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Information Perception and Climate Change Adaptation

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Abstract

Despite 97% of scientists believing that climate change is occurring, a far smaller proportion of ordinary citizens agree with this statement and the proportion of those who do greatly diverge by political affiliation. This paper lays out a dynamic information updating model with adaptation choice as the final outcome, linking information perception, belief perception, and behavioral implementation. Furthermore, this paper examines how various behavioral and environmental factors affect the agent's adaptation choices by means of such cognitive processes. This research has implications for further research on climate change preference formation and effective communication strategies, such as informative or normative nudges.

Keywords

Climate change adaptation, information updating, belief formation

Cover Page Footnote

For providing general guidelines and helpful feedback, as well as supporting my intellectual curiosity in economics throughout my college career, I would particularly like to thank professor Sarah Jacobson at Williams College.

Information Perception and Climate Change Adaptation

1. Introduction

In this paper, I construct a model of individual adaptation to climate change in both the presence and absence of perceived climate change and examine agents' cognitive processes of information selection and perception.

I begin by constructing a standard utility maximization model for adaptation. Expected environmental damages are represented as a function of damages dependent on an agent's believed state of the world. Assuming an agent's beliefs about the state of the world directly affect her adaptation decisions, I then explore how the agent arrives at such beliefs to begin with in the presence and absence of objective information using a dynamic information updating model. Whether a certain information signal is perceived as objective is determined by the individual agent.

An agent who processes information purely on its scientific validity alone will engage in Bayesian updating and realize the true state of climate change regardless of her priors. However, under the assumption that the agent attaches a measure of "opinionated-ness" to all information signals, a separate model is needed to describe how the agent assigns weights. This model takes into account how the agent's priors affect the cognitive process of assigning weights to each information signal the agent encounters. Through this model, I demonstrate that reinforcement of the agent's priors, especially that of false beliefs, is the most likely outcome due to behavioral and environmental factors. Though not officially modeled, I also analyze how information selection interacts with such processes, ultimately resulting in under-adaptation.

Most of the previous literature that have analyzed the relationship between climate change perception and adaptation decisions have done so through examining the role of risk perception. By modeling an agent's cognitive processes of belief updating, this paper aims to contribute to the existing literature by shifting the focus to how real-life behavioral or environmental factors may affect both the agent's belief updating processes and adaptation decisions.

2. Context and Motivation

2.1 Political Ideology and Beliefs on Climate Change

There is a well-established consensus among adult Americans regarding climate change and the degree of human contribution. According to a survey conducted by the Yale Program on Climate Change Communication (Howe et al., 2020), approximately 72% of Americans believed that global warming is happening, and 57% believed that human activity was the main driving force behind global warming.

Though these numbers themselves do not seem problematic at face value, further analysis presents two major concerns. First, the numbers stated above fall far behind the consensus within the scientific community in which 97% of scientists believe that global warming is underway and caused by human activity (Gustafson and Goldberg, 2018). There are several reasons that can explain this discrepancy between the scientific community and the general population: people's opinions about climate change being affected by factors other than direct science, misinformation campaigns, and the lack of publication of a scientific consensus.

What is interesting is that all three factors have to do with how information is disseminated, perceived, and processed by individual agents. Accounting for other factors besides scientific evidence has to do with how much people weigh scientific facts against other types of information or beliefs; misinformation campaigns directly affect people's perceptions of reality; wider information dissemination would allow more people to become aware of the scientific consensus and evidence in support of global warming.

The second concern in addition to the relatively low awareness among the general public compared with the scientific community is that these trends diverge even further when broken down by political affiliation. Whereas 95% of liberal Democrats and 89% of moderate/conservative Democrats agree that global warming is happening, only 44% of conservative Republicans do so (Leiserowitz et al., 2019). Such discrepancies exist in more complex assessments as well, such as whether one agrees whether different entities should do more to address global warming or whether global warming should be a "high" priority for the president and Congress.

Though the fact that political affiliation affects an individual's stance towards climate change is nothing new, the larger concern is that, despite climate change and global warming being a scientific phenomenon, such trends hold true even when taking the level of acquired scientific knowledge into account. According to a recent survey by the Pew Research Center (2019), the proportion of adult Democrats in the United States who believed that human activity greatly contributed to climate change was positively correlated with the acquisition of scientific knowledge. However, such a pattern was not found among Republicans.

