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GLOBAL WARMING: TO BELIEVE OR NOT TO BELIEVE?

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Global Warming: To Believe or Not To Believe?

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Abstract

This paper looks at the issue of formation of collective beliefs over risk of natural catastrophes such as global warming. The dynamics of belief formation is analyzed in an adaptive learning framework where individuals are exposed to a new set of information periodically. The impact of this information in setting of beliefs is influenced by the adherence of individuals to a particular cohort with certain values and interests which may be helped or undermined by the formation of these beliefs. In this paper we demonstrate three crucial points. One, the level of learning from random climatic signals could be easily adulterated by the individual's reference frame which is defined by his group adherence. Two, there is interaction between different groups with different ideologies that shape the long run convergence of beliefs. Three, the process of belief formation also influences public policies where various groups compete to get favorable policy decisions made by the government. Contrary to the common perception that public beliefs influence public policy over uncertain events such as global warming, this paper argues that the link between beliefs and public policies is much complex than that of simple unidirectional causality.

Introduction

Due to the uncertainties that are argued to persist over the causes and consequences of global warming, it is becoming exceedingly hard to come to a common consensus over the adequate course of action, both at national and international levels. In light of these uncertainties, the steps required to curb carbon emissions and take other mitigative measures become even more challenging to implement as they come at irreversible costs to society in terms of forgone consumption or capital accumulation. Further, the enormous challenges associated with modeling the geo-physical aspects of global warming in its entirety, make it impossible to accurately predict the extent of causality and damages associated with anthropogenic carbon emissions. While one may argue that the risks of global warming are fairly known, the risk perception of global warming is not a static phenomenon and varies with nationality, race, education, gender, etc. Further, it is subject to revisions from influx of new information. Consequently, the ability of the governments to reach a common consensus is heavily influenced by public perception, as it may be extremely hard for governments to take cutbacks in consumption and growth against public wishes even if that might seem to be a prudent thing to do. Therefore, formation of public opinion over the risks of global warming is an issue of great concern and needs to be studied in greater details.

Public opinion could differ on the basis of gender, race, education, political affiliation, etc. Bleda and Shackley (2005) argue that businesses would not change their perceptions towards climate change until affirmative signals are received consistently for a long period of time. They further argue that reality is perceived by businesses after being filtered through a reference frame and is not perceived objectively. Consequently, experienced reality may differ from actual reality due to perceptions which are based upon their interests, etc. It is further argued that direct signals of climate change may be subject to misinterpretation as isolated weather related signals and thus could be discarded if re-interpretation of these signals requires significant organizational changes (Berhout et al 2004).

Another example of skewed risk perceptions is of a recent case in Britain of refusal by parents to vaccinate their kids for mumps, measles and rubella under the unsubstantiated fears that such vaccination could lead to autism. Parents not only refused to avail of this free vaccination program, they also vehemently refuted and propagated their own beliefs against scientific evidence demonstrating no links, whatsoever, between the vaccine and autism (Nature 2006). Interpretations of signals or experiences have been found to be governed by the frame of reference of the receiver and could be resilient to objective revisions (Daft and Weick, 1984).

This paper looks at the issue of formation of collective beliefs over risk of natural catastrophes such as global warming. The role of group adherence, interests and other factors in influencing an objective interpretation of climatic signals is explored in an adaptive learning framework. In absence of conclusive scientific evidence, public policy formation may be subject to other influential forces such as popular opinion, lobby groups, political interests, etc. For instance, in case of global warming, individuals who see the cut-back on carbon emissions as a threat to their individualistic life styles are more likely to discount the available information related to global warming. Whereas, individuals who are egalitarian in nature would be more willing to accept the possibility of global warming as they would be more concerned about the intergenerational equity. These cohort loyalties can be easily seen in the current societies where people identify themselves as liberals or conservatives and are likely to weigh the same information differentially to come at different conclusions. Such differences in public opinion due to group loyalties are likely to lead to an impasse in formation of efficacious public policies.

Formation of beliefs, especially over risky events, is influenced by individual's adherence to certain cohorts in the society, their level of education, race, age, sex, etc. Women have been argued to be more risk averse than men. Also, Kahan et al. (2005) mention that whites are more likely to be less risk averse as compared to minorities to certain types of risks involving abortion, guns, global warming, etc. This phenomenon often termed as the 'white male effect' is explained by their more individualistic and anti-egalitarian lifestyles. Gusfiled (1986) argues that individual's perceive their status in a society by their adherence to a particular group. Consequently it is possible for risk to be perceived by the impact it would have on their status within a particular group and society.

However, it is unlikely that all issues could be seen as black and white by different groups, with the possibility of most issues falling under a grey area comprising some believers and non-believers in each cohort. This leads to the question of whether belief formation is a dynamic process and is it possible for society to come to an agreement on several key collective risks despite adherences to cohorts pulling in different directions.

Therefore, it is crucial to understand the formation and evolution of risk perception of society in order to recommend policy measures. This is especially important as a low perception of even higher levels of real risks would make such mitigative measures hard to implement as governments would seldom take steps to go against the majority opinion.

