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Cognitive Biases in the Assimilation of Scientific Information on Global Warming and Genetically Modified Food

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Abstract: The ability of scientific knowledge to contribute to public debate about societal risks depends on how the public assimilates information resulting from the scientific community. Bayesian decision theory assumes that people update a belief by allocating weights to a prior belief and new information to form a posterior belief. The purpose of this study was to determine the effects of prior beliefs on assimilation of scientific information and test several hypotheses about the manner in which people process scientific information on genetically modified food and global warming. Results indicated that assimilation of information is dependent on prior beliefs and that the failure to update beliefs in a Bayesian fashion is a result of several factors including: misinterpreting information, illusionary correlations, selectively scrutinizing information, information-processing problems, knowledge, political affiliation, and cognitive function.

Keywords: Bayesian updating, beliefs, climate change, biotechnology

JEL Codes: D83, Q16, Q54

The possible negative outcomes associated with societal risks such as genetically modified (GM) crops/foods and global warming (GW) are unclear, particularly for the general public. Therefore, individuals' decisions of whether to support or oppose GM crops or policies aimed to mitigate GW are made under uncertainty. Such decisions require individuals to assign subjective probabilities to possible outcomes, and these subjective measures may vary for two reasonable individuals (Savage, 1954).

Bayesian decision theory posits that an individual has a prior belief, receives new information, and then combines the prior belief with new information to form a posterior belief. The posterior belief is essentially an updated belief formed by allocating weights to a prior belief and the new information. Thus, a Bayesian approach provides a way of explaining how individuals incorporate new information to make decisions under uncertainty.

The Bayesian approach has been applied in a wide array of contexts such as game theory (e.g., Myerson, 1991), determining the economic value of weather information to agricultural producers (e.g., Doll, 1971; Baquet, Halter, and Conklin, 1976; Byerlee and Anderson, 1982; Marshall, Parton, and Hammer, 1996), projecting the evolution of agricultural yield expectations (e.g, Krause, 2008), determining returns of using soil sample information (e.g., Pautsch, Babcock, and Breidt, 1999), and understanding how individuals update beliefs about GW from fluctuations in local weather (Deryugina 2013), just to give a few examples. An implicit assumption when employing a Bayesian approach is that individuals process information optimally. However, information processing does not always conform to Bayesian decision theory. Posterior beliefs do not always converge to new information and may diverge in some instances. For example, while there appears to be a consensus in the scientific community about the safety of GM foods, the same cannot be said about public opinion. This disconnect implies

that many people do not receive or accept of scientific information, or it could be that they place greater weight on other types of non-scientific information.

Violations of the assumptions of Bayesian decision theory are thought to arise through a variety of heuristics and cognitive biases in decision making (e.g., Tversky and Kahneman, 1971, 1973, 1974; Kahneman and Tversky, 1972; Grether, 1980; El-Gamal and Grether 1995; Zizzo et al., 2000; Charness and Levin, 2005; Charness, Karni, and Levin, 2007). In the present study, we are interested in the effects of subjective prior beliefs on the acceptance of scientific information. Prior beliefs may affect how an individual processes new information; new information that is contrary to a prior belief is often met with skepticism. Distrust in information may result in an individual assigning more weight than is appropriate to a prior belief – conservatism – or possibly even reaffirm a prior belief contrary to new information – confirmation bias – when forming a posterior belief.

The purpose of this study is to determine how the public assimilates scientific information on GW and GM food and examines cognitive biases that cause belief perseverance or biased information assimilation. The objectives of this study are to determine whether: 1) information processing is independent of prior beliefs; and 2) previous theories about information processing are observed empirically in this context. Understanding how the public responds to scientific information is important because substantial resources are invested to mitigate societal risks. The economic value of scientific information is dependent on the ability of scientists to communicate with the general public in a way that scientific knowledge is received and understood.

The next section reviews the literature on information assimilation and derives some research hypotheses. Then, our research design and data collection approach are described. The following section presents the results, and the last section concludes.

Background

Conservatism bias occurs when an individual over-weighs a subjective prior belief and under-weighs new information. Conservatism has been observed in previous experiments by comparing posterior probabilities estimated by research participants to the predicted posterior probability estimate of an optimal Bayesian decision-maker (e.g, Phillips, Hays, and Edwards, 1966; Phillips and Edwards, 1966). Prior research suggests a tendency to underestimate the strength of new information, and people require more certainty than Bayesian decision theory would predict to alter posterior beliefs sufficiently. Probability estimation may be too complex for the average research participant and thus may not be an appropriate measure to formulate meaningful conclusions about belief perseverance (Pitz, Downing, and Reinhold, 1967). Nevertheless, individuals often overestimate scientific support for prior beliefs, and Kahan, Jenkins-Smith, and Braman (2011) posited that failure of scientific consensus to temper public disagreement was due to individuals perceiving expert support for a prior belief and rather than a lack of willingness to adopt scientific evidence. In the present study, we specifically define conservatism as an individual giving no weight to new information and relying solely on a prior belief.[1]

Confirmation bias occurs when an individual biasedly assimilates new information to form a posterior belief that diverges from new information and converges to a prior belief.

[1] Our specific definition of conservatism is not to be confused with *anchoring*, another cognitive bias, where estimates are biased toward initial or induced values (Tversky and Kahneman, 1974).