One good news is that these initial opinions towards climate change are not permanently fixed and can be reversed to some degree. Another survey by the Yale Program of Climate Change Communication (Deeg et al., 2019) asked whether people had shifted their beliefs on global warming and examined whether those who did shared any specific characteristics. Approximately 8% of Americans had shifted their beliefs in the past year, and 84% of those who did became more concerned about global warming, demonstrating that it was

possible for people to shift their beliefs in both directions. Out of those who became more concerned, 20% attributed their increased concern to becoming more informed about the subject matter and 18% to hearing about the impacts of global warming. This suggested that increased exposure to the relevant information could nudge, if not entirely persuade, people in forming "accurate" beliefs, which underscored the role of effective communication strategies.

The absence of a converging worldview towards climate change is concerning because an accurate perception of the status quo serves as a gateway belief for other derivative beliefs that potentially translate into public support or political capital for politicians to shape relevant public policies. Throughout this paper, I define the true state of the world as one in which climate change is severe, and "objective," "correct," or "accurate" information as one that relays or supports this worldview.

2.2 Belief Polarization

Based on the assumption that humans are rational (i.e. care about their self-interests), it would not be difficult to also assume that despite an individual's *current* beliefs about climate change, she would be willing to change her mind in the right direction once exposed to new information that points. However, studies have shown that the exact opposite occurs in controversial topics such as climate change. Despite it being their best interests to update her beliefs in the direction suggested by the evidence, more commonly known as Bayesian updating, people with a strong set of priors (i.e. prior beliefs) come out of the updating process by holding on to their beliefs more strongly than before.

This phenomenon is more commonly known as belief polarization, also defined as a situation in which a group of people receive the same information but update their beliefs in diverging directions. This can also be observed among other contentious social issues, such as the death penalty or the use of nuclear weapons. Studies showed that both supporters and opponents of any social issue emerged as more adamant in their previous beliefs after encountering mixed information that incorporated both sides' arguments (Lord, Ross, and Lepper, 1979). This phenomenon also presented itself in encounters with purely factual reports, which has to do with the fact that despite information being "objective," the individual perceiving such information is not.

According to Bayesian updating, a rational agent would update her prior beliefs on the basis of new evidence to form a revised posterior set of beliefs, and such beliefs would only be updated in the direction suggested by the evidence (Cook & Lewandowsky, 2016). However, those who exhibit belief polarization will not take into account the unambiguous scientific evidence regarding climate change. To those agents, information signals are not taken in as objective facts, but instead attached with a measure of "opinionated-ness"

that is used to gauge how consistent each information signal is with their current worldview and used to solidify their priors. I will later show that this irrational process not only creates a gap between an agent's input and output, but also in her believed state of the world and reality.

To reduce the gap between their believed and actual state of the world, agents must be provided with factually accurate and reasonably complete information. Based on this information, they should update their beliefs in an unbiased way that focuses on the factual content of the information provided rather than the degree to which it fits their social or political agenda. The reason that I emphasize "reasonably complete" as opposed to full information before an agent makes any changes to her beliefs is that full information may not always be valuable considering the costs of collecting information. Therefore, while a certain amount of information is necessary in making any optimizing decision, most people make decisions with less than complete information.

While the processing of information signals is dependent on the agent's motivation and ability to comprehend information, this does not take away from the importance that scientific or political institutions hold in information dissemination. The chances of the agent picking up information signals needed to update their beliefs in the right direction (i.e. conducting Bayesian updating) can be increased by the wider dissemination of proper information and eradication of misinformation campaigns.

2.3 Adaptation

In the previous subsection, I stated that the way in which new information is inherently perceived by the agent (i.e. whether information is perceived as factual evidence or as a measure of "opinionated-ness") affects the agent's assessment of the state of the world and described how the processing of information may result in belief polarization when the agent's priors are taken into account. In this section, I explain how the agent's beliefs that arise out of such a belief updating process affect her adaptation responses, one of the two widely used strategies to manage climate change. This is consistent with my hypothesis stated in the introduction that the way in which an agent processes the information signals she encounters will initially affect belief formation, which will in turn affect the agent's practical adaptation decisions (i.e. an agent requires forming a belief about the state of the world before making any adaptation decisions).

Adaptation is defined as the process of adjustment to actual or expected climate change and its effects. In the context of global warming and climate change, it inherently carries self-protective characteristics (IPCC, 2018). Though adaptation can be carried out by entities with varying scopes of influence, I focus on individual responses throughout this paper.

Along with mitigation, adaptation is considered as one of the two key strategies to combat climate change. The two strategies are not only complementary in that both are required to successfully reduce and manage the risks of climate change, but also interactive in that calculating potential damages, which affects predicting the efficacy of mitigation efforts, is a direct function of individual adaptation and behavior. A more precise prediction of damages would provide a closer range of estimates for climate change-related losses, and therefore lay out a more accurate timeline for mitigation that reflects the most up-to-date reality. Moreover, mitigation levels affect the magnitude of climate change, and greater rates of climate change will increase the likelihood of exceeding adaptation limits and the types of adaptation strategies available for the average individual agent (IPCC, 2014).