In this paper, first an adaptive learning model is designed, based upon an earlier work by Ellison and Feudenberg (1993). Learning from climatic signals is incorporated to analyze long run propensity of the system to dwell into various possible states of the system. The dynamics of belief formation is analyzed in an adaptive learning framework where individuals are exposed to a new set of information periodically. The impact of this information in setting of beliefs is influenced by the adherence of individuals to a particular cohort with certain values and interests, which may be helped or undermined by the formation of these beliefs. The impact of group adherence on influencing the interpretation of signals is explained and the interaction between competing groups is taken up to explore their influence on each other's opinions. Finally, the role of belief dynamics in public policy formation is analyzed within a political economy framework. In this paper we demonstrate three crucial points. One, the level of learning from random climatic signals could be easily adulterated by the individual's reference frame which is defined by his group adherence. Two, there is interaction between different groups with different ideologies that shape the long run convergence of beliefs. This interaction is chiefly ruled by the level of benefits (both tangible and intangible) that individuals derive from either adhering to or rejecting a particular notion about global warming. Three, the process of belief formation also influences public policies where various groups compete to get favorable policy decisions made by the government. Failure or success of these efforts also influences the long term benefits to the groups from sticking to a particular view point, thereby making the process of belief formation endogenous. Contrary to the common perception that public beliefs influence public policy over uncertain events such as global warming, this paper argues that the link between beliefs and public policies is much complex than that of simple unidirectional causality. In fact, when public policies have differential impact on different cohorts in society, formation of beliefs is endogenous to the impact of public policies on the cohorts' common interests. Thereby, belief formation may be subject to certain inertia from cohort adherence which may inhibit or alter optimal selection of public policies.

Model

We build upon the adaptive learning model for technology adoption proposed by Ellison and Feudenberg (1993) to incorporate a collective risk formation framework. Consider a population that is exposed to periodic information related to the possibility of a natural hazard. This information could be in the form of observation of phenomenon supposedly correlated with global warming[1]. Individual beliefs are influenced by several factors. One of them is the knowledge over what every one else in society believes. Other factors are a person's cultural background, his level of education, income, risk attitudes, etc. Information received through signals is parameterized by ε which is uniformly distributed between $\{-\sigma,\sigma\}$. The individual belief of global warming phenomenon is influenced by his observation of the actual value of ε in each period. This parameter could stand for an increased frequency of weather related events such as hurricanes or an increased variability in events such as mean summer or winter temperatures. We only

[1] For instance, hurricanes are considered to be caused by oceanic warming which is directly related to global warming. An increased frequency of hurricanes could then be taken as a proof of the global warming process. Recent evidence does find a 'smoking gun between global warming and hurricane intensity' (New Scientist 2005). The individual's decision to believe it or not as such is based upon his observation of these related events that occur periodically.

consider a specific signal perceived to be most significant in belief formation related to global warming here. Assume that if the value of ε is positive, he is going to become a 'believer' in global warming. If it is negative he is going to remain a 'non-believer'. It is also possible for the believers to turn into non-believers after subsequent observations of the contrary evidence. Other factors such as culture, race, education and risk aversion also influence an individual belief patterns but are not taken up here.

In order to incorporate dependence upon rest of the population for belief formation, we borrow from the literature on adaptive learning and allow for what has been termed as 'popularity weighing'. Popularity weighing implies that an individual is more likely to fall in line with the majority belief pattern as the number of believers or non-believers increases. Ellison and Feudenberg (1993) use the function $m(1-2x)$ to incorporate popularity weighing, which implies that once the fraction of population (given by x) is more than half, the sign of the term in the function reverses. Suppose that the individual is going to turn into a believer when: $\varepsilon > m(1-2x)$. Here, a positive value of ε is not enough for him to change his beliefs. He is going to wait until a majority of the population believes positively about global warming, after which even a slight negative value of ε would be enough for him to change his beliefs. It is possible that this fraction of population beyond which the sign of the term $m(1-2x)$ changes is less than half, based upon several factors. For instance, when there is heterogeneity in the population in terms of their risk perception, education, race, etc., the impact of 'popular opinion' may start showing as early as when only a third or a fourth of the population has turns into believers.

In order to see how popularity weighing influences risk perception, figure 1 below demonstrates the weighted probability of a person (or a fraction of population) turning into believer even as the actual probability of a positive signal remains constant. If one assumes that the random event is drawn from a uniform distribution, the probability that $\varepsilon > 0$ is given by $1/2$. However, when there is popularity weighing involved; the probability that $\varepsilon > m(1-2x)$ is given by $\frac{\sigma - m(1-2x)}{2\sigma}$. Notice that this term will always be less than half as long as x is positive. Also, this value will be increasing in magnitude as x increases as shown below.

INSERT FIGURE 1 HERE

In order to explore this issue in more detail we construct a simple example. Let $0 < x(t) < 1$ be the fraction of people who have turned into believers at time *t*. There is inertia in the system as a result of which only a fraction of the population can believe or reject its current stand per unit of time. More specifically, the fraction of people who have turned believers can take the following possible steps:

(1) $$x(t) = 0, \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1$$

The probabilities of forward and backward steps are given by:

(2) $$\begin{aligned} p(x(\tfrac{1}{4}) \to x(\tfrac{1}{2})) &= p(\varepsilon > m(1-2x)) \\ p(x(\tfrac{1}{2}) \to x(\tfrac{1}{4})) &= p(\varepsilon < m(1-2x)) \end{aligned}$$

For M=2;σ=4, the probabilities of transition between states are given as: {p1, p2, p3, p4, p5}= {0.25, 0.375, 0.5, 0.625, and 0.75}. Long run fraction of time spent in each of the states is given by: $\{P1, P2, P3, P4, P5\} = \{.323, .129, .097, .129, .323\}$, where p1 is the probability of transmission from $x(0) \rightarrow x(\frac{1}{4})$ and so on and P1 is the long term fraction of time spent in state $x(0)$. Notice that both the sates when the entire population is either a believer or a non-believer are equally attractive in the long run. Due to a popularity weight of 2 (on *m*), the fraction of times spent in states 0 and 1 is equal, thus implying that in the long run belief patterns are going to fluctuate wildly between the extreme states. When the variance in the random signals is reduced,(*m*=2;σ=3;) the long run distribution is given as: $\{P1, P2, P3, P4, P5\} = \{.375,.094,.062,.094,.375\}$, which leads to an even higher fluctuation between the extremes. When the popularity weight is increased to {M=3,σ=4} the distribution is given as: $\{P1, P2, P3, P4, P5\} = \{.4,.07,.04,.07,.4\}$. It is obvious that the fraction of times spent in each of the states is a function of the key parameters such as the extent of popularity weighing, *m*, and the range of the random event σ. In order to explore the possibility of full convergence to extreme states where every one is either a believer or non-believer all the time, we follow the analysis in Ellison and Feudenberg (1993) and present the conditions they have derived in Appendix A.

