A MICROECONOMIC APPROACH TO CLIMATE CHANGE

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ABSTRACT OF THE DISSERTATION

A Microeconomic Approach to Climate Change

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This thesis is applied microeconomics in climate change and environmental economics. Climate scientists express strong consensus on anthropogenic climate change. Although science is based on "hard facts", there have been cases where scientists have been found to misrepresent data, or to hide relevant facts. Since politicians in general have no scientific background and they often suspect that scientific data could be misrepresented or manipulated, it is worthwhile to study the strategic interaction between a climate scientist and a politician who suspects the scientist may be manipulating the data. This thesis is a rigorous analysis of these controversial topics by applying formal game-theoretic models and empirical techniques. In Chapter 2, I develop a cheap-talk game of the three parties associated with climate change: the government, the climate scientist, and the median voter. I show that a credibility gap is created between the scientist and the government if the preference of the scientist is not perfectly aligned with that of the government. In the case where climate change is likely to be a serious problem, the credibility gap leads to too much burning of fossil fuels. The credibility gap is eliminated and the *ex-ante* social welfare is maximized if and only if the scientist's preference is perfectly aligned with that of the government. This is endogenously achieved when the government is allowed to appoint its optimal scientist without election concerns. In the case where the government has election

concerns, if the median voter perceives an alarming message from the climate scientist, then even a "right-wing" government must choose an aggressive climate change policy to avoid losing the election. Accordingly, it will prefer to appoint a climate scientist who is unlikely to send an alarming message. Thus the government deliberately creates a credibility gap which may cause distorted climate change policies in a democratic society. Nevertheless, the model predicts that countries with more democratic political institutions will have climate change policies that are more targeted towards renewable energy.

In Chapter 3, I test this theoretical prediction. In the analysis of international panel data of 1980-2012, I find that a one-unit increase in the Polity II index is associated with approximately 11-13 percent increase in the proportion of electricity due to renewable energy. I also find that a one-unit increase in the Polity II index is associated with approximately 3 percent decrease in the CO2 emissions per capita. That is, countries with more democratic institutions practice more environment-friendly policies; and they also produce lower CO2 emissions. I further study how the population environmental preferences, as measured by the LCV scores, influence state governors to become more concerned about the environment. From a U.S. panel data in the period of 1971-2007, I find the Republican state governors increase the environmental expenditure per capita by approximately 1.5 percent as the Democrat LCV scores increase by 1 percent; and they increase the environmental expenditure per capita by 4.8 percent as the Republican LCV scores decrease by 1 percent. That is, Republican governors respond positively to the LCV scores of the Democrats, but not to Republican LCV scores.

In Chapter 4, I extend the strategy of manipulating conflict developed by Baliga and Sjöström (2012) and apply it to climate-change politics between two asymmetric decision-makers under incomplete information. The decision-makers choose progressive or conservative actions towards climate change. A decision-maker from a country

with greater damage from climate change is more likely to be progressive than a country with lesser damage. Climate scientists can manipulate this decision-making by sending publicly observed cheap-talk messages. The likelihood of both players choosing progressive action on climate change decreases if both players are "coordination" types and the scientist is conservative. The conservative scientist can cause this by sending skeptical messages that trigger a spiral of climate change skepticism. This reduces the welfare of both decision-makers. If both players are opportunistic types, a progressive scientist can send alarming messages that cause the decision-maker from the country with greater damage from climate change to be more progressive. This reduces his welfare but benefits the other decision-maker. I show that there does not exist any communication equilibrium for either kind of scientist, for any other combination of player types.

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Dedication

To my family.