While mitigation focuses on reducing emissions, which makes it an effective strategy only when conducted on a global scale, adaptation has been proven to effectively decrease monetary damages even at the individual or local level by using capabilities that are available to a particular community (Adger, 2001). In fact, it is precisely because of its flexibility and capacity to be carried out at the individual level, along with the realization that a certain amount of climate change is inevitable, that adaptation has recently been considered an effective response tool against climate change — since climate change is very much underway, adaptation could help lessen the degree to which individuals and local populations remain vulnerable to some of the inevitable damages.

Adaptation is also unique in that unlike other large-scale entities, which require a collective decision-making process, an individual agent is solely responsible for her adaptation decisions. This also implies that under-resourced individuals may be left vulnerable when proper information dissemination does not occur. Hausman and Stolper (2020) explored how information failures, which typically led the individual agent to systemically underestimate her exposure to pollution, affected housing choice as a function of a household's distance from a pollution source. They found that when more information became available, individuals' willingness to pay for environmental goods such as air quality increased, demonstrating a positive correlation between exposure to relevant information and people's willingness and capacity to use it.

Believing that information possesses the ability to directly shape an agent's perception of the state of the world, previous research has attempted to demonstrate the link between perception, intention, and behavior. Fishbein and Ajzen (2010) created the Reasoned Action Approach (RAA) in which agents' attitudes towards a certain behavior, their perceived norms, and perceived behavioral control were believed to determine their intentions, which in turn affected behavior. Findings consistent with this theory were demonstrated by Mase et al. (2017) in which they discovered that the beliefs that farmers in the Midwest region of the United States had towards climate change significantly

predicted adaptation behaviors. Furthermore, to the extent that adaptation strategies were influenced by beliefs, attitudes, and perceived climate risks, the rate and scope of their implementation were able to be influenced by information campaigns, education, and training, with social norms acting as behavioral nudges.

More generally, the willingness to use risk-assessing information was found to be correlated with direct exposure, emphasizing the need for targeted, localized information campaigns. Higginbotham et al. (2013) and Bickerstaff et al. (2004) found that direct exposure to climate change impacts led to increased threat appraisal, and that only then were weather or climate information incorporated into adaptive or mitigative behaviors. This was consistent with the findings of O'Connor et al. (2005) in which water managers who had directly experienced adverse weather events were not only more likely to expect such events in the future, but also that their willingness to use weather and climate forecasts in their adaptation decisions was closely tied to their feeling at risk, regardless of its specific source.

2.4 Misestimation of Environmental Damages

In the previous subsection, I explored how the fact that information perception affects belief formation, which in turn affects adaptation choice makes it imperative for the information being disseminated to be factually accurate to begin with. In this section, I analyze how a misstep in either of the prior two steps (i.e. either information perception or belief formation) may result in an agent's misestimation of climate change-induced damages.

In principle, a misperception of the status quo could cause the agent to either underestimate or overestimate her environmental damages, preventing the most efficient use of resources. Failure to develop an adequate adaptation strategy would result in either underpreparing and facing more damages than previously thought or overpreparing and consuming more time and resources than was necessary. Between the two, I assume that underestimation is more common than overestimation.

One reason I assume underestimation is more common is that governments typically institute regulations and preventative measures after new information comes into light. Only then do individuals and businesses refrain from conducting business as usual in compliance with such regulations. This holds true for pre-existing EPA regulations, which have generally become more stringent in light of new information, especially that pertaining to new pathways for damages. For example, the Clean Air Act (2017) was expanded from its original set of guidelines such that sources of air pollution that were initially regulated at the state-level became monitored by the federal government. This quickly established regulatory programs with more specific air quality requirements, federal enforcements, and federally issued permits. The

amendments also added several new pollutants such as acid rain, CFCs, and halon to the list of chemicals that needed to be monitored.

Assuming that the public primarily refers to EPA regulations to obtain information about general environmental quality and its valuation (Hausman & Stolpher, 2020), it is evident that the average individual faces considerable obstacles if she wishes to predict the precise amount of environmental damages that she will face. Several factors may prevent the average individual agent from accurately assessing the progression of climate change.

One of the reasons that the individual agent may not be able to accurately assess the progression of climate change is that national and local media outlets may send conflicting signals regarding the state of climate change. In this case, the agent may be prevented from forming a coherent set of beliefs about the state of the world or make the wrong assessment when she chooses a news source that seems more applicable to her (e.g. a national news source says climate change is severe, while a local news source may omit or relay the opposite information).