Previous experiments have observed confirmation bias for complex issues like capital punishment (e.g., Lord, Ross, and Lepper, 1979) and nuclear energy (e.g., Plous, 1991). Both experiments prescreened and separated participants into two groups dependent on prior beliefs (i.e., pro versus anti capital punishment or pro versus anti-nuclear energy) and then provided participants with information. Lord, Ross, and Lepper (1979) provided two sets of information to all participants; one set of information indicated that capital punishment lowered murder rates and another set of information indicated that capital punishment increased murder rates. Plous (1991) provided identical ambiguous information to all participants. The majority of participants in both studies interpreted information to confirm a prior belief. Moreover, posterior beliefs diverged for the two groups; meaning that a pro participant formed a posterior belief more in favor of an issue and an anti participant formed a posterior belief less in favor of an issue. Based on this literature, we hypothesize that individuals will assimilate information, whether that assimilation be biased or unbiased, to confirm a prior belief.

Rabin and Schrag (1999) posited that confirmation bias can be attributed to the misinterpretation of new information rather than a violation of Bayesian updating *per se*. Such a phenomenon could explain the findings of Plous (1991), as ambiguous information is open to interpretation by research subjects. However, scientific information about GM foods and human involvement in GW has emerged on a consensus. Credible scientific sources, and identical source in some instances, agree that GM foods are safe to consume and human activities are causing GW and it is an increasing threat to society. Thus, these societal risks and accompanying scientific information provide an appropriate scenario to examine the hypothesis that individuals misinterpret new information when displaying confirmation bias.

Rabin and Schrag (1999) also conjectured that information-processing problems, specifically selectively scrutinizing evidence and illusionary correlation, contribute to confirmation bias. Participants who received identical information in the Lord, Ross, and Lepper (1979) study did indeed more closely dissect information that did not conform to a prior belief. Illusionary correlation occurs when an individual believes a correlation to exist between two events that uncorrelated, correlated but to a lesser extent than believed, or correlated in an opposite direction than believed (Chapman, 1967). Examples of illusionary correlation are some individuals believe that GM foods are responsible for recent increases in autism or food allergies. We posit that such illusionary correlation is related to the manner in which people process scientific information on GW and GM foods; greater illusionary correlation is expected to be associated with a departure from optimal Bayesian updating.

It is possible that variations in familiarity, or knowledge, about a societal risk have some effect on information processing across individuals. Jang (2013) examined whether participants selected to read scientific information that confirmed or contradicted a prior belief about stem cell, evolution, GM foods, and GW. He concluded that participants who had a high level of perceived science knowledge were more likely to read scientific information that confirmed a prior belief. Participants with a high level of perceived knowledge also allocated more time reading confirming scientific information as opposed to contradicting scientific information. Conversely, participants with a high level of actual scientific knowledge, not just perceived, did not display confirmation bias when selecting scientific information to read. However, both perceived scientific knowledge and actual scientific knowledge variables were created by asking questions about science in general, not questions about the specific societal risks included in this study. Based on this literature, we hypothesize that individuals with higher levels of perceived

knowledge are more likely to suffer from biased assimilation and individuals with higher levels of actual knowledge are more likely to Bayesian update.

A contemporaneous discussion about differences in acceptance of scientific evidence across political affiliations has emerged and there are conflicting conclusions. The point of contention in the literature is whether belief preservation is uniform for Democrats, or liberals, and Republicans, or conservatives. It has been argued that Republicans are more likely to deny scientific evidence (i.e., Mooney, 2005; Mooney, 2012) or not fully understand possible impacts of societal risks (Hamilton, Cutler, and Schaefer, 2012); however, it has also been argued that Republicans and Democrats are equally susceptible to biased assimilation of scientific information (Kahan, 2013). Complicating the issue, McCright et al. (2013) argued that differences in acceptance of scientific evidence across political affiliations could be explained by the Anti-Reflexivity Thesis. The Anti-Reflexivity Thesis posits that conservatives will trust science that provides innovations for economic production (i.e., GM crops) and distrust science that identifies negative impacts of economic production (i.e., GW), and liberals will behave in an opposite manner. From the Anti-Reflexivity Thesis, we hypothesize that Democrats and Republicans will be more accepting of scientific information about GW and GM crops, respectively.

The method in which information is assimilated may depend on whether an individual processes information in a deliberative cognitive style, as presumed by a Bayesian approach, or in a more heuristic and subconscious style. Stanovich and West (2000) formally defined two generic modes of cognitive function, System 1 and System 2. System 1 is associated with fast, largely unconscious, and often emotionally charged cognitive functions; while System 2 is associated with slower, deliberately controlled, and usually rule governed functions. System 1

and 2 can be thought of more generally as intuition and reasoning, respectively (Kahneman, 2003). Stanovich and West (2000) conjectured that the two systems likely interact in concert when processing information; however, System 2 may act as an override system for automatic information-processing results occurring from System 1. In commentary to Stanovich and West (2000), Ball and Quayle (2000) speculated that System 1 may serve as an escape hatch when processing demands increase and for information processing that is not automatic. Thus, we hypothesize that an individual's predisposition to rely on System 1 or System 2 affects information processing related to GM and GW information, with System 2 thinkers being more likely to update information in a manner consistent with Bayesian decision theory than System 1 thinkers.

Kahan (2013) used the Cognitive Reflection Test (CRT) to determine the extent to which an individual's predisposition to rely on System 1 or System 2 caused biased assimilation, and we follow his lead. The CRT, introduced by Frederick (2005), is a three-question test designed to generate incorrect intuitive answers and has been used to measure the ability of an individual to engage in higher forms of reasoning. Kahan (2013) concluded that individuals relying on System 2 were more prone to biased assimilation.