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Chapter 1

Introduction

This thesis is applied microeconomics in climate change and environmental economics. Climate scientists express strong consensus on anthropogenic climate change. Although science is based on "hard facts", there have been cases where scientists have been found to misrepresent data, or to hide relevant facts. Since politicians in general have no scientific background and they often suspect that scientific data could be misrepresented or manipulated, it is worthwhile to study the strategic interaction between a climate scientist and a politician who suspects the scientist may be manipulating the data. This thesis is a rigorous analysis of these controversial topics by applying formal game-theoretic models and empirical techniques. In Chapter 2, I develop a cheap-talk game of the three parties associated with climate change: the government, the climate scientist, and the median voter. I show that a credibility gap is created between the scientist and the government if the preference of the scientist is not perfectly aligned with that of the government. In the case where climate change is likely to be a serious problem, the credibility gap leads to too much burning of fossil fuels. The credibility gap is eliminated and the *ex-ante* social welfare is maximized if and only if the scientist's preference is perfectly aligned with that of the government. This is endogenously achieved when the government is allowed to appoint its optimal scientist without election concerns. In the case where the government has election concerns, if the median voter perceives an alarming message from the climate scientist, then even a "right-wing" government must choose an aggressive climate change policy to avoid losing the election. Accordingly, it will prefer to appoint a climate scientist who is unlikely to send an alarming message. Thus the government deliberately creates a credibility gap which may cause distorted climate change policies in a democratic society. Nevertheless, the model predicts that countries with more democratic political institutions will have climate change policies that are more targeted towards renewable energy.

In Chapter 3, I test this theoretical prediction. In the analysis of international panel data of 1980-2012, I find that a one-unit increase in the Polity II index is associated with approximately 11-13 percent increase in the proportion of electricity due to renewable energy. I also find that a one-unit increase in the Polity II index is associated with approximately 3 percent decrease in the CO2 emissions per capita. That is, countries with more democratic institutions practice more environment-friendly policies; and they also produce lower CO2 emissions. I further study how the population environmental preferences, as measured by the LCV scores, influence state governors to become more concerned about the environment. From a U.S. panel data in the period of 1971-2007, I find the Republican state governors increase the environmental expenditure per capita by approximately 1.5 percent as the Democrat LCV scores increase by 1 percent; and they increase the environmental expenditure per capita by 4.8 percent as the Republican LCV scores decrease by 1 percent. That is, Republican governors respond positively to the LCV scores of the Democrats, but not to Republican LCV scores.

In Chapter 4, I extend the strategy of manipulating conflict developed by Baliga and Sjöström (2012) and apply it to climate-change politics between two asymmetric decision-makers under incomplete information. The decision-makers choose progressive or conservative actions towards climate change. A decision-maker from a country with greater damage from climate change is more likely to be progressive than a country with lesser damage. Climate scientists can manipulate this decision-making by sending publicly observed cheap-talk messages. The likelihood of both players choosing progressive action on climate change decreases if both players are "coordination" types and the scientist is conservative. The conservative scientist can cause this by sending skeptical messages that trigger a spiral of climate change skepticism. This reduces the welfare of both decision-makers. If both players are opportunistic types, a progressive scientist can send alarming messages that cause the decision-maker from the country with greater damage from climate change to be more progressive. This reduces his welfare but benefits the other decision-maker. I show that there does not exist any communication equilibrium for either kind of scientist, for any other combination of player types.

Chapter 2

Rational Skeptics: On the Strategic Communication of Scientific Data

2.1. Introduction

Climate scientists express strong consensus on anthropogenic climate change. Although science is based on "hard facts", there have been cases where scientists have been found to misrepresent data, or to hide relevant facts. Since politicians in general have no scientific background and they often suspect that scientific data could be misrepresented or manipulated, it is worthwhile to study the strategic interaction between a climate scientist and a politician who suspects the scientist may be manipulating the data. The fundamental reason for this distrust must be different preferences: the politician may care more about economic growth, while the scientist cares more about the environment. This raises the following issue: suppose the politician cares less about the environment than the average citizen does. How does the welfare of the average citizen depend on the scientist's preferences? I study this issue in a game-theoretic model, where politician is not sufficiently educated to verify the scientific evidence, but is forced to rely on the scientist's judgment of the risk of climate change. I find a remarkable result: Social welfare is maximized when the scientist's preferences agree with the politician's, even if these do not represent the average citizen. Intuitively, it may seem the scientist's preferences ought to be aligned with the average citizen's; after all, it would mean that the scientist internalizes the true preferences of the society when she communicates the results of the scientific study to the politician. However, there is the counter balancing effect: when the scientist's preferences differ from the politician, there may be a lack of trust, which is the "crying wolf" problem. In the "Boy who cried wolf (Aesop's fable)," since the boy cried wolf too often, nobody believed him when a wolf actually came. The main contribution of my study is to model a communication game with the average citizen (the third agent) to examine how the welfare of the average citizen depends on the scientist's preferences.