Somewhat related to the different kinds of messages sent by different kinds of media is the fact that some media systemically bias their news reports for the sake of promoting "fairness." J. Boykoff and M. Boykoff (2004) analyzed news reports from 1988 to 2002 and discovered that widely accepted journalistic practices and norms to promote "balance" not only diverged popular discourse from scientific accuracy, but also contributed to the biased coverage of anthropogenic contributions to global warming. Though not the focus of this paper, it was also found that some news outlets, in the interest of serving fossil fuel companies or other organizations, have been serving up climate change denialism. This demonstrates how news outlets, which constitute one of the principal sources of how ordinary citizens come to acquire information, may have various different motivations for reporting conflicting, sometimes outright false, information.

Another reason the individual agent may not be able to accurately assess the state of the world is optimism bias. Climate change is a particularly vulnerable field because such cognitive biases are more likely to occur when uncertainty levels are high. Howe et al. (2017) conducted a national survey and found that 57% of Americans believed that climate change would harm Americans in general, whereas only 42% believed that climate change would affect them *personally*.

This phenomenon is more commonly known as optimism bias or unrealistic optimism. When it comes to assessing personal risk, individuals evaluate their own situations differently from those of the general population, perceiving their personal risk of being harmed by a certain threat to be smaller

than the average probability. Through FMRI (Functional Magnetic Resonance Imaging), Sharot et al. (2011) discovered that such optimism was partially derived from a failure to learn systemically from "new, undesirable information." After asking participants to estimate a range of negative events both before and after being exposed to their true average probability, they observed that only when the estimates were more pessimistic did participants update their estimates accordingly.

Lastly, individuals may simply not have access to the most recent or accurate information that primarily circulates within academic or scientific communities. Even if they do have access, they may lack the capacity to fully comprehend academic reports and translate them into practical decisions. For each information source, I hypothesize that there is a measure of accuracy (i.e. how close it is to portraying the accurate state of the world) and potential bias (i.e. how systematically wrong it is) such that when agents misestimate such parameters, they would systemically misinterpret the information given and make decisions that are skewed in one direction. The average agent is likely to not be fully aware what the parameters are for each source, since the "true" state of the world is rarely revealed. Without such information, agents are left with no objective or reliable metric to base their decisions on.

A lack of access to information may have larger socioeconomic implications than previously thought as mentioned by Hausman and Stolpher (2020). Individuals tend to underestimate pollution by having only a partial understanding of the extent of hazards they are exposed to. Therefore, individual optimization decisions regarding consumption and adaptation will only factor in the effects of climate change indicators or pollutants they are aware of. This implies that the average individual agent will primarily refer to visible indicators of climate change and exclude less visible sources from her calculations. This also implies that she would also have to take time and resources to obtain information that would get at the "true" state of the world, since pathways of climate change are more diverse and complex than what an average individual can ordinarily think of.

3. Theory

Given the effect of psychological and behavioral heuristics on information perception and behavior, I will construct a model of individual adaptation to climate change in both the presence and absence of perceived climate change. I model an information perception model in which one's priors and cognitive mechanisms for weighing information affect information perception, which in turn affect adaptation decisions. In section 3.1, I will lay out a basic behavioral model in which an agent optimizes the amount of adaptation. In section 3.2, I will lay out the damage function and its properties. In section 3.3, I will combine the elements of 3.1 and 3.2 to distinguish people into two categories based on their information perception habits. In sections 3.4

and 3.5, I will expand on such cognitive processes and demonstrate how those who believe information is inherently biased or opinionated will likely result in under-adaptation.

3.1 Basic Behavioral Model

I begin with a simplified model of utility maximization. The model is a standard utility model in that it depicts an agent optimizing over the choice of the amount of adaptation and a numeraire representing all other goods, given a budget constraint. For all of the models, it is important to note that all of the subsequent optimization problems represent the ex-ante believed utility she is making choices on, which is different from the ex-post utility she will actually receive when the level of damage hits. Based on our assumptions regarding cognitive heuristics and human behavior, I derive a simple consumer optimization model in which the agent receives utility from two goods:

$$\max_{a,y} U = f(y) - d(a|s) \text{ s.t. } P_a \cdot a + y \leq m \quad (1)$$

where the first term of the utility function denotes general consumption. This is increasing and concave with a diminishing marginal utility to provide a trade-off between general consumption and damages.

- d represents climate change damages, which is in turn a variable of climate change adaptation (a). Note that the damage does not represent actual damages, but believed damages.
- y represents general consumption, defined as dollars worth of consumption. For convenience, we assume $P_y = 1$.
- $s \in \{0,1\}$ is a binary variable that denotes the agent's believed state of the world. $s = 0$ represents a low level of climate change and $s = 1$ represents the opposite. We also define adaptation as a binary choice variable such that she can choose to undergo either a low or high level or adaptation.