While full convergence of beliefs is definitely of interest for policy purposes, it is yet to be determined how beliefs may converge in a society that is heterogeneous. Society is characterized by various interest groups with differing stakes in the outcomes of global warming and polices aimed at containing it. These interest groups or cohorts may be prone to interpreting the same signal in a different way, thus accepting or discarding the notion of global warming. A possibility also exists that these groups might try to influence each others beliefs either through direct communication or through indirect ways such as influencing public polices that punish or reward behavior that augments or mitigates the risk from global warming.

Next, we consider the evolution of beliefs when they may be influenced by individual's adherence to certain cohorts in society with common interests and well settled belief patterns that are characterized by race, education, ethical and ideological beliefs.

Cohorts and Interaction

People belonging to a particular group are likely to treat such threats as challenge to their own ways of life and position in the society (Kahan et al. 2005). The risk of global warming requires serious cutbacks in emissions which come at a cost of the current energy-consuming lifestyles of the developing and developed nations. Even within a country, there are various groups that would react to such threats differentially. Assume that there are two cohorts now, L (liberals) and C (conservatives). The groups, liberals and conservatives, are defined here in terms of their location on the scale representing individualism and solidarism as the two extremes (see Kahan et al. 2005 for more discussion on individualism and solidarism). Liberals are assumed to be solidarists; more receptive to the risk of global warming and are more likely to revise their beliefs based upon positive observations over the global warming phenomenon. Conservatives are assumed to be more individualists and therefore would tend to care less about the collective impact of global warming. However, the population dynamics of believers within that cohort is now given by: accept the risk of global warming if: $\varepsilon > l + n(1-2x)$, where l is the amount of discounting done on any random periodic event and is a function of the allegiance to the liberal group. In this framework, l is the *cohort adherence* weighting and $n(1-2x)$ is the *popularity weighting* within the cohort. Similarly, the population dynamics within the conservative cohort is given by: $\varepsilon > c + m(1-2x)$, with $m > n$ and $c > l$. That is, the conservatives are prone to discount the periodic information at a higher rate than the liberals due to their stronger group allegiance and are also more likely to pay attention to what others believe within their cohort due to their hierarchical pattern. Liberals are more likely to be egalitarian and thus independently assess the information. Assuming σ=4;n=2;l=1; we can derive the steady state distribution of beliefs within the liberal cohort as: $\{0.74, 0.12, 0.04, 0.03, 0.04\}$. Notice that the fraction of time spent in the states when risk of global warming is highly discounted is very high. This is due to the extra group adherence weighing added to the model. For the case of conservative cohort, we actually see convergence to the state when everybody completely discounts the risk of global warming. For the parameters, σ=4; m=2; c=2; we get the steady state distribution as: $\{1,0,0,0,0\}$. Consequently, due to their higher group adherence weighing and popularity weighing tendencies, conservatives are more likely to converge to a state in the long run where every one is a non-believer. In order to precisely derive the condition for full convergence, as given by equation (13): $x^g > 1, x^f > 0 \Rightarrow x(t) \to 0$, where $x^g \geq \frac{\sigma + m + c}{2m}$ and $x^f \leq \frac{(c + m - \sigma)}{2m}$. Notice that equation (13) would be satisfied when: $\sigma + c \geq m$ and $m + c \geq \sigma$, which would be satisfied when $\sigma = m + c$. That is for any given level of σ, since $c > l$ and $m > n$, the conservatives are more likely to converge to the state 0.

Next we allow for communication between the two groups. Besides believing the believers within one's own cohort, an individual now also considers the number of believers inside the opposite cohort. The problem for the individual within the liberal group is then to accept the prospect of global warming if: $\varepsilon > l + n(1 - 2(x + y))$. Similarly, the problem for the individual within the conservative group is to become a believer if: $\varepsilon > c + m(1 - 2(x + y))$. Now, the dynamics within the two groups is dependent upon the believer population in each of them. For instance, a high number of believers within the conservative group would expedite convergence towards full belief over global warming in the entire population, as it would provide positive feedbacks to the signals received in each period. On the other hand, a high number of non-believers amongst the liberal group would lead to the entire population moving towards a state of non-belief. This is akin to providing resiliency in the system towards sticking to extreme ends. Two caveats apply; first, starting level of believer (or non-believer) population in the two cohorts would play a crucial role in determining which set of beliefs is converged to by the entire population. Besides, the speed of convergence itself may increase. Second, we assumed that individuals are influenced in a positive fashion by the believing (or non-believing) population in the opposite cohort. It may happen that individuals within one cohort react adversely to the beliefs held by majority population in the other cohort. Consequently, a higher number of non-believers in the conservative cohort may actually force the liberals to assign an even higher positive weightage to the periodic signal. Strong group adherence may play an important role in this kind of behavior, as individuals may perceive an increasing number of people holding contrary opinion in the opposing group as a threat to their own set of values that their group stands for. In this way, weightage applied to the signal would include all those other values that might get threatened by adoption (or dis-adoption) of belief over global warming. We explore these issues in the following example.