Social concern about climate change has been steadily high. According to a national poll on global warming conducted by Stanford University, Resource For the Future, and the *New York Times* in January 2015, United States citizens perceive climate change (global warming) to be the most serious problem facing the world in the future if nothing is done to address it. At the same time, many people seem to fear that the government is not dealing sufficiently with climate change. As of January 2015, 53% of U.S. citizens thought that the government *should* do more than a moderate amount about climate change, but only 15% of citizens thought that the government *was* currently doing more than a moderate amount to deal with climate change.[1]

To explain the underlying disparity in the data about social concerns surrounding climate change, it is natural to consider a hypothesis that the government's preference for climate change policies may be different from that of the median voter. Specifically, the government may be less concerned about climate change than the median voter. Let us consider two dimensions of economic policy regarding climate change: economic growth and the environment. We consider these two concerns to be on opposite ends of a sliding scale, so that a policy which is more pro-growth will by nature be less pro-environment, and vice versa. We also assume that the right-wing political party prefers pro-growth economic policies, while the left-wing political party prefers pro-environment ones. We specifically consider a pro-growth government which advocates for economic development through the exploitation of natural resources. In simple

[1] Figures 1-2 show the results of Global Warming National Poll conducted by SSRS from January 7-22, 2015, organized by Resource For the Future, the *New York Times*, and Stanford University.

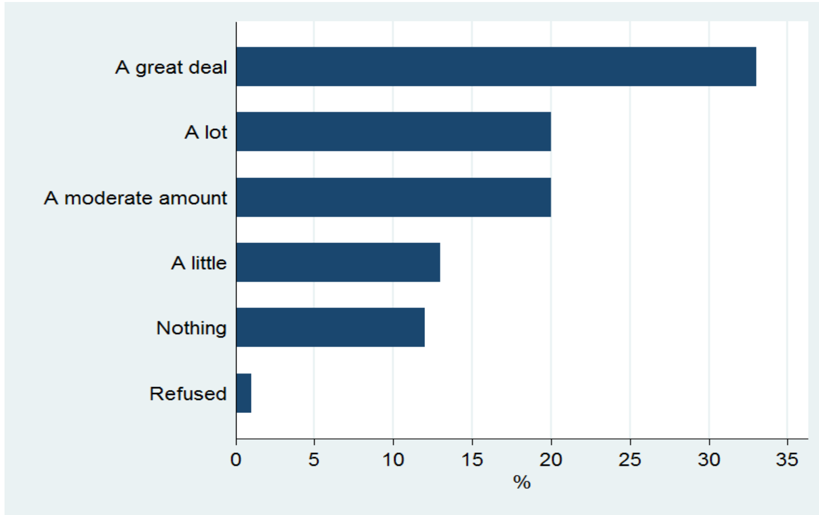

Figure 1: % of U.S. citizens who think that the government should do about global warming: a great deal, a lot, a moderate amount, a little, or nothing, *Global Warming National Poll conducted January 7-22, 2015.*