Methods

Subjects

To address the research questions, an internet survey was developed and administered to a representative sample of the U.S. population. The survey was sent to a sample of 961 participants enrolled in an online panel maintained by Qualtrics© and their associated partners. The survey was fielded from April 24, 2013 through April 27, 2013. Qualtrics© prescreened

participants by gender, education, and income to ensure the sample was representative of the U.S population. According to the 2012 U.S. Census Bureau, females represented 50.8% of the population, 28.2% of persons age 25+ held a Bachelor's degree, and the median household income was $52,762. Our sample closely matched these population statistics. Fifty-one percent of the survey sample was comprised of females (*SD* = 0.50), 29% percent held a Bachelor's degree (*SD* = 0.46), and the median income category was $40,000 to $59,999.

Survey Overview

After participants consented to take the survey, a variety of questions about the safety of GM foods and human involvement in GW were asked. Questions about the two societal risks were asked in blocks, and the blocks were counterbalanced across respondents to eliminate an order effect. Questions within a block were as follows: 1) two questions to measure a participant's prior belief; 2) a question to determine if a participant believed scientific research supported a prior belief; 3) three questions to determine if a participant held illusionary correlations; 4) three questions to determine knowledge of the issue; 5) presentation of scientific information; 6) a question to measure if a participant correctly interpreted the information; and 7) a question to measure how the scientific information changed a belief. After completing both blocks, participants were asked if the scientific information provided was accurately presented and were asked political party affiliation. Participants finished the survey by completing the CRT. It is important to note that none of our questions ask about with *preferences* – e.g, whether people want or will eat GM food; rather, our questions deal solely with *beliefs* – e.g., whether people think GM food is safe to eat. Details on each of the questions are presented in the following sub-sections.

Prior Beliefs

A participant's prior belief for a societal risk was measured by asking the level of agreement with two statements. Statements about the safety of GM foods were: "Genetically modified crops are safe to eat" and "Food that has genetically modified ingredients is safe to eat." Statements about human involvement in GW were: "The Earth is getting warmer because of human actions" and "Human actions are a cause of global warming." Participants chose a level of agreement for each statement from a symmetric five-point scale with response options: Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, and Strongly Agree.

Answers were coded from one (Strongly Disagree) to five (Strongly Agree) and were summed across the two statements; so that a prior belief score for each societal risk could range from two to ten. Based on a prior belief score, prior beliefs for each societal risk were categorized into one of the following groups: *Believer*, *Denier*, or *Neutral*. For example, a participant whose prior belief score was in the two to five range was categorized in the *Denier* group, in the seven to ten range was categorized in the *Believer* group, and a score of six was categorized in the *Neutral* group. While it is not always desirable to create a discrete variable from a continuous measure, defining prior beliefs as a categorical better served the purposes of this study as we expected to observe differential effects for each category.

Presentation of Scientific Information

The scientific information provided to participants about GM foods and GW is shown in figures 1 and 2, respectively. Scientific information was collected from several authoritative sources (American Association for the Advancement of Science, 2007; American Association for the

Advancement of Science, 2012; American Medical Association, 2012; Food and Agriculture Organization of the U.N., 2000; Intergovernmental Panel on Climate Change, 2007; National Research Council, 2001; National Research Council, 2004; Royal Society, 2010) and constrained to a sentence or two per source to minimize the reading efforts of participants. The screen displaying a scientific information sheet forced participants to view the information for at least 30 seconds before moving on in the survey. As much as possible, we attempted to maintain symmetry in the GM and GW information statements insofar as the sources utilized and the type of information conveyed.

Assimilation of Information

Similar to Lord, Ross, and Lepper (1979), information-processing outcomes were measured by asking how the presented information changed beliefs. Participants were asked if they now believed GM foods were: Much Less Safe, Slightly Less Safe, Neither More Safe nor Less Safe, Slightly More Safe, or Much More Safe; and if they now believed human involvement in GW was: Much Less Involved, Slightly Less Involved, Neither More Involved nor Less Involved, Slightly More Involved, or Much More Involved. Answers to the change in belief questions for each societal risk were categorized as one of the following information-processing outcomes: *Conservative, Convergent*, or *Divergent*. For example, a participant who believed GM foods were Much Less Safe or Slightly Less Safe was categorized in the *Divergent* group, a participant who indicated Slightly More Safe or Much More Safe was in the *Convergent* group, Neither More Safe nor Less Safe was categorized in the *Conservative* group. Like the prior belief variables, defining information-processing outcomes as a category better served the purposes of

this study; as will be discussed momentarily, separate regression coefficients are estimated for each group, and the assumption of a linear effect is clearly violated.

Rabin and Schrag (1999) Hypotheses

Six questions were asked to measure illusionary correlation, three for GM and three for GW. For GM foods the agree/disagree questions were: "Genetically modified foods have caused an increase in food allergies"; "Genetically modified foods have caused an increase in incidence of Autism"; and "Genetically modified foods were invented by Monsanto and are ruining humanity." GW illusionary correlation agree/disagree statements were: "The Earth is not warming, the Earth is actually cooling"; "The warming of the Earth is just a natural cycle"; and "Global warming is a conspiracy to redistribute wealth from the United States to other countries." Similar to the prior belief variables, aggregated variables were created by summing answers to multiple agreement statements measuring illusionary correlations for both societal risks (*Illusionary Correlation*). A higher score indicates greater illusionary correlation for a given societal risk.

