the four uncertainty and the one control frames, for the three topics (each figure).

Appendix A

Scale Reliabilities, Descriptive Statistics, and Scale Items

	α	*EV1*	*EV2*	*FL*	*M*	*SD*
Prior Issue Position (climate change)	**.90**	**3.60**	**0.66**		**5.08**	**1.52**
1. Climate change (aka "global warming") is happening				.851	5.56	1.74
2. Humans are the main cause of climate change				.797	5.05	1.87
3. The climate change we see today is part of a natural cycle of warming and cooling (r)				.605	3.82	1.87
4. Climate change is going to have serious negative impacts on our planet				.919	5.54	1.70
5. … on our way of life				.918	5.42	1.74
Prior Issue Position (GMO foods)	**.88**	**3.47**	**0.60**		**3.80**	**1.49**
1. GMO foods are harmful to our health (r)				.893	3.64	1.76
2. ... are unethical (r)				.794	3.71	1.88
3. … are beneficial to society				.784	3.88	1.71
4. It is morally wrong to be changing nature with genetic engineering (r)				.737	3.89	1.91
5. Widespread use of GMO food does more good than bad				.652	3.85	1.75
Prior Issue Position (vibrating machinery)	**.74**	**2.61**	**0.84**		**3.96**	**0.94**
1. A career in farming or agriculture work is dangerous				.684	4.39	1.46
2. … is safe (r)				.593	3.82	1.30
3. … is healthy (r)				.430	3.12	1.22
4. Farmers and agriculture workers could get hurt easily				.571	5.06	1.25
5. … should fear for their health				.615	3.41	1.47
Deference to Science	**.76**	**2.36**	**0.65**		**4.58**	**1.36**
1. Scientists should listen to the wishes of the public, even if they think citizens are mistaken or do not understand their work (r)				.789	4.07	1.81
2. Scientists should do what they themselves think is best, even if they have to persuade the public that it is right				.698	4.52	1.64
3. Public opinion is more important than scientists' opinions when making decisions about scientific research (r)				.834	5.04	1.59
4. We depend too much on science and not enough on faith (r)				.746	4.67	2.03
Hierarchical/Egalitarian	**.88**	**3.40**	**0.68**		**4.58**	**1.69**
1. We have gone too far in pushing equal rights in this country (r) (*not in final scale*)				-	4.65	2.19
2. Our society would be better off if the distribution of wealth was more equal				.815	4.79	2.02
3. We need to dramatically reduce inequalities between the rich and the poor, between whites and people of color, and between men and women				.866	4.98	1.97
4. Discrimination against minorities is still a very serious problem in our society				.815	5.28	1.83
5. It seems to me like blacks, women, homosexuals, and other groups don't want equal rights; they want special rights just for them (r)				.836	4.26	2.34
6. Society as a whole has become too soft and sensitive (r)				.763	3.61	2.17
Individualism/Collectivism	**.76**	**2.67**	**0.89**		**3.43**	**1.20**
1. The government interferes far too much in our everyday lives (r)				.452	3.09	1.71
2. The government needs to make laws that keep people from hurting themselves				.689	4.32	1.63
3. It's NOT the government's business to try to protect people from themselves (r)				.821	3.84	1.77
4. The government should stop telling people how to live their lives (r)				.541	2.90	1.59
5. The government should do more to advance society's goals, even if that means limiting freedom and choices of individuals				.432	2.99	1.70
6. The government should put limits on the choices individuals can make so they don't get in the way of what's good for society (*not in final scale*)				-	2.92	1.67
External Uncertainty (4 Uncertainty Types) (manipulation check)	**n/a**	**n/a**	**n/a**		**n/a**	**n/a**
1. These scientists think there is still a lot that they don't know about this subject				**n/a**	3.23	1.62
2. These scientists think that the findings of this research are rough estimates that could vary by a wide margin				**n/a**	3.43	1.58