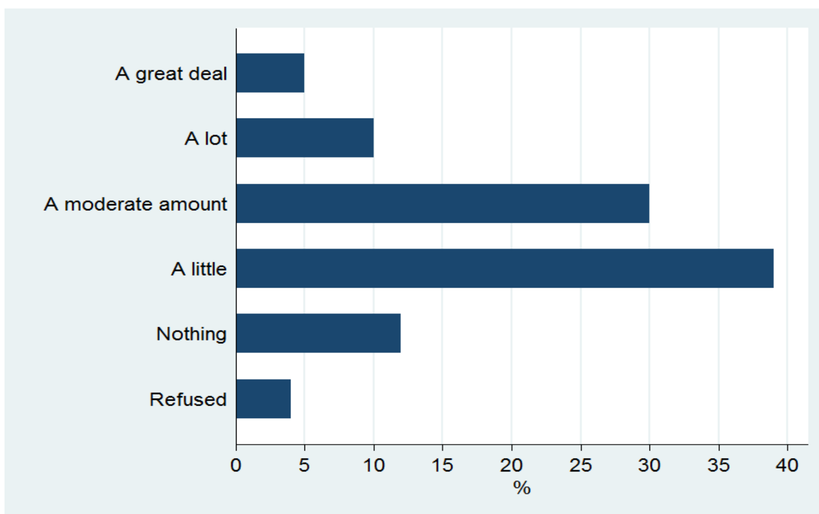

Figure 2: % of U.S. citizens who think that the government is currently doing: a great deal, a lot, a moderate amount, a little, or nothing to deal with global warming, *Global Warming National Poll conducted January 7-22, 2015.*

terms, we assume that such a government is more right wing (pro-growth) than the median voter.

However, this hypothesis does not seem sufficient to explain why governments and policymakers do not act on climate change warnings from the majority of climate scientists. Although the scientific community expresses a strong consensus on human-

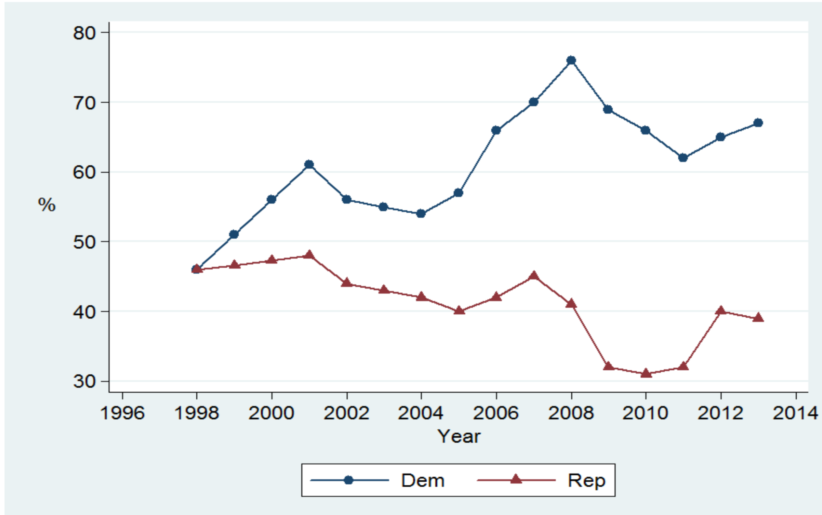

Figure 3: % of U.S. citizens who believe that effects of global warming are already occurring, by major U.S. political party, *Gallop Poll conducted March 7-10, 2013*

caused climate change, there are drastically different personal beliefs about climate change held by major players in the political arena.[2] In fact, there seems to be a remarkable divergence between the messages of climate scientists and the beliefs of the political arena. Figure 3 shows the percentage of U.S. citizens who believe that effects of global warming are already occurring, by major political party.[3] Republican view on climate change is certainly different from that of Democrats, and as is clear, the belief gap between the two parties has been increasing since 1998. The percentage of Republicans who believe in climate change has decreased since then, even though the scientific community has gained greater scientific confidence in human-caused climate change over the same period of time.

Some politicians refuse to believe the messages sent by climate scientists.[4] For

[2]While former U.S. vice president Al Gore made a documentary film, *An Inconvenient Truth*, to educate people about climate change, former president George W. Bush pulled out of the Kyoto Protocol, which was signed by the Clinton Administration when Al Gore was the vice president.