Consider the groups *l* and *c*. For simplicity we do away with the group adherence weights *l* and *c* and consequently, the decision to believe for the liberals is now given as: $\varepsilon \geq (n(1-2x) - q1(1-2y)$, where *y* is the population of believers in the conservative group. When parameter *q1* is positive, it would imply positive feedback from beliefs within the opposing group and vice versa. Decision to believe within the conservative group is now made if: $\varepsilon \geq m(1-2y) - q2(1-2x)$, where *x* is the population of believers within the liberal group. Probability of a forward step for liberals is given by:

$$(16) \qquad P[\varepsilon \geq (m(1-2x) - q1(1-2y)] = \frac{\sigma + q1(1-2y) - m(1-2x)}{2\sigma}$$

Probability of a forward step for conservatives is given by:

$$(17) \qquad P[\varepsilon \geq (m(1-2y) - q2(1-2x)] = \frac{\sigma - m(1-2y) + q2(1-2x)}{2\sigma}$$

Now, in order to look at the steady state distribution of the system, we divide the state space into nine parts as follows:

$$(18) \qquad \{\, x0y0, x0y.5, x0y, x.5y0, x.5y.5, x.5y, xy0, xy.5, xy\}$$

The transition matrix representing the probability of transition between these nine states is shown in the Appendix. When there is no cross cohort learning, good possibilities exist for full convergence of both groups towards turning into full believers or non-believers. This can be demonstrated for a given set of parameters: (σ=5; m=2; n=1; q1=0; q2=0). The steady state distribution (say for the base case) is now defined as:

(19) $\{x0y0, x0y.5, x0y, x.5y0, x.5y.5, x.5y, xy0, xy.5, xy\}$

{0.166,0.086,0.13,0.11,0.08,0.08,0.13,0.07,0.12}

Next we allow for learning between cohorts. That, is one group positively reacts to the information set available within the other group. This is shown by making the learning parameters *q1* and *q2* negative, which implies that one group is more likely to discount positive information related to global warming if the other group does that too and vice versa. For the given parameters:(σ =5;m=2;n=1;q1=-2;q2=-2), the steady state is solved as:

(20) $\{x0y0, x0y.5, x0y, x.5y0, x.5y.5, x.5y, xy0, xy.5, xy\}$

{.34,.06,.04,.09,.05,.06,.04,.04,.23}

Now, notice the sharp increase in tendency towards the states xy and $x0y0$. However, notice a counter intuitive result in the below examples which arises from reversing the learning behavior from opposite groups. Now, liberals react adversely to an increase in the number of believers in the conservative group by negatively weighing the information based upon the population of believers amongst the conservatives. Notice that, now the system spends significant and equal amounts of time in the states $x0y$ and $xy0$. This is due to the aversion of the liberals cohort towards conservatives' belief systems. For the given parameters:(σ =5;m=2;n=1;q1=2;q2=-1), the steady state is solved as:

(21) $\{x0y0, x0y.5, x0y, x.5y0, x.5y.5, x.5y, xy0, xy.5, xy\}$

{0.12,0.09,0.16,0.11,0.06,0.09,0.16,0.08,0.09}

Next, consider the possibility that even conservatives react adversely to the beliefs of the liberals and are likely to discount a positive signal related to global warming if the majority of the population amongst the liberal group is a believer. For parameter values (σ =5;m=2;n=1;q1=2;q2=1), the steady state distribution in these nine states is given as:

(22) $\{x0y0, x0y.5, x0y, x.5y0, x.5y.5, x.5y, xy0, xy.5, xy\}$

{.084,.076,.22,.097,.07,.07,.24,.07,.066}

Notice that highest possibilities exist for states $x0y$ and $xy0$. This says that the system has a propensity to move towards states where either liberals have turned fully into believers and the conservatives into non-believers or vice versa as predicted before. When the aversion of conservatives towards liberals is increased, this behavior is even more pronounced. This is given by parameters: (σ =5;m=2;n=1;q1=2;q2=2), the steady state distribution is now given as:

(23) $\{x0y0, x0y.5, x0y, x.5y0, x.5y.5, x.5y, xy0, xy.5, xy\}$

{0.06,0.058,0.26,0.09,0.06,0.064,0.28,0.055,0.05}

The extent of role played by group aversion in influencing risk perception could be a significant issue, but can only be empirically or experimentally ascertained. So far we have focused upon belief formation without considering the impact of these beliefs on public policy. Next section takes up this issue.

Formation of Behavioral Thresholds

The above section assumed static thresholds over cohort weights *l* and *c*. However, it is possible that each cohort's threshold may get adjusted in a dynamic fashion due to collective reassessment of the situation or hardening of evidences. But, this threshold so far has been assumed to be exogenously given. It is likely that this threshold would signify what the individual may have to sacrifice in order to switch his belief pattern from a non-believer to a believer. For instance, producers of carbon emitting devices may have a lot to loose from a confirmation of the risk of global warming. Their own forgone profits therefore would become a factor in influencing their belief patterns. However, the collective threshold should be representative of forgone profits of the entire cohort. In order to derive this threshold, we take recourse to the political economy framework that assumes that different cohorts in the society bargain with the government to further their own interests. The government in turn selects policies that maximize its chance of survival which are a function of the revenues received and the impact of such policies on its future votes.