The second term translates environmental damages as a direct function of adaptation dependent on one's believed state of the world, represented as s. Because her utility would decrease as damages increase, unlike general consumption, this function is decreasing and concave with diminishing marginal utility. It is important to note that, even though the agent infers rather than observes s and d, the true value of d is what ultimately impacts her utility.

3.2 The Damage Function

The next component of the model is environmental damages. To ease calculations in the model, I simplify the damage function by taking a linear approximation. The damage function will be a function of the amount of adaptation chosen and have the state of the world as parameters:

$$d = (\beta_0 - a) \cdot s \quad (2)$$

$s \in \{0,1\}$ is a binary variable that denotes the agent's believed state of the world. $s = 0$ represents a low level of climate change and $s = 1$ represents the opposite. I also define adaptation as a binary choice variable such that she can choose to undergo either a low or high level or adaptation. Given this information, β_0 represents the actual level of damages an agent will receive when she believes that climate change is severe but does not choose to adapt, since $d = \beta_0$ when $a = 0$ and $s = 1$.

This is consistent with the basic intuition that a higher level of perceived climate change would result in a higher level of perceived damages. When $s = 0$, damages become 0. When $s = 1$, then $d = (\beta_0 - a)$. Damages would be positive only when $\beta_0 - a > 0$, or $\beta_0 > a$. However, a is a choice variable, so either the range of a is restricted to be from 0 to β_0, or the price of a is high enough such that a consumer would never choose to buy negative damages.

Based on these assumptions, the damage function will entail the following characteristics:

1) $d(a = low|s = 1) > d(a = high|s = 1)$

which means that given that there is a significant degree of climate change, a higher level of adaptation will decrease damages than a lower level of adaptation.

2) $d(a = low|s = 0) = d(a = high|s = 0)$

which means that given that there is not a significant degree of climate change, the damages would not be dependent on the level of adaptation. That is, the level of damages would be equal for both low and high levels of adaptation given that we predict a low level of climate change.

With this damage function, I expand from the optimization problem stated in section 3.1 and incorporate a mechanism for processing and updating information. I represent $s = g(\sigma)$ as the strategy that maps a signal realization σ into a guess about the state of the world, s. For example, given the fact that the agent believes that the IPCC is a credible institution regarding climate change (and thus, its information signals are accurate), $g(s|\sigma_{IPCC} = 0) = 0$. This is because the institution's credibility, among other factors, will lead the agent to guess that the state of the world is identical to the signal that she receives. Credibility is defined as an idiosyncratic belief in the accuracy of the source such that if a signal comes from that source, it causes an update in that direction. Updating in the opposite direction may occur a low credibility rating is assigned to the information source.

Given the damage function, I expand from the simple optimization problem represented by equation (1) and incorporate the information updating mechanism. Incorporating this intuition into the model, the generalized utility function will look like:

$$\max_{a,y} U = f(y) - d[a|g(\sigma)] \text{ s.t. } P_a \cdot a + y \leq m \quad (3)$$

This utility function represents damages as a function of adaptation conditional on the guessed state of the world, which in turn is a function of the information signals received by the agent. This is different from equation (1) which represents a static model that assumes the agent to have a fixed believed state. Equation (3) represents a dynamic model in which she continues to guess and update one's believed state from the information signals received.

The basic intuition for the dynamic model is that when agents update information, they are receiving additional information that affects their assessment of the state of the world and environmental damages. This assessment occurs every time the agent receives information she deems relevant. However, not all additional signals necessarily translate into a new guessed state of the world. While some signals may overturn prior beliefs, some may reinforce them. In the next section, I lay out how this information updating would work.

3.3 Information Updating

With the given optimization problem in mind, I characterize the agent's processing of information signals as a two-stage choice. The first stage is information selection in which the agent chooses to accept or reject the consumption of information even before becoming aware of its content. This is largely determined by her previous biases and personal characteristics, such as age, political affiliation, area of residence, etc. This may or may not reinforce her priors, but the absence of information stimuli will have no effect on her perceived state of the world and adaptation decisions and thus the level of environmental damages she will receives remains identical.

The second stage occurs when the agent decides to accept the information presented. I assume that people update their beliefs in proportion to the degree they believe the information received is true. Expanding from this assumption and integrating the information processing model, I divide the world into two potential scenarios, the main difference between the two being whether the agent perceives the information presented as "objective" or "true." Note the final outcome as the amount of adaptation, and the individual's perceived state of the world as an intermediate outcome.