[3]This graph shows responses to the following question from the Gallop Poll: Which of the following statements reflects your view of when the effects of global warming will begin to happen – [*they have already begun to happen; they will start happening within a few years; they will start happening within your lifetime; they will not happen within your lifetime; but they will affect future generations; (or) they will never happen*]?

[4]For a specific example, see the prepared statement of Mr. Markey of the Hearing on the Administration's View on the State of Climate Science from the 111th Congress, which Mr. Markey complains of "systematic suppression of dissenting opinion," "intimidation," "manipulation of data

example, Congressman Paul Ryan, Republican of Wisconsin, restated his view on climate change in an October 2014 debate, in which he was asked if he thought human activity was to blame for changes to the planet's climate, by saying "I don't know the answer to that question. I don't think science does, either."[5]

Is this refusal to state a belief in the scientists' messages simply irrational? To study this issue, I develop a game-theoretic model of the three parties associated with climate change in the socio-economic political context: the government, the climate scientist, and the median voter. I work out the implications of having a government with "right-wing bias". My basic model shows that a credibility gap between the climate scientist and the government is created if the climate scientist's preference for what policy to enact is not perfectly aligned with the government. Specifically, if the climate scientist is more favorable toward renewable energy than the government, the credibility gap can result in too much burning of fossil fuels. The "left-wing" climate scientist sends an alarming message about climate change too often. As a result, a "right-wing" policymaker may feel that the "left-wing" climate scientist is sending an alarming message about climate change too often. The policymaker may then discount the alarming message, assuming that it is just exaggeration from the left wing. This may be indeed the case when the state is not bad. However, when the state *is* truly bad, the scientist cannot credibly communicate the danger. This results in a shortfall of renewable energy, which is very costly to society. To illustrate the credibility gap, we can turn to one of Aesop's fables, "The Boy Who Cried Wolf." Since the boy cried wolf too often, nobody believed him when a wolf actually came. If the preferences of the climate scientist and the government could be better aligned, this problem could be mitigated.

The credibility gap is eliminated and the *ex-ante* social welfare is maximized if and only if the climate scientist's preference is perfectly aligned with the government.

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and models, possible criminal activity," and more.

[5]Climate Change Skepticism, the *Guardian*, Nov 17th 2014.

If the government is allowed to appoint its climate scientist, then it would select one whose preference agrees with its own preference. Therefore, we can endogenously eliminate the credibility gap and maximize the *ex-ante* social welfare. This is a striking result. One might think that if the government is "right-wing biased" compared to the median voter, then the voter would not want the government to appoint a scientist that shares its preferences, because doing so could lead to bad climate change policies. However, I show that the opposite is true: When a right-wing government appoints its favorite scientist, the *ex-ante* social welfare is maximized. The intuition here is that when the government appoints a scientist, it appoints someone that it trusts not to "cry wolf" too often. This improves information transmission: In a truly dangerous state, the government will trust the alarming message and implement climate change policies accordingly. Thus it is socially optimal for the government to appoint a scientist who it feels comfortable with, even if the scientist is a "right-wing extremist."

Finally, we introduce election concerns. Under this constraint, if the median voter perceives an alarming message from the climate scientist, then even a right-wing government will be forced to choose an aggressive climate change policy to avoid losing the election. This deviation from its unconstrained optimum (without election concerns) is costly to the government, so it prefers to appoint a climate scientist who is unlikely to send an alarming message, i.e., one with more right-wing views.[6] Intuitively, the right-wing government has a political incentive to distort the communication with the scientific community, because it knows that it will have to respond to an alarming message with stronger climate change policies than it would like. Thus, a government with election concerns deliberately creates a credibility gap by appointing a scientist whose preferences differ from its own. For instance,

[6] In the opposite case when a left-wing government is in power, the climate change policy distortion causes the government to commit to a more left-wing climate scientist, which means that it is more likely to receive an alarming message.