In this section, there is interaction allowed between cohorts in terms of their standings over risk perception within a political economy framework. Let the fraction of believer population within the liberal and conservative cohorts be given as x and y. Let S(x+y) be the political gain to the incumbent government from supporting the population that believes in global warming and acting according to their demands. Then S(2-x-y) would be the gain from supporting the non-believers. Let C_c be the contribution made by the conservatives and L_c the contribution made by the liberals to influence public decision making related to global warming. Let C_b be the benefit (perceived and tangible) to the conservatives from the incumbent government not taking any policy measures such as carbon abatement, etc. Similarly, the (perceived and tangible) benefit to the liberals from the incumbent taking carbon abatement measures is L_b. Negotiations between government and the two groups happen in the form of a bargaining game where the two maximize the product of their surpluses. The product of the surpluses of conservatives and the government is given by:

(24) $\left[s(2-x-y)+C_c-S(x+y)-L_c\right]\left\{C_b-C_c\right\}$

Maximization of this surplus with respect to contributions by conservatives leads to:

(25) $C_c=\frac{1}{2}\left\{C_b+L_c+S(x+y)-S(2-x-y)\right\}$

The above gives a best response function for the contribution of the conservatives as a function of the contribution of the liberals. Therefore, we need to solve the best response functions of the two groups simultaneously in order to derive their respective contributions. The product of surpluses for the bargaining game between the liberals and the government is given by:

(26) $\left[s(x+y)+L_c-S(2-x-y)-C_c\right]\left\{L_b-L_c\right\}$

Maximization of which with respect to contributions from the liberals leads to:

(27) $L_c=\frac{1}{2}\left\{L_b+C_c+S(2-x-y)-S(x+y)\right\}$

For any given level of population of believers within the two cohorts, there is going to be a unique solution where either the liberals or the conservatives make the higher contribution, thus influencing public policy. In order to see this, consider the scenario where: S=1, $C_b=1=L_b$. Then, the response function of the two cohorts is given as: $Cc=\frac{1}{2}\{1+Lc-2\}$ and $Lc=\frac{1}{2}\{1+Cc+2\}$, solving which we get the level of contributions where both the cohorts have the same response to each others contributions. When the population of believers is low (say zero), the liberals are forced to make very high contributions in order to be able to influence public policy. In fact, when x=0=y, the contribution required from liberals in order to match the response of the conservatives is 1.6, which is more than their benefit of 1. Consequently, liberals will not be able to influence public policy under this situation. Table 1 below shows the benefits to the two groups from bargaining for given levels of population divisions.

INSERT TABLE 1 HERE

The figures below show the intersection of response functions for the two groups when there are no believers in both groups and when there is equal number of believers in both the groups.

INSERT FIGURE 2 and 3 HERE

A Nash equilibrium outcome like the one derived above does not say anything about how it would be reached. It is more likely that one of the more dominant groups would act as a Stackelberg leader and the other the follower. In here, we assume that the conservatives act as leaders and the liberals as the followers. In this game the conservatives incorporate the best response function of the liberals in their own surplus maximization problem with the government as:

$$(29) \qquad \left[s(2-x-y)+C_c-S(x+y)-Lc\right]\left\{C_b-C_c\right\}$$

which leads to the below outcomes as shown in table 2:

INSERT TABLE 2 HERE

Notice that for the first two cases when the fraction of believers among the two groups combined is 0 and 0.5, the conservatives are able to influence public policy. Their surplus after contributions in the two cases is 1 and 0.5 respectively. That is, the surplus keeps declining as the number of supporters of the global warming hypothesis falls. This would imply that as the surplus from bargaining falls, the benefits from group adherence also decline and therefore the group adherence threshold would fall too. This would make it easier for the remaining population to adjust their beliefs faster, thus hastening convergence. Similar logic would imply that as the population of believers declines, convergence towards non-believing states is hastened.

Conclusion

In this paper we demonstrated three crucial points. One, the level of learning from random climatic signals could be easily adulterated by the individual's reference frame, which is defined by his group adherence. There is interaction between different groups with different ideologies that shape the long run convergence of beliefs. This interaction is chiefly ruled by the level of benefits (both tangible and intangible) that individuals derive from either adhering to or rejecting a particular notion about global warming. Finally, the process of belief formation also influences public policies in which various groups compete to get favorable policy decisions made by the government. Failure or success of these efforts also influences the long term benefits to the groups from sticking to a particular view point, thereby making the process of belief formation endogenous. Further, when the process of belief formation becomes endogenous to groups' interests and the impact of public policies on them, the process of belief formation may suffer from an inertia making objective judgment of climatic signals difficult.

While individuals tend to weigh risks of losses and gains, it is still not clear how individual weighing of risks transforms into a collective weighing at the societal level. In order to understand a possible link, a probable hypothesis could be that in absence of individual's own lack of faith in the signal received from the periodic event, he or she is more likely to weigh the observation by what others perceive the signal to be. When the loss is personal, an individual would treat that risk differently as compared to the case when the loss is at a much aggregated level, even though the amount of expected loss is the same in both cases. This discrepancy may arise due to the interdependence of individuals on society for learning the nature of risks. An individual is more likely to discount the risk of an event that affects the entire society if every one else in the society discounts it too. Whereas, when the risk is personal, he or she is more prone to rely on his own judgments, thus showing the observed inverted s-shaped weighing of risks. Based on accumulated evidence in economics and psychology literature (see summary in Hurley and Shogren, 2005), one could assume that the individual assigns higher weights to low probabilities of a catastrophe and lower weights to high probabilities of the same event (also see Starmer, 2000). The weighing function usually follows an inverse S-shape as has been assumed in the literature. Following Prelec (1998), a two-parameter weighting function could be used to define the weight as: $w(p) = e^{-\theta(-\ln p)^{\gamma}}$, where θ is the parameter that primarily determines elevation, and γ is the parameter that primarily determines curvature. *Elevation* reflects the inflection (reference) point at which a person switches from overestimating low probability events to underestimating high probability events, i.e., the degree of over- and underestimation; *curvature* captures the idea that people become less sensitive to changes in probability the further they are from the inflection point (Tversky and Kahneman, 1992; Gonzales and Wu, 1999). By adding a subjective weighing that discounts high probabilities, an individual cares lesser about the catastrophe; the higher is its probability. The inflexion point of the inverted s-shaped curve is critical and can only be determined empirically. This weighing scheme is shown in the figure below.