Immediately after receiving scientific information, participants were asked level of agreement to the statements, "The information I just read indicated that genetically modified foods are safe to consume"; and "The information I just read indicated that the Earth is warming due to human activities." These questions were asked to test the hypothesis by Rabin and Schrag (1999) that participants who display confirmation bias misinterpret information. The variables *Correct Interpretation* were created from answers to the agreement statements and a greater *Correct Interpretation* indicated that a participant more correctly interpreted the scientific information for a given societal risk.

Individuals displaying confirmation bias are often believed to selectively choose and scrutinize scientific evidence. In the present study, scientific information was provided and thus a participant could not selectively choose information. However, to determine if a participant scrutinized the scientific information provided, participants were asked, "Do you think the scientific research about genetically modified crops (global warming) was accurately presented in the Genetically Modified Foods <<Global Warming>> Information Sheet?" If a participant answered "Yes" to the GM crop/foods or GW question, the variable *Information Accuracy* was equal to one for a given societal risk and zero otherwise.

Perceived and Actual Knowledge

Before receiving scientific information, participants were asked level of agreement to a statement measuring perceived knowledge. The statements used were: "Scientific research supports my views about the safety of genetically modified crops" and "Scientific research supports my views about human activity and global warming." Answers were used to create a *Perceived Knowledge* variable for each societal risk; the greater a *Perceived Knowledge* variable the more a participant believed scientific evidence supported their prior belief.

To measure actual scientific knowledge, three true/false questions were asked for each societal risk. Questions measuring actual scientific knowledge about GM foods were retrieved from Gaskell et al. (1999), a study examining public opinion differences between Europe and the U.S., and included the true/false questions: "Ordinary tomatoes do not contain genes while genetically modified tomatoes do"; "By eating a genetically modified fruit a person's gene could become modified"; and "Genetically modified animals are always bigger than ordinary ones." Questions measuring actual scientific knowledge about GW included: "Climate often changes

from year to year"; "Changes in local weather indicate changes in climate"; and "The greenhouse effect is the same thing as global warming." The correct answer to all questions was false and correctly answered questions were coded as a one, zero otherwise. The score from the three answers were combined for each societal risk to create *Actual Knowledge* variables. Higher *Actual Knowledge* indicates that a participant had a greater objective knowledge about scientific information regarding GM crop/foods or GW.

Political Affiliation

To account for the effects of political affiliation on variation in information-processing outcomes for GM crop/foods and GW, participants were asked to questions that measured political party affiliation. Participants chose political affiliation from the following response options: Strong Democrat, Democrat, Independent Lean Democrat, Independent, Independent Lean Republican, Republican, Strong Republican, I don't know, and Other. Indicator variables *Democrat* and *Republican* were created and set equal to one for participants that chose any of the three Democrat or Republican response options, respectively, and set equal to zero otherwise.

Cognitive Reflection Test

Questions asked by the CRT are: 1) "A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?"; 2) "If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?", and 3) "In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half the lake?" The questions are designed to elicit the intuitive answers: $0.10, 100 minutes, and 24 days, respectively;

however, the correct answers are: $0.05, 5 minutes, and 47 days, respectively. A correct answer to a CRT question was coded as a one, zero otherwise. A variable (*CRT*) was created by summing the number of correct answers for a participant. A higher *CRT* indicates that a participant was more likely to engage in System 2 processing and less likely to rely on intuitive, System 1.

Results

We begin by examining summary statistics, and if information processing is independent of prior beliefs. We then investigate whether previous theories about information processing are observed empirically in the context of GM food and GW.

Summary Statistics

Table 1 shows the relative frequencies of prior beliefs and information-processing outcomes for both societal risks. Approximately 64% of the sample believed human actions are causing GW prior to receiving information, approximately 18% were unsure, and the remaining 18% did not believe humans are to blame. The sample was almost evenly distributed across the three prior belief categories about the safety of GM foods. Thus, the safety of GM foods was more divisive than human involvement in GW.

Participants were more accepting of scientific information about human involvement in GW; however, only about 50% and 45% of participants' posterior beliefs converged to information about human involvement in GW and safety of GM foods, respectively. Therefore, about half of the sample did not update a belief in the fashion assumed Bayesian decision theory.

Even more astonishing, 12% of participants formed a posterior belief *opposite* of the scientific information provided about the safety of GM foods.

Table 2 shows descriptions and means of explanatory variables used in econometric analysis. GM foods models and GW models were estimated using 946 and 954 observations, respectively, because some participants failed to provide answers to all questions used to create explanatory variables.

Information Processing and Prior Beliefs

The first objective of this study was to determine if information processing was dependent on prior beliefs. The null hypotheses that assimilation of scientific information about GM foods or GW is independent of prior beliefs was tested using a Pearson's Chi-squared test. A rejection of a null hypothesis indicates that an information-processing outcome (*Conservative*, *Convergent*, or *Divergent*) was dependent on a participant's prior belief (*Believer*, *Denier*, or *Neutral*) for the given societal risk.

The null hypothesis that assimilation of scientific information was independent of prior beliefs was rejected ($p < 0.001$) for both GM foods and GW. Figures 3 and 4 illustrate the assimilation of scientific information for people with different prior beliefs for GM foods and GW, respectively (error bars represent 95% confidence interval bounds).

After receiving the GM foods scientific information, a participant in the *Believer* or *Denier* prior belief category was most likely to be in the *Convergent* or *Conservative* information-processing outcome category, respectively. That is, people who previously believed GM foods were safe to eat were most likely to respond that the scientific information made them believe GM foods were more safe; while the beliefs of people who previously believed GM

foods were not safe to eat were most likely unchanged after receiving scientific information. A participant in the *Neutral* prior belief category was equally more likely to be in the *Conservative* or *Convergent* information-processing outcome categories, indicating that people who previously were indifferent about the safety of GM foods were more likely to hold beliefs that were unchanged or believe that GM foods were safer after the scientific information was provided.