1) Presence of an objective source of information

In this scenario, the individual agent is an objective processor of information. Again, I define objective information as one that brings individuals to believe that climate change is exacerbating $(s = 1)$. Accumulated information signals that point at towards the true direction of climate change will make the agent eventually believe that the level of climate change is high, which is consistent with Bayesian updating. However, we will prove in the next section that this is highly unlikely, since an agent's priors not only affect her

initial behavior towards various information signals, but also on how she weighs subsequent information signals.

a. $s = 0 \rightarrow s = 1$ (enlightenment)
b. $s = 1 \rightarrow s = 1$ (reinforcement of true beliefs)

2) Absence of an objective source of information

In this scenario, an individual believes that all information is opinionated; she believes there is an agenda underlying the "objective" information. Therefore, the convergence that was seen in the previous section is no longer present and all four outcomes become possible.

a. $s = 0 \rightarrow s = 0$ (reinforcement of false beliefs)
b. $s = 0 \rightarrow s = 1$ (enlightenment)
c. $s = 1 \rightarrow s = 0$ (erosion/misinformation of beliefs)
d. $s = 1 \rightarrow s = 1$ (reinforcement of true beliefs)

3.4 Information and Weights

In the previous section, I assumed that an agent would update her beliefs in proportion to the degree in which she believes the information she received is true. In this section, I expand on this assumption by explaining the degree of this shift in terms of the different weights the agent places on each information source. In other words, I will attribute the different outcomes regarding the agent's believed state of the world and the degree to which she shifts her beliefs to the fact that not all processed information is weighted equally. If two different agents who possess the same set of priors $(s = 0)$ and encounter the same piece of information regarding climate change $(\sigma = 1)$ end up with different beliefs, this can only be attributed to the fact that the two agents have assigned different weights to the most recent information signal they have encountered.

The different weights agents assign to different information signals ultimately dictate their beliefs and final adaptive behavior. To draw out this mechanism, I write a weight vector w and a sigma vector σ that lay out n different weights assigned to n pieces of information. I also write a vector α that represents an individual's idiosyncratic characteristics, such as political affiliation or age group.

I assume that an agent's guess about the state of the world g is a weighted sum of her priors and accumulated information up until that point in time. The updating process is parallel to Bayesian updating in which one's prior set of probability distributions are altered after encountering an information signal. Similar to Bayesian updating, the proposed model is continuous in that an agent assigns a weight whenever she encounters new information, and if necessary, reassigns weights to previous pieces of information with their weights serving as a reference for their reassignment. Based on this hypothesis, the weighted information updating mechanism looks as follows:

$$g = h(\alpha) \cdot w_0 + w(\alpha) \cdot \sigma \quad (4)$$

The first term represents the proportion an agent's priors are taken into account in her decision-making process. An agent's priors, which I represent as $h(\alpha)$, take on a fixed value based on the agent's characteristics and are likely to be fixed (i.e. such biases are "predetermined" in the sense that individuals with certain characteristics are more likely than not to hold certain beliefs as true). I denote people's previous biases as some function of α and assign a weight vector w_0 that represents how much an agent's personal traits, and by extension, her biases, are considered even when new information comes in.

The latter term, which represents the accumulation of an individual's processed information, can also be written as the sum of the product of the weight vector and the sigma vector ($w_n\sigma_n$). The first few signals retained in an agent's memory at a given time are represented as σ_1 and σ_2, and their corresponding weights as w_1 and w_2, all the way to σ_n and w_n. Similar to how I represented the agent's priors, the weight vectors are represented in terms of α such that if two people have distinct values of α, then they would assign different weights to it and come up with different guesses about the state of the world even if they receive the same information. In other words, the way in which people assign different weights to each piece of information is affected by individual characteristics, which can be represented by $w(\alpha)$. Therefore, α contributes to both an agent's priors and the way in which she weighs different pieces of information as updating occurs.

Suppose that α is a vector that represents political affiliation. While one's political preference may contribute to forming prior biases about climate change in that one may hold beliefs consistent with party lines, it may also affect how one assigns weights to incoming and past information. For example, Democrats or younger people may not only be more concerned about climate change to begin with, but also more receptive of new information, thus assigning higher weights to such information signals as long as they are believed to be credible.

Given that g can only take on the value of 0 or 1, we set up the weight vector so that the sum of w_0 and all other weight vectors w_n equal 1. This ensures that according to this set-up, while both the sigmas and the prior biases are on the range of 0 to 1, g will be as well. Though this would represent g as a number between the continuous scale of 0 and 1 (as opposed to discrete values), we interpret it as the guessed likelihood that one's guessed state equals 1. Therefore, the individual is taking on probabilistic, rather than discrete, views of the state of the world. This is more consistent with the idea that an individual does not have a static, discrete view of the world, but a dynamic and continuous one. Reflecting the change from a static to a dynamic updating process, we also alter the damage function such that $d = (\beta_0 - a) \cdot g(\sigma)$.