3. These scientists think that they often disagree with each other or have controversy with each other about this subject				**n/a**	4.16	1.68
4. These scientists think that their findings and opinions about this topic will significantly change as future research progresses				**n/a**	3.20	1.57
Claim Belief	**.91**	**4.15**	**0.61**		**4.73**	**1.39**
Internal Certainty	**.84**	**2.29**	**0.48**		**4.78**	**1.49**
1. I myself am very certain that __ is indeed causing negative effects on _				.859	4.84	1.67
2. I myself am skeptical of the idea that __ is indeed causing negative effects on __ (r)				.750	4.54	1.80
3. I myself think there is very strong evidence for believing that __ is indeed causing negative effects on __				.885	4.94	1.64
Perceived Risk	**.84**	**2.29**	**0.50**		**4.69**	**1.43**
1. I think __ poses serious dangers to agriculture workers.				.872	4.78	1.69
2. I think farmers and agriculture workers should be worried about ___.				.876	5.00	1.61
3. I think, despite __, farmers and agriculture workers will be able to continue on as usual, remaining mostly unaffected. (r)				.735	4.29	1.62
Credibility	**.93**	**5.33**	**0.80**		**5.29**	**1.27**
1. Incompetent … Competent				.815	5.59	1.39
2. Knowledgeable … Ignorant (r)				.849	5.58	1.47
3. Unskilled … Skilled				.791	5.70	1.38
4. Intelligent … Unintelligent (r)				.821	5.72	1.48
5. Trustworthy … Untrustworthy (r)				.885	5.11	1.60
6. Honest … Dishonest (r)				.890	5.31	1.53
7. Biased … Unbiased				.673	4.60	1.87
8. Telling the Whole Truth … Withholding Information (r)				.814	4.74	1.74
Behavioral Intentions	**.73**	**1.98**	**0.69**		**3.55**	**1.44**
1. "*Recently, non-profit organizations have been raising money to provide financial assistance to the farmers, workers, and their families whom the research study claims have been affected by ____.*"						
If you were given the option to donate part of your payment for this survey to this charitable cause, how much of it do you think you would give?				.444	2.25	1.63
2. *"Some countries and states have considered creating a small tax on agricultural products, which is then used to provide financial assistance to the workers that the research study claims have been affected by ___."*						
Would you vote Yes in favor of creating this tax to assist workers?				.897	3.76	1.92
3. *"Some other countries and states have considered giving a small tax break to the agricultural workers that the research study claims have been affected by____, which would be a way to provide financial assistance to them."*						
Would you vote Yes in favor of creating this tax break to assist workers?				.702	4.64	1.80

Note: All values calculated across all 15 main study conditions (except Prior issue position values, which are within each issue's five conditions); α=Cronbach's alpha; EV1=initial eigenvalue for one-factor solution; EV2=eigenvalue of two-factor solution; FL=EFA factor loadings for a one-factor solution; M=means for scales and items; SD=standard deviation for scales and items. All items had response ranges of from 1=strongly disagree to 7=strongly agree, except: News media consumption: from 1=never to 7=more than 15 times a day; Perceived credibility: 7-point semantic differential scales; and Behavioral intention (3 items): Donation from survey compensation: 7 choices at equidistant intervals from 0% to 100%.; Support legislation (two items): 1=certainly not (0%) to 7=certainly yes (100%).

Appendix B

Exemplar Stimulus: Climate Change (Issue) with Consensus Uncertainty (Frame)

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Climate Change is Harming Farmers, One Study Says

New evidence says the effects of climate change are a threat to millions of agriculture workers, although some experts disagree.

April 25, 2018 at 9:00 AM

By Ryan Goei and Amy Hubbard

MINNEAPOLIS (Minn.) – Researchers at the University of Minnesota published a scientific report this week indicating that the livelihood of millions of farmers and agriculture workers around the world may be harmed by the effects of climate change. However, other experts disagree.

Dr. Thomas Mozzetti, a research scientist who led the study, said:

"Our data show that global warming is detrimental to individual workers by significantly changing ecosystems and local weather patterns, making it difficult to grow crops in locations and seasons where they used to thrive."

He continued, "We are finding that this is frequent around the globe. The impact of climate change appears to include damage to the livelihood of working-class farmers and laborers, although this is in contrast to the research of some other scientists. Our study suggests that because of the effects of climate change, many have less opportunities to work, and when they do have work it yields less produce."

> ***"The impact of climate change appears to include damage to the livelihood of working-class farmers and laborers, although this is in contrast to the research of some other scientists."***

The study collected data from more than 15 countries, including advanced economies such as the United States and France, as well as developing economies such as Nicaragua and Bangladesh. The findings showed that in areas where the effects of climate change were most severe, the livelihood and security of local farmers and agricultural laborers were most negatively affected.

The study also accounted for the effect of many other variables, including current political unrest, each nation's wealth, and global demand for that region's leading exports.

When considering the findings reported in this study, it is important to note that there is continued controversy in the scientific community about the effects of climate change on agriculture workers' livelihood, with some scientists contending that climate change is not causing the observed pattern of lower earnings by farmers and laborers.