Results for prior belief categories after participants received the GW scientific information demonstrated a nearly identical pattern of results as with GM food. The exception is the *Neutral* prior belief category. After receiving the GW scientific information sheet, a participant in the *Neutral* category was most likely to be in the *Conservative* category, then the *Convergent* category, and least likely to be in the *Divergent* category.

Participants in *Believer* prior belief category were less likely to be in the *Conservative* category than the *Denier* or *Neutral* prior belief categories. This appears logical, as you would expect people who receive information that does not align with a prior belief to discredit the information more than people who hold a prior belief aligning with the information. Participants in the *Denier* category were less likely to be in the *Convergent* category and more likely to be in the *Divergent* category than participants in the *Believer* or *Neutral* prior belief categories. It makes intuitive sense that people who do not agree with information would be less accepting of it; however, it is not clear why anyone would form a posterior belief opposite of information, regardless of prior belief. These findings appear to be robust as the ordering of prior belief categories were identical for both GM foods and GW for all information-processing outcome categories.

Determinants of Information Processing

The second objective of this study was to test the aforementioned hypotheses about information processing. To complete this objective, information-processing outcome categories were used as dependent variables to estimate six binary logistic regression models (three for each societal risk). For example, participants in the *Convergent* information-processing outcome category were coded as a one and all other participants were coded as a zero, for a given societal risk. This process was repeated for the other two information-processing outcomes (*Conservative* and *Divergent*) for both societal risks.

Marginal effect estimates for the GM foods models and GW models are shown in tables 3 and 4, respectively. Relative to participants who were in the *Neutrals* prior belief category, participants in the *Believers* and *Deniers* categories were less likely to be in the *Conservative* information-processing category; as both variables were negative and significant for both societal risks. Participants in the *Deniers* category were less likely to converge posterior beliefs to scientific information about the safety of GM foods. *Deniers* were more likely to diverge posterior beliefs from scientific information about both societal risks. These finding further confirmed our hypothesis that people assimilate information to confirm a prior belief.

The hypotheses posited by Rabin and Schrag (1999) were confirmed in both *Divergent* models, as the variable *Illusionary Correlation* was significant and positive, and the *Correct Interpretation* and *Information Accuracy* variables were significant and negative for both societal risks. Thus, participants suffering from confirmation bias (forming a posterior belief that diverged from scientific information) were more likely to misinterpret new information and experience information-processing problems (i.e., holding illusionary correlations and scrutinizing scientific information provided). Interestingly, participants who were conservative when forming a posterior belief also misinterpreted and scrutinized the information provided, as

Correct Interpretation and *Information Accuracy* were significant and negative in both *Conservative* information-processing outcome models. However, participants in the *Conservative* information-processing category were less likely to hold illusionary correlations about GM foods; *Illusionary Correlation* was significant and negative, and thus these participants did not believe GM foods were linked to negative outcomes that have been disputed by scientific evidence. Not surprisingly, participants who Bayesian updated by forming a posterior belief that converged to scientific information were more likely to correctly interpret the information provided and believe it to be accurately presented as indicated by *Correct Interpretation* and *Information Accuracy* variables being significant and positive in the *Convergent* information-processing outcome models.

For the *Conservative* information-processing category, *Actual Knowledge* was significant and positive for the GM foods model. The results indicated that people who were conservative, i.e., gave the scientific information no weight, had a high level of scientific knowledge about GM foods. Participants whose posterior beliefs did not converge to scientific information about GM foods had a low level of scientific knowledge about GM crops; *Actual Knowledge* was significant and negative for the GM foods model. Participants who Bayesian updated were more likely to believe scientific research supported a prior belief about GW. However, these participants were also more likely to have a lower level of actual scientific knowledge about GM foods; *Perceived Knowledge* was significant and positive for the GW model, while *Actual Knowledge* and was significant and negative. These findings rejected our hypotheses that individuals with higher levels of perceived knowledge are more likely to suffer from biased assimilation and individuals with higher levels of actual knowledge are more likely to Bayesian update.

Democrats were more accepting of scientific information for both GM foods and GW; *Democrat* was significant and positive in both *Convergent* information-processing outcome models. It should be noted that these estimates were relative to a base of participants that self-identified as not belonging to a political party, not knowing their political affiliation, or belonging to a party other than the two major parties. Thus, the results do not imply that Republicans deny science; rather, Democrats were more accepting of scientific information relative to the base. This finding does appear to contradict the Anti-Reflexivity Thesis; as it would suggest that conservatives would be more accepting of scientific information about GM foods and liberal would be more accepting of scientific information about GW. *Democrat* was significant and negative in the GW model for the *Conservative* information-processing category; indicating that people whose posterior and prior beliefs about human involvement in GW were equivalent after receiving scientific information were less likely to self-identify as a Democrat.

Participants who were conservative when forming a posterior belief about GW were more likely to have a higher CRT score; *CRT* was significant and positive for the GW model for the *Conservative* information-processing category. Conversely, participants who Bayesian updated were more likely to have a lower CRT score; *CRT* was significant and negative for both societal risks for the *Conservative* information-processing category. These findings confirm Kahan (2013), which concluded that individuals relying on System 2 were more prone to biased assimilation, and seem to further corroborate Ball and Quayle (2000) hypothesis that System 1 serves as an escape hatch for information processing that is not automatic.