3.5 Theoretical Implications

With the information updating model like equation (3) that takes into account the process in which different pieces of information are weighted, I hypothesize that when a new piece of information is processed, an agent can acquire any of the four possible outcomes previously mentioned in section 3.3: reinforcement of true beliefs, enlightenment, erosion of true beliefs, and reinforcement of false beliefs. The kind of outcome and that which happens will depend on what the agent's priors are, how heavily the priors are weighted, and how heavily the agent weighs a given information source (i.e. how credible she believes it to be).

Given the utility function, an agent chooses an optimal value of a (i.e. level of adaptation) to maximize her utility. If an agent were exposed to correct information and was an unbiased processor of that information, she should end up at the best possible guess of adaptation regardless of her priors; if that decision was made based on a sufficient amount of information, she should arrive at her true optimal adaptation level. As the agent's perceived state of the world changes, her damage function will shift as well, which will cause the agent to re-optimize her adaptation levels. In other words, an agent's priors and biases create a gap between a', which represents the optimal level of adaptation under the true state of the world, and $a"$, which represents the level of adaptation an agent undertakes due to her perception of climate change.

Though not officially modeled, information selection is a source of bias that may affect the agent's objective processing of information. I assume that most mainstream media and educational institutions lean towards $s = 1$ such that if an agent with a prior of 0.5 (i.e. completely unbiased towards either direction) was continuously exposed to a random selection of sources with uncorrelated sigmas, she would acquire the belief $g(\sigma) = 1$. I also assume that people tend to consume a specific set of media that align with their priors and acquired beliefs rather than a balanced bundle, which suggests selection bias.

Furthermore, such consumption habits would form relatively quickly after the initial exposure to an information source, since all information that the agent encounters would project signals that would continue to elicit subsequent opinions and reactions within the agent. For example, an agent who initially encounters a media source leaning towards $s = 1$ may either be persuaded by it or seek out information to the contrary after thinking its argument is "false" or "overly pessimistic." She would then seek out the next source that either confirms or goes against her initial belief, be persuaded or dissuaded by it, and continue this process until both her opinion towards climate change and her information consumption habits are solidified. However, the fact that there is a mutual interaction between the selection of information and opinion formation makes it easier for the agent to quickly acquire a highly opinionated belief. If the information signals an agent encounters over time point towards the same direction (i.e. the agent forms segregated media habits), it would be unlikely

that her beliefs will be corrected. Such behavior also affects the mechanisms that interfere with the agent's information processing.

I will now analyze how the three real-life factors laid out in section 2.4 make under-adaptation, rather than over-adaptation, the more likely outcome. First, an agent who is too sticky with her priors will assign relatively small weights to newly perceived information signals. Information selection affects the process in which an agent forms her own opinions by determining the degree in which the agent may be willing to accept new information. This makes the overturning of beliefs in either direction unlikely since the agent is certain of her priors to the extent that she is unwilling to listen to new evidence that may contain updated or factually correct information. When the agent's priors lean towards $g(\sigma) = 0$, she will come out with greater certainty of her priors since she will not have access to information relaying true signals about climate change. This is likely the product of the agent's sticky priors interacting with her media consumption habits in that she will choose information that will further confirm, rather than cast doubt on, her priors to continue being right. Therefore, the agent is prone to under-adaptation. Though those with priors of $g(\sigma) = 1$ are more likely to engage in some level of adaptation, it is unclear whether they may reach their optimal levels.

Second, optimism bias also decreases individual sensitivity to risk by preventing agents from extrapolating factually correct information that apply to the general population to themselves. Agents prone to optimism bias will believe their own probability of being exposed to a certain risk is lower than the stated factual number, despite being aware of the damage function and the effects of adaptation on their expected damages. In the damage function $d = (\beta_0 - a) \cdot g(\sigma)$, β_0 represents an agent's true damages since $d = \beta_0$ when $a = 0$ and $g(\sigma) = 1$. The value of β_0 may differ based on a number of factors (e.g. geography, average regional temperature), but optimism bias will make the agent perceive a level of β_0 smaller than its true value rather than affecting $g(\sigma)$. With this perception of β_0, assuming the agent has an upper limit to the level of damages she is willing to tolerate, she will choose a level of a equivalent to when she would have believed $g(\sigma) < 1$, thus gravitating towards under-adaptation.