George W. Bush, former president of the U.S., appointed Dr. John Marburger as the head of the White House Office of Science and Technology Policy. Dr. Marburger served as the presidential science adviser for Bush's entire time in office, and defended Bush administration policies which were often criticized by most scientists. As soon as Bush took office in 2001, his administration pulled out of the Kyoto Protocol. Dr. Marburger was widely criticized for defending these policies on climate change, particularly his defense against an assertion by the National Academy of Sciences that political influence was contaminating the scientific research in government agencies. He defended the Bush Administration from accusation that the Bush administration had distorted scientific information that would conflict with its policy preferences, especially on climate change policy and stem cell research. There is a series of evidence that the Bush administration has deliberately distorted the communication with the scientific community. [7]

This is in sharp contrast to the case where the government has no election concerns and therefore can choose its unconstrained optimal response to the scientist's message. In the unconstrained case it prefers to minimize the credibility gap by appointing a scientist with the same preference as itself. Thus, I have a surprising result: Election concerns may be the cause of a credibility gap in a democratic society, and this leads to distorted climate change policies. Despite this surprising result, I show that there will be more renewable energy when the government has election concerns than when it does not. Thus, from my model, I obtain a theoretical prediction that countries with more democratic political institutions will have climate change policies more targeted towards renewable energy.

I review the related literature in Section 2. The basic model is discussed in Section 3. I analyze equilibria where a government does not have election concerns in Section 4, and equilibria with election concerns in Section 5. I conclude in Section 6.

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[7] See The *Union of Concerned Scientists* 2004 Scientist Statement on *Restoring Scientific Integrity to Federal Policy Making* for further details.

2.2. Related Literature

My theoretical model is directly related with Crawford and Sobel (1982), in which a better informed sender sends a possibly noisy signal to a receiver, who then takes an action that determines the welfare of both. They characterize the set of Bayesian Nash Equilibria, which I apply to my model. Compared to usual Crawford and Sobel model, the main difference is that in my model there is not just a sender of messages (the scientist) and a receiver who takes an action (the politician), but there is also a third party: the median voter. I consider how communication between the sender and receiver determines the welfare of the third party. Moreover, via election concerns, the third party can influence the cheap-talk game, both by influencing how the receiver responds to messages, and by causing the receiver to deliberately create a credibility gap (by strategic selection of a sender).

My research relates to the democratic political decision-making framework of Schultz, where political parties have more information about the economy than voters. In his research, policymakers are the ones who gather information about the true state of the economy and make decisions, and they are often aided by experts. Schultz examined whether or when policymakers will reveal information truthfully to voters and what consequences these revelations will have. He showed that nonrevealing equilibria exist when political parties have sufficiently different preferences from the median voter's; and that revealing equilibria exist when one of the parties has a preference close to the median voter. The political decision-making framework in our research differs from his in a few ways. First, as Schultz acknowledges, policymakers often rely on experts' advice when they make political decisions. I include climate scientists (experts) in the framework to see how experts affect policymakers' decisions. Second, I assume that voters can observe the message about the true state of the world from climate scientists. This is a plausible assumption because information regarding climate change is not restricted from voters the way it was in prior years. It is now easy for voters to access to the messages from climate scientists (e.g., research papers, newspaper articles, scientific reports available on the Internet, and etc.).

My model is also related with Baliga and Sjöström (2012). They examined how an extremist can influence political decision-making by sending publicly observed messages. They showed that a publicly observed cheap-talk message sent by one country's extremist can influence the other country's political decisions. Specifically, an extremist can increase the likelihood of conflict between two different countries.

Public perception of climate change in one of the key factors in determining climate change policies in our model. Leiserowitz (2006) argue the importance of public perception of climate change in the socio-economic political context. The direction of climate change policy (for example, public support or opposition to climate change policies such as carbon taxes or clean energy subsidies) is substantially influenced by public perceptions of climate change. Lorenzoni and Pidgeon (2006) survey how climate change is conceptualized in the Europe and the U.S., and conclude that awareness of climate change is widespread but that it is considered less important than other personal or social issues. Furthermore, the public showed limited understanding of the causes of, and the solutions to, climate change.