For the *Divergent* information-processing category, *Age* was significant and negative for the GM foods model. In the GW models, *Income* was significant and positive for the

Conservative category and significant and negative for the *Divergent* category. There were no hypotheses, *a priori*, about the effects of demographic characteristics on information processing.

Conclusions

As world population increases, so does the need for innovation and increased agricultural productivity. However, agricultural innovators and producers may be limited by consumer aversion to crop and food technology. The future is also uncertain because of challenges presented by global warming, and although ample disagreement exists on which policies are best pursued, the issues is confounded by public dispute over the state of knowledge on the subject. The ability of scientists, and for scientific knowledge, to contribute to these pressing problems depends on how the public assimilates information resulting from the scientific community. The purpose of this study was to determine the effects of prior beliefs on assimilation of scientific information and test several hypotheses about the manner in which people process scientific information on genetically modified food and global warming.

Bayesian decision theory assumes that people update a belief by allocating weights to a prior belief and new information to form a posterior belief. In theory, the weights allocated to a prior belief and new information is a function of variance, and whichever has the lowest variance is allocated a greater weight. We found, however, that a prior belief clearly affects how people assimilate information, and weight allocation is more than a function of just variance. This conclusion suggests caution in adopting conventional Bayesian decision theory as a prescriptive model for how consumers process scientific information on controversial agricultural and environmental issues. Results suggest that the extent to which new information is adopted depends on the extent to which it conforms to prior belief.

Participants who did not Bayesian update misinterpreted the information provided. Rabin and Schrag (1999) asserted that people suffering from confirmation bias misinterpret evidence to conform to a prior belief. The results here confirmed that people suffering from confirmation bias do indeed misinterpret information, and suggest that people conserving a prior belief misinterpret information. This is more evidence that assuming optimal Bayesian updating may only be appropriate when new information is somewhat aligned with a prior belief.

Future research may provide more insights into the kinds of information that are likely to be most influential. In the present study, only declarative scientific information was provided from top scientific organizations. Stories, emotional appeals, or alternative formatting may have more pronounced effects on how people update prior beliefs.

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Genetically Modified Crops/Food Information Sheet

The following are statements and information on genetically modified crops from the American Association for the Advancement of Science, American Medical Association, Food and Agriculture Organization of the U.N., and National Research Council.

"Foods containing ingredients from genetically modified (GM) crops pose no greater risk than the same foods made from crops modified by conventional plant breeding techniques."

- American Association for the Advancement of Science

"To date, no evidence has supported an increased degree of allergenicity of bioengineered foods compared to their non-bioengineered counterparts. This is due in part to the safety assessments to which bioengineered foods are subjected prior to marketing."

-American Medical Association

"It could lead to higher yields on marginal lands in countries that today cannot grow enough food to feed their people."

-Food and Agriculture Organization of the U.N.

"To date, no adverse health effects attributed to genetic engineering have been documented in the human population."

-National Research Council (National Academies of the United States)

Figure 1. GM Foods Scientific Information Sheet Provided to Participants

Global Warming Information Sheet

The following are statements and information on genetically modified crops from the American Association for the Advancement of Science, Intergovernmental Panel on Climate Change, National Research Council, and Royal Society.

"The scientific evidence is clear: global climate change caused by human activities is occurring now, and it is a growing threat to society."
- American Association for the Advancement of Science

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."
- Intergovernmental Panel on Climate Change

"Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising."
- National Research Council (National Academies of the United States)

"There is strong evidence that the warming of the Earth over the last half-century has been caused largely by human activity, such as the burning of fossil fuels and changes in land use, including agriculture and deforestation."
-Royal Society