Third, a lack of access to the most recent or accurate scientific information implies that the agent may disproportionately receive noisy information such that even if she were not behaviorally biased to begin with, she could end up with the wrong beliefs. With the aforementioned assumption that perception directly shapes behavior, the agent would gravitate towards under-adaptation. Furthermore, without continued exposure to scientific information, agents may lack the ability to critically process that information or assign the correct weights to subsequent information signals they encounter. Lacking the ability to process what is objectively true or important, agents may be tempted to "fall back" on their priors instead of going through the mental process of sorting and digesting information. Those without access to scientific information may

continue to believe $g(\sigma) = 1$ and choose their optimal adaptation levels, but the thought process is identical to the agent having sticky priors towards $g(\sigma) = 1$.

Furthermore, even if an agent has a prior leaning towards $g(\sigma) = 1$, it is more likely than not that the average agent is unable to keep up with the full scope of damages she will potentially become exposed to as climate change accelerates and new damage pathways are becoming discovered.

Because I am assuming a dynamic model in which the agent perceives the world in probabilistic terms, the agent's perceived state of the world is important for her adaptation decisions even if her perceptions are not precisely $g(\sigma) = 1$. I will divide this into two basic scenarios, when the agent's perceptions are exactly $g(\sigma) = 0$ and when they are not.

First, I assume that the agent's perceived state of the world is $g(\sigma) = 0$. Given the damage function $d = (\beta_0 - a) \cdot g(\sigma)$, the level of perceived damages is $d = 0$ regardless of the value of a the agent chooses. Therefore, the agent is free to choose whatever value of adaptation she sees fit. However, since adaptation is costly and requires consumption to be given up, if the agent believes that $d = 0$, adaptation provides no benefits. Therefore, assuming that the agent is a rational economic agent, no adaptation will be done ($a = 0$).

On the contrary, the level of adaptation greatly depends on the agent's perceived state of the world if she believes that $g(\sigma) > 0$. If one agent believes in a larger value of $g(\sigma)$ than another (i.e. believes with a higher probability that the state of climate change is very severe), it follows that the former would have to choose a higher level of a if she wants to receive the same amount of perceived damages as the agent who is less cautious. While both agents would believe that they are receiving the same amount of damages, the actual level of damages would be very different since the former agent would undertake a higher level of adaptation than the latter. Furthermore, if the true state of climate change is more severe than that perceived by the agent who is more cautious, both agents would fail to meet the ideal amount of adaptation that is required to offset the damages they receive.

When the agent becomes influenced by any of the three factors mentioned in the beginning of this section, reinforcement of false beliefs becomes the most likely outcome. I conclude that information has the possibility, but is not very likely, to overturn an agent's priors that have been accumulated for a prolonged period of time. Simply put, without the surrounding community's reinforced input or access to the most updated scientific information, it is difficult for the average agent who has a prior leaning towards $g(\sigma) = 1$, or even a balanced prior, to sustain a reversal in her beliefs due to behavioral heuristics. By underestimating the state of climate change, the agent is likely to a level of adaptation that is less than optimal, therefore receiving a higher level of actual damages than she had originally expected.

4. Conclusion

In this paper, I constructed a model of individual adaptation to climate

change in the presence and absence of perceived climate change and examine agents' cognitive processes of information selection and perception. With agents taking in information signals as inputs, the agent's perception of the presence or absence of objective individual would affect the agent's involvement in a rational Bayesian updating process. Those who do not believe in the presence of objective information are more likely to engage in reinforcement of their priors, and particularly reinforcement of false beliefs. With the assumption that beliefs towards a certain behavior affect one's intention of carrying out such behavior, such agents were more likely to choose a level of adaptation lower than their optimal level, thus widening the gap between their expected and actual level of damages and utility.

Previous studies have focused on how individual perception of risk, including that of climate change, affects adaptation behavior, cognitive pathways relevant to risk perception, and motivation. However, this paper contributes to the existing literature by generating a standard utility model that takes into account the dynamic process of information updating and laying out how the behavioral and environmental factors affect such cognitive processes.

As long as information about climate change is relayed from outside sources and individual adaptation behavior is directly formed by such communicative and cognitive processes, there will be an increasing need for more effective communication regarding not only the risks of climate change, but also targeted adaptation techniques. Kahan et al. (2012) suggested that communicators should endeavor to create a deliberative climate in which accepting the best available science does not threaten any group's values, such as using culturally diverse communicators or information-framing techniques that invest policy solutions with messages congenial to diverse groups. The way in which information about climate change and the state of the earth is communicated and dissemination must be effective, nudging people to acquire true beliefs before they reinforce their priors with both selective information consumption and information updating. Further research could compare communicative strategies in an experimental setting, examining the most effective way to induce socially optimal behavior or increase the retention or comprehension of information.

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