Some of the future challenges along this line of thought could be to incorporate individual weighing of risks in the models presented in this paper and figure out the role of risk weighing in influencing belief formation from the other factors mentioned in this paper. There are other factors not discussed in this paper that too could play a crucial role in belief formation. Studies have found that people often learn of the quality of sea water from beach closings instead of forming their own judgments based upon direct observation. Media information could play a much more crucial and dominant role in influencing belief formation instead of popularity weighing, which could be a slower process. The influence of media information and government actions are crucial in influencing belief formation. A lot of work is remaining to be done in deciphering this simultaneity possible between belief formation and public decision process.

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Appendix A: Derivation of Conditions for convergence based upon Ellison and Feudenberg (1993)

Following their approach, let x^g be the level beyond which the belief over global warming is certain to be adopted. This can be derived noting that x is certain to move forward if the minimum value of weighted random event is positive. This is possible when $\varepsilon = -\sigma$:

(4) $x(t) \geq x^g \equiv -\sigma \geq m(1-2x)$

This gives:

(5) $x^g \geq \dfrac{\sigma + m}{2m}$

Similarly, the value of x, say x^f below which a backward step (towards non-belief) takes place with certainty is given as:

(6) $x(t) \leq x^f \equiv \sigma \leq m(1-2x)$, which gives:

(7) $x^f \leq \dfrac{(m-\sigma)}{2m}$

Also, realizing that the minimum probability of an upward step is positive when x=0, we get this probability as:

(8) $P(\varepsilon \geq m)$, or,

(9) $P[\varepsilon \geq m] = \dfrac{\sigma - m}{2\sigma} = \dfrac{-x^f(2m)}{2\sigma}$

Similarly, the minimum probability of a downward step is realized when x=1:

(10) $P(\varepsilon \leq -m)$, or,

(11) $P[\varepsilon \leq -m] = \dfrac{\sigma - m}{2\sigma} = \dfrac{(x^g - 1)(2m)}{2\sigma}$

From above we can derive the conditions for convergence of the beliefs as:

(12) $x^g < 1, x^f < 0 \Rightarrow x(t) \to 1$

(13) $x^g > 1, x^f > 0 \Rightarrow x(t) \to 0$

(14) $x^g > 1, x^f < 0 \Rightarrow$ no convergence

(15) $x^g < 1, x^f > 0, if \ x_0 > x^g \Rightarrow x(t) = 1$, however if $x_0 < x^f \Rightarrow x(t) = 0$

Condition (12) implies that the belief over global warming will eventually get adopted by everyone if $x^g < 1, x^f < 0$. Also note that when $m > \sigma$,: $x^g < 1$, but $x^f > 0$. Similarly, when $m < \sigma$, $x^g > 1$, but $x^f < 0$. Therefore, the conditions for full convergence as given by equations (14) and (15) do not hold. Further discussions and extensions over these conditions (though in a different setting) are nicely detailed in Ellison and Feudenberg (1993).

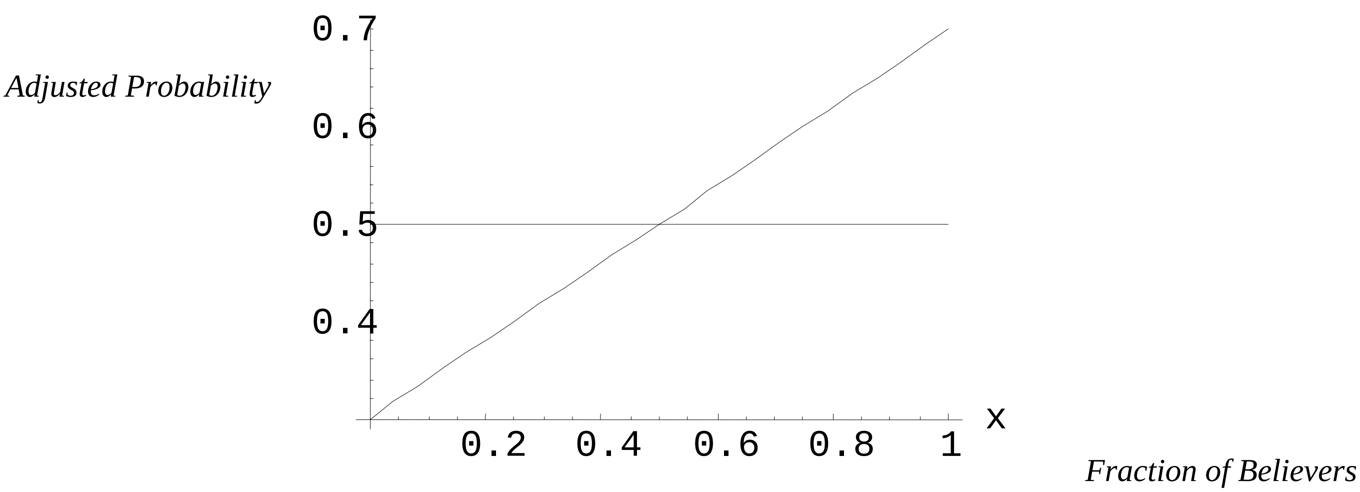
Table 1 : Benefits to the two Groups from Bargaining for a given Level of Believing Population