Figure 2. GW Scientific Information Sheet Provided to Participants

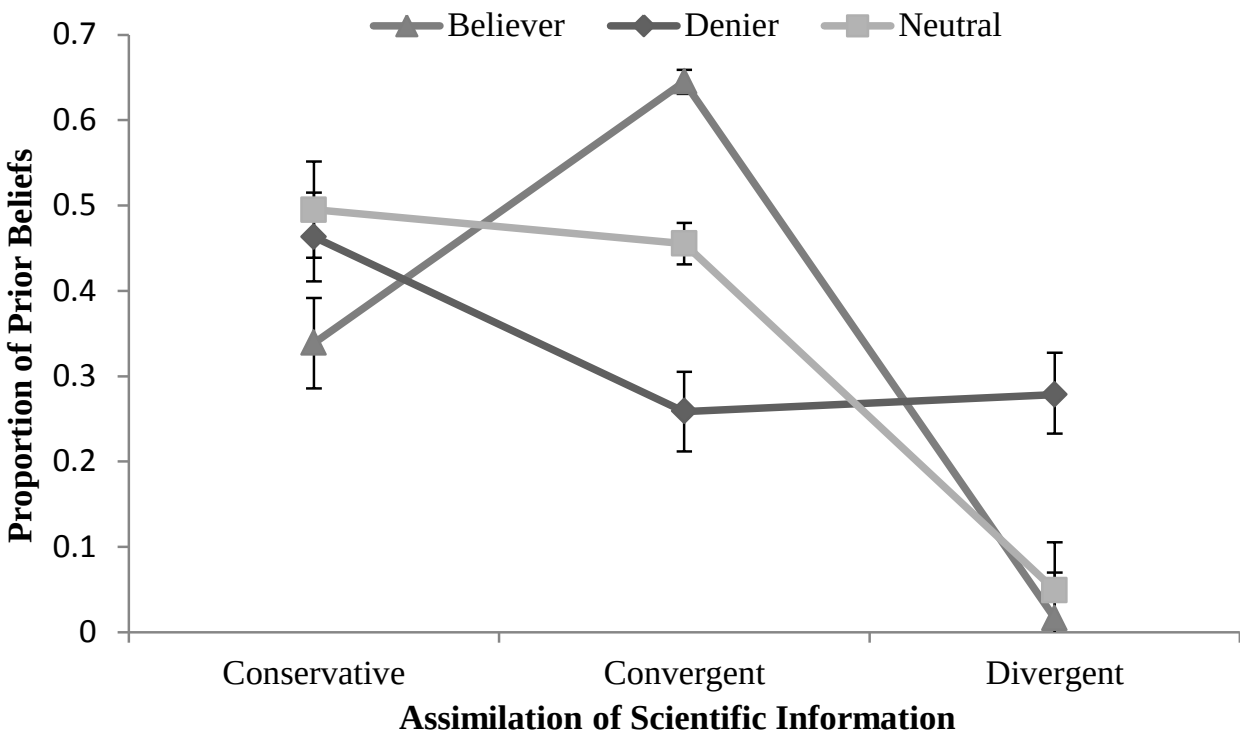

Figure 3. Assimilation of Scientific Information about GM Foods by Proportion of Prior Beliefs

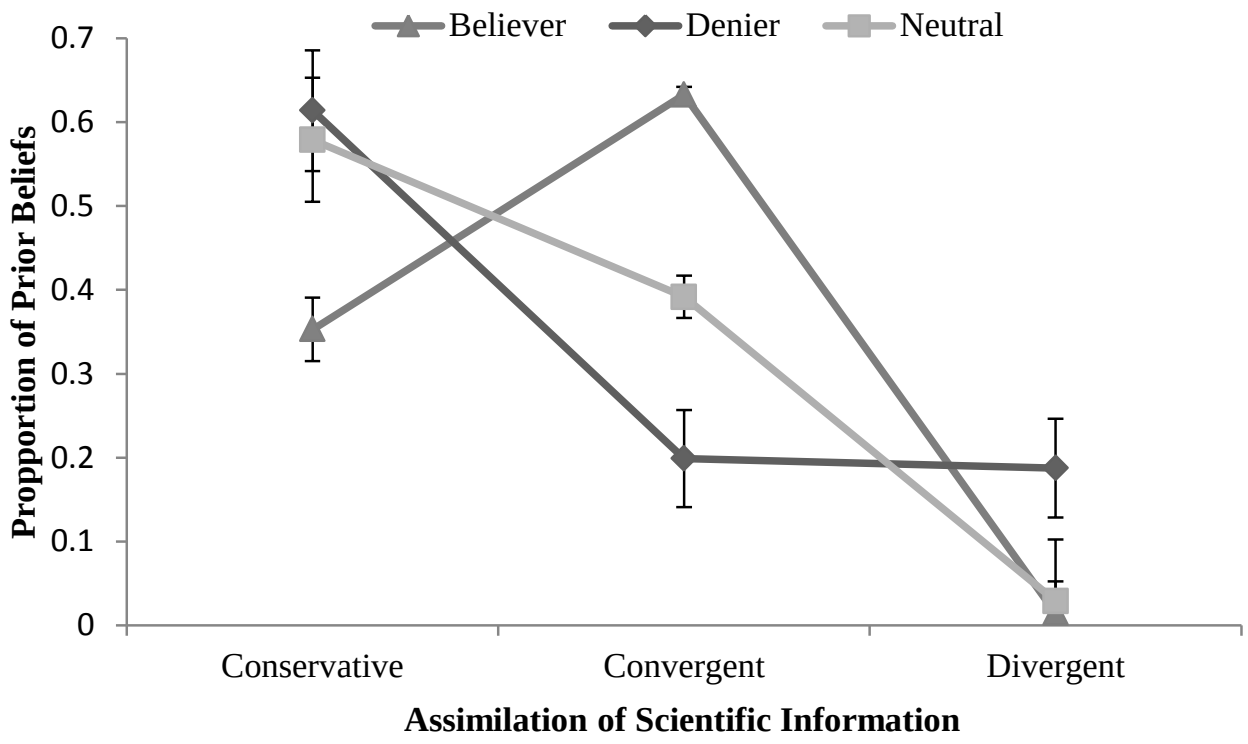

Figure 4. Assimilation of Scientific Information about GW by Proportion of Prior Beliefs

Table 1. Descriptions and Relative Frequencies of Prior Beliefs and Information Processing Categories

Variables	Descriptions	Relative Frequencies	
		GM	GW
Believers	Participants who believe GM foods are safe to eat or human actions are causing GW.	0.319	0.639
Deniers	Participants who deny GM foods are safe to eat or human actions are causing GW.	0.366	0.183
Neutrals	Participants who neither believe nor deny GM foods are safe to eat or human actions are causing GW.	0.315	0.178
Conservative	Participants whose beliefs about safety of GM foods or human involvement in GW was unchanged after scientific information.	0.434	0.441
Convergent	Participants whose beliefs about safety of GM foods or human involvement in GW converged to scientific information.	0.444	0.511
Divergent	Participants whose beliefs about safety of GM foods or human involvement in GW diverged from scientific information.	0.122	0.048
Number of Observations		961	961