A country's political system may influence its climate change policies in our model. I found several empirical research on the relationship between environmental policies and political systems. Hassler and Krussel (2012) construct a model to quantify how key features of heterogeneity between different regions of the world affect those regions' preferences for different climate change policies. They show that in the absence of international transfer mechanisms, Pareto-improving policies to curb climate change may not exist. Fredriksson and Neumayer (2013) study the relationship between countries' democratic capital stocks and climate change policies. Using data for 87 countries starting from as far back as the year 1800, they show that larger democratic capital stocks are associated with more stringent climate change polices.

Congleton (1992) provides a simple model to show how different political institutions affect the enactment of environmental regulations. He finds empirical evidence that political institutions play a significant role to the pollution control policies. My contribution to this literature is that I provided a rigorous game-theoretic model to theoretically explain those empirical results.

Both the causes of and the solutions to climate change involve intrinsic global externalities, which led many governments to the negotiations table for international cooperations against climate change. There is an abundant literature in climate change agreements. It provides important implications for designing climate change agreements. Battaglini and Harstad (2012) analyze a dynamic game where countries decide whether to participate in international environment agreements. They show that participants eliminate the hold-up problem associated with their investments if complete contracts are feasible; however, the free-rider problem is not resolved. If investments are non-contractible, countries face a hold-up problem when they negotiate, but the free-rider problem can be mitigated and significant participation is feasible. Harstad (2012) presents a dynamic game where players contribute to a public bad, invest in technologies, and write incomplete contracts. He shows that investments are sub-optimally small if the contract is short term or close to its expiration date if only the contribution levels are contractible. To encourage investments, the optimal contract is more ambitious if it is short term, and it is tougher to satisfy close to its expiration date and for players with small investment costs.

Public perception of climate change and the associated public consensus may be critical determinants of domestic political decisions about climate change policies. The link between public perception and policy depends on the political system of the country, including the participation of the public and the competitiveness of the political system. Decisions to participate in international climate change agreements should be a part of, and based on, the domestic political decisions about climate change. Therefore, domestic political decisions about climate change should be considered first before stepping up to the negotiations table for international cooperations against climate change. I examine the socio-economic political context of climate change by examining the domestic political decision-making framework for climate change policies, which involves governments (policymakers), climate scientists, and median voters.

2.3. Basic Model

I consider a cheap-talk game among a government (policymaker), a climate scientist, and a median voter. I show how a credibility gap is created between the scientific community and the political arena. We note that the messages from climate scientists, which are scientific reports on climate change, are not verifiable by governments. Therefore, the messages themselves are talk-costless, nonbinding, and nonverifiable claims, which make the game a cheap-talk game. I note that the policymaker's preference is critical when he or she implements climate change policies.

A government (country) produces GHGs by consuming fossil fuels, and I denote the government's quantity of GHG emissions per capita as G. I assume that consuming fossil fuels produces the same quantity of GHGs. Thus we may interpret G as either GHG emissions per capita or fossil fuel consumption per capita. The quantity of energy consumption per capita generated by renewable energy sources (clean energy), which do not emit GHGs, is denoted by R. We can also interpret R as the level of clean technology that a country uses to mitigate its GHG emissions. The quantity of total energy consumption per capita is denoted by y, which I assume is fixed. I assume that each country has two sources of energy: energy from fossil fuels (G) and energy from renewable energy sources (R). If a country increases its quantity of renewable energy (R) when the total quantity of energy (y) is fixed, then it would decrease its consumption of fossil fuels and thereby its GHG emissions (G) would fall.

Therefore, we have the following relationship:

$$G = y - R. \tag{1}$$

If we interpret R as the level of clean technology employed to mitigate GHGs, then G is interpreted as the quantity of GHGs mitigated by the clean technology (R). There is a one-to-one relationship between G and R: reducing one unit of GHGs or fossil fuels (G) is equal to increasing one unit of renewable energy (R).