C_c	C_l	x	y
1.66	.33	0	0
1.33	.66	.25	.25
1	1	.5	.5
.66	1.3	.75	.75
.33	1.6	1	1

Table 2: **Benefits to the two Groups from Bargaining for a given Level of Believing Population when Conservatives Act as Stackelberg Leaders**

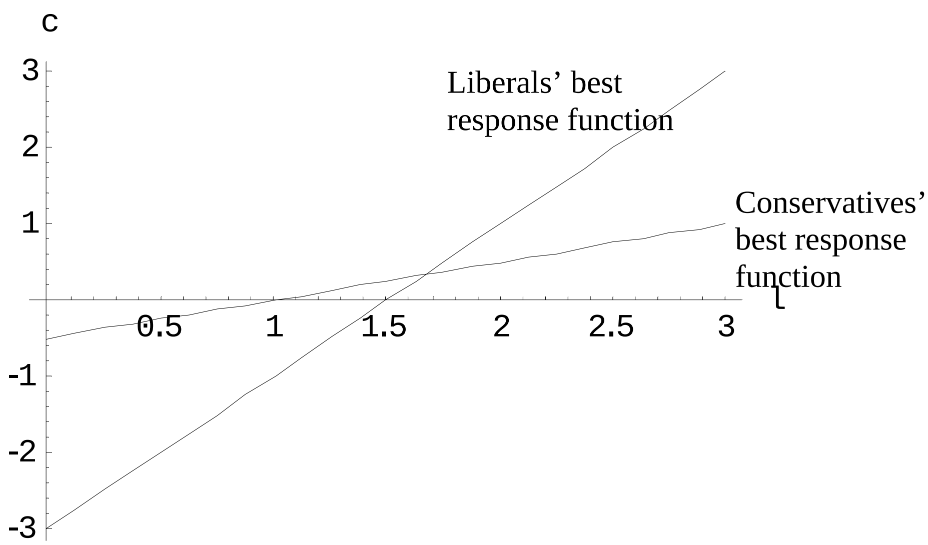
X	Y	Cc	lc
0	0	0	1.5
.25	.25	.5	1.25
.5	.5	1	1
.75	.75	1.5	.75

Figure 1: Influence of Popularity Weighting and Risk Perception



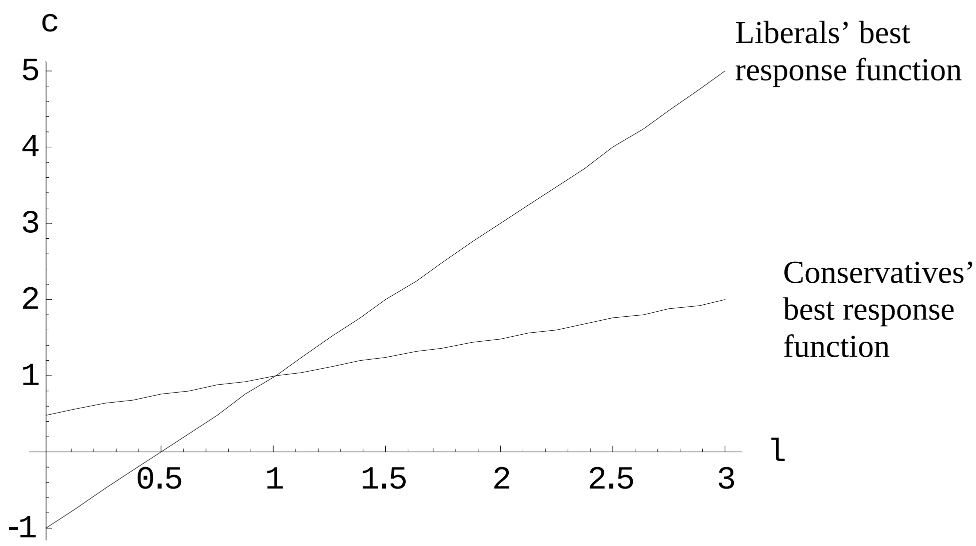
sigma=5;m=2;

Figure 2: Intersection of Response Functions for the two Groups when there is no Believer in Either Group