Table 2. Descriptions and Means of Variables Used in Logit Model Estimations

Explanatory Variables	Descriptions	Means	
		GM	GW
Believers	1 if a participant believed GM foods are safe to eat or human actions are causing GW, 0 otherwise.	0.316	0.642
Deniers	1 if a participant denied GM foods are safe to eat or human actions are causing GW, 0 otherwise.	0.368	0.182
Illusionary Correlation	An integer variable ranging from 3 (strongly disagree) to 15 (strongly agree), determined by the sum of three level of agreement questions measuring illusionary correlations about GM crops/foods or GW.	8.982	7.715
Correct Interpretation	An integer variable ranging from 1 (strongly disagree) to 5 (strongly agree), determined by the level of agreement that the scientific information provided indicated that GM crops/foods are safe to consume or human actions are causing global warming.	3.863	4.055
Information Accuracy	1 if a participant believed the scientific information provided about the safety of GM crops/foods or human involvement in GW was accurately presented, 0 otherwise.	0.665	0.732
Perceived Knowledge	An integer variable ranging from 1 (strongly disagree) to 5 (strongly agree), determined by the level of agreement that scientific research supported a prior belief about the safety of GM crops/foods or human involvement in GW.	3.277	3.662
Actual Knowledge	An integer variable ranging from 0 to 3, determined by the number of correctly answered true/false questions about GM crops/foods or GW.	2.049	1.061
Democrat	1 if a participant self-identified as a Democrat, 0 otherwise.	0.388	0.392
Republican	1 if a participant self-identified as a Republican, 0 otherwise.	0.293	0.290
CRT	An integer variable ranging from 0 to 3, determined by the number of correctly answered Cognitive Reflection Test questions.	0.321	0.319
Age	Age in years.	26.716	26.753
Bachelors	1 if Bachelor's degree or higher, 0 otherwise.	0.291	0.294
Female	1 if female, 0 if male.	0.512	0.512
Income	An integer variable ranging from 1 to 8, used to represent income categories (1=$0-19,999, 2=$20,000-$39,999…8=$140,000 or more).	3.359	3.355
Number of Observations		946	954

Table 3. Marginal Effect Estimates for Genetically Modified Crops/Foods Logit Models

	Dependent Variables		
Explanatory Variables	*Conservative*	*Convergent*	*Divergent*
Believers	-0.090**	0.020	-0.044
	(0.043)	(0.037)	(0.034)
Deniers	-0.074*	-0.073*	0.081***
	(0.039)	(0.038)	(0.024)
Illusionary Correlation	-0.024***	0.001	0.023***
	(0.008)	(0.007)	(0.005)
Correct Interpretation	-0.059***	0.150***	-0.047***
	(0.017)	(0.019)	(0.008)
Information Accuracy	-0.277***	0.346***	-0.042**
	(0.038)	(0.035)	(0.020)
Perceived Knowledge	-0.029	0.029	-0.014
	(0.020)	(0.019)	(0.009)
Actual Knowledge	0.061***	-0.042***	-0.015*
	(0.017)	(0.016)	(0.009)
Democrat	-0.051	0.069**	-0.008
	(0.036)	(0.033)	(0.022)
Republican	-0.045	0.036	0.015
	(0.039)	(0.035)	(0.023)
CRT	0.035	-0.048**	0.012
	(0.025)	(0.023)	(0.016)
Age	0.000	0.000	-0.001*
	(0.001)	(0.001)	(0.001)
Bachelors	-0.017	0.039	-0.027
	(0.037)	(0.034)	(0.021)
Female	0.043	-0.017	-0.007
	(0.032)	(0.029)	(0.019)
Income	0.003	0.001	-0.004
	(0.010)	(0.009)	(0.006)
Log Likelihood	-586.81	-490.06	-231.78

Note: Estimates are from binary logit using 946 observations. Standard errors are reported in parenthesis. Standard errors are reported in parenthesis. Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level.

Table 4. Marginal Effect Estimates for Global Warming Logit Models

	Dependent Variables		
Explanatory Variables	*Conservative*	*Convergent*	*Divergent*
Believers	-0.100***	0.055	0.002
	(0.048)	(0.045)	(0.023)
Deniers	-0.093**	-0.047	0.055**
	(0.047)	(0.055)	(0.027)
Illusionary Correlation	-0.007	0.003	0.006*
	(0.008)	(0.007)	(0.003)
Correct Interpretation	-0.059***	0.099***	-0.017***
	(0.018)	(0.019)	(0.006)
Information Accuracy	-0.291***	0.342***	-0.036**
	(0.044)	(0.042)	(0.017)
Perceived Knowledge	-0.033	0.034*	-0.005
	(0.021)	(0.021)	(0.006)
Actual Knowledge	0.019	-0.027	0.006
	(0.018)	(0.017)	(0.008)
Democrat	-0.063*	0.060*	-0.004
	(0.037)	(0.034)	(0.018)
Republican	-0.044	0.041	-0.004
	(0.038)	(0.037)	(0.015)
CRT	0.098***	-0.098***	-0.005
	(0.026)	(0.025)	(0.011)
Age	-0.002	0.001	0.000
	(0.001)	(0.001)	(0.001)
Bachelors	-0.021	0.008	0.006
	(0.036)	(0.034)	(0.016)
Female	0.001	0.008	-0.005
	(0.031)	(0.029)	(0.014)
Income	0.015*	-0.007	-0.009**
	(0.009)	(0.009)	(0.004)
Log Likelihood	-574.95	-520.23	-135.29

Note: Estimates are from binary logit using 954 observations. Standard errors are reported in parenthesis. Standard errors are reported in parenthesis. Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level.