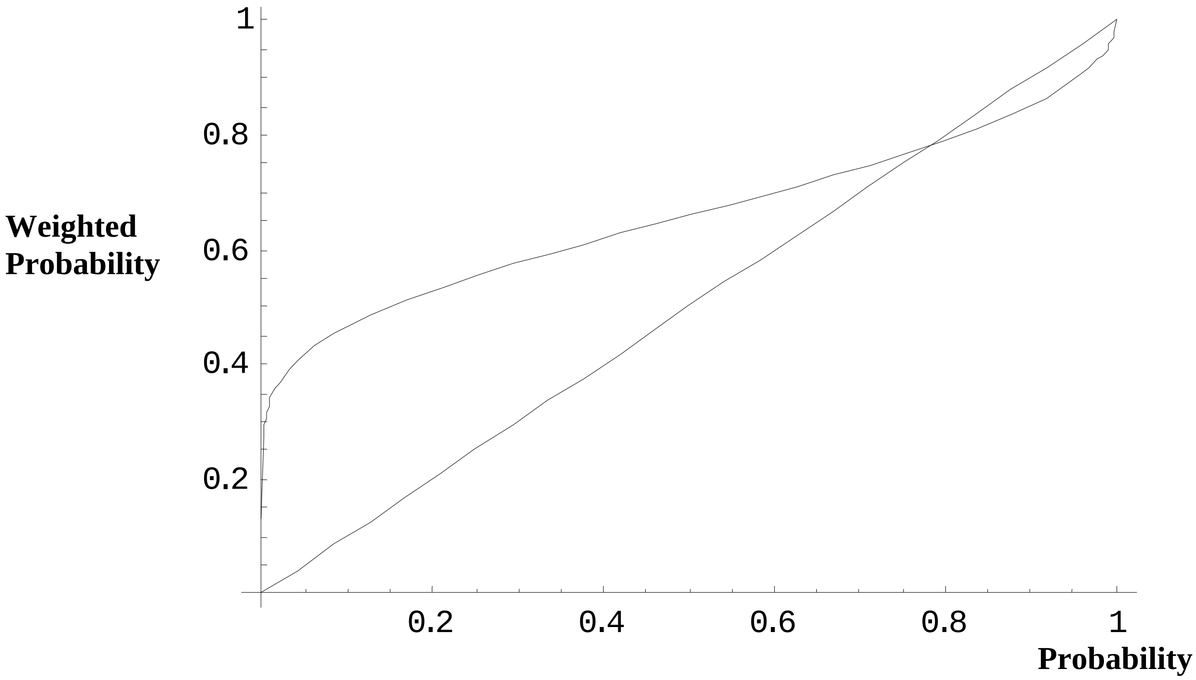
x=y=0

Figure 3: Intersection of Response Functions for the two Groups when there are Equal Number of Believers in Both the Groups.



x=y=.5

Figure 4: Weighing of Risks by Individuals



a=.5;b=.5;Plot[{p,E^(-a(-Log[p])^b)},{p,0,1}] ;

Table 4: Transition Matrix between States

$\{x0y0, x0y.5, x0y, x.5y0, x.5y.5, x.5y, xy0, xy.5, xy\}$

$\left\{\frac{-n+q1+s}{2s}, \frac{[illegible]m+q2+s}{2s}, \frac{[illegible]m+q[illegible]+s\left(\frac{-n+q1+s}{2s}\right)}{2s}, 0, \frac{[illegible]n+q[illegible]+s\left(\frac{-m+q2+s}{2s}\right)}{2s}, \frac{(n+q[illegible]+s)(m+q[illegible]+s)}{4s^2}, 0, 0, 0, 0\right\},$

$\left\{\frac{n+s}{2s}, \frac{[illegible]q2+s}{2s}, 0, \frac{[illegible]q2+s\left(\frac{-n+s}{2s}\right)}{2s}, \frac{[illegible]n+s\left(\frac{q2+s}{2s}\right)}{2s}, 0, \frac{(n[illegible]s)([illegible]q2+s)}{4s^2}, 0, 0, 0\right\}$

$0, \left\{\frac{-n-q1+s}{2s}, \frac{[illegible]+q2+s}{2s}, \frac{[illegible]n+q2[illegible]s\left(\frac{-n-q1+s}{2s}\right)}{2s}, 0, \frac{[illegible]n-q[illegible]+s\left(\frac{-m+q2+s}{2s}\right)}{2s}, \frac{(n-q[illegible]+s)(m+q[illegible]+s)}{4s^2}, 0, 0, 0\right\},$

$\left\{\frac{m+s}{2s}, \frac{[illegible]n+q1+s}{2s}, \frac{[illegible]m+s\left(\frac{-n+q1+s}{2s}\right)}{2s}, 0, 0, 0, 0, \frac{[illegible]n+q[illegible]+s\left(\frac{-m+s}{2s}\right)}{2s}, \frac{(m+s)([illegible]+s)}{4s^2}, 0, 0\right\}$

$\left\{\frac{1}{4}, 0, \frac{1}{4}, 0, 0, 0, \frac{1}{4}, 0, \frac{1}{4}\right\}$

$0, \left\{\frac{[illegible]m+[illegible]}{2s}, \frac{[illegible]q1+s}{2s}, \frac{[illegible]n+s\left(\frac{-q1+s}{2s}\right)}{2s}, 0, 0, 0, 0, \frac{[illegible]q1+s\left(\frac{m+s}{2s}\right)}{2s}, \frac{([illegible]n+s)([illegible]q1+s)}{4s^2}\right\},$

$0, 0, 0, \left\{\frac{n+q1+s}{2s}, \frac{m-q2+s}{2s}, \frac{[illegible]m-q[illegible]+s\left(\frac{n+q1+s}{2s}\right)}{2s}, 0, \frac{[illegible]+q1+s\left(\frac{-m-q2+s}{2s}\right)}{2s}, \frac{(n+q1+s)(m-q[illegible]+s)}{4s^2}, 0\right\},$

$0, 0, 0, \left\{\frac{n+s}{2s}, \frac{[illegible]q2+s}{2s}, 0, \frac{[illegible]q2+s\left(\frac{n+s}{2s}\right)}{2s}, \frac{[illegible]+[illegible]\left(\frac{-q2+s}{2s}\right)}{2s}, [illegible], \frac{([illegible]+s)([illegible]q2+[illegible])}{4s^2}\right\}$

$0, 0, 0, 0, \left\{\frac{n-q1+s}{2s}, \frac{[illegible]-q2+s}{2s}, \frac{[illegible]-q2+s\left(\frac{n-q1+s}{2s}\right)}{2s}, 0, \frac{[illegible]-q1+s\left(\frac{m-q2+s}{2s}\right)}{2s}, \frac{([illegible]-q1+s)([illegible]q2+s)}{4s^2}\right\}$

Note: Elements in each of the nine parentheses denote transition from the state corresponding to that parenthesis to all other states.