We normalize G and R in (1) to be fractions:

$$g = 1 - r, \tag{2}$$

where $g = G/y$ and $r = R/y$. Since I assume that the total quantity of energy (y) is fixed, choosing the proportion of total energy due to fossil fuel (or equivalently renewable energy) is what the government cares about in our model. I denote the proportion of total energy due to fossil fuel and the proportion due to renewable energy g and r, respectively.

When choosing its optimal energy policy, a government considers not only the benefit of consuming fossil fuels (g) but also the adverse effects from excessive consumption of fossil fuels. Thus I assume that a government's utility of consuming fossil fuels, $u(g)$, is represented by a quadratic and concave function of the proportion of total energy due to fossil fuel:[8]

$$u(g) \quad = \quad -g^2 + \bar{\beta} g. \tag{3}$$

$\bar{\beta} \in [0, 2]$ is a parameter that represents the general preference for clean environment of a government. It is assumed to be smaller (closer to 0) as countries naturally

[8] I follow Battaglini and Harstad (2012) among many others.

prefer cleaner environments. Notice that $u'(g) = 0$ when $g = \bar{\beta}/2$. If a government does not have any preference for a clean environment (i.e., $\bar{\beta} = 2$), then all of its total energy consumption comes from burning fossil fuels (i.e., $g = 1$). Alternatively, we can interpret that there is no clean technology mitigating GHGs if $\bar{\beta} = 2$, and thereby $g = 1$.

We can express the utility function (4) as a function of r (the proportion of total energy due to renewable energy or the level of clean technology) by using the one-to-one relationship between g and r:

$$u(r) = -1 + \bar{\beta} + (2 - \bar{\beta})r - r^2. \tag{4}$$

2.3.1. The State of the World

I assume that there are two possible states of the world, *Good State* and *Bad State*. In the *Good State*, there is no possibility that climate change results in disaster, so each government can conduct its business as usual. In the *Bad State*, it is certain that climate change will result in disaster, so each government must take precautionary actions against climate change. The government does not know the true state of the world, and it cannot observe the probability of the *Bad State*. But it has a prior distribution F with a continuous density f over the probability of the *Bad State*, $\theta \in [0, 1] \equiv \Theta$. The climate scientist can observe the probability of the *Bad State*, θ. The utility function of the climate scientist is

$$U^S(r, \theta) = \theta \underbrace{\left[-1 + \beta_S + (2 - \beta_S)r - r^2\right]}_{\text{Payoff in } \textit{Bad State}} + (1 - \theta) \underbrace{\left[-1 + \bar{\beta} + (2 - \bar{\beta})r - r^2\right]}_{\text{Payoff in } \textit{Good State}}. \tag{5}$$

The government's utility function is

$$U^G(r, \theta) = \theta \underbrace{\left[-1 + \beta_G + (2 - \beta_G)r - r^2\right]}_{\text{Payoff in } \textit{Bad State}} + (1 - \theta) \underbrace{\left[-1 + \bar{\beta} + (2 - \bar{\beta})r - r^2\right]}_{\text{Payoff in } \textit{Good State}}. \tag{6}$$

Notice that the payoff in the *Good State* is the same as (4).

I have a few criteria to define the preferences for energy policies in the *Bad State*, i.e., climate change policies. First, the government's preference may be different from the climate scientist's. Note that the government and the climate scientist each have a parameter, β_G and $\beta_S \in [0, 2]$, respectively, when they are in the *Bad State*. They measure how the government and the climate scientist weigh the importance of renewable energy when they are in the *Bad State*. If β_G and β_S are closer to 0, then the government and the climate scientist prefer higher levels of renewable energy (r) when he or she is in the *Bad State*. Second, I assume that both the government and the climate scientist put a greater weight on renewable energy when they are in the *Bad State* than when they are in the *Good State*. Thus we have the following assumption.

Assumption 1. $0 \leq \beta_G < \bar{\beta} \leq 2$ *and* $0 \leq \beta_S < \bar{\beta} \leq 2$.

Notice that the payoff in the *Bad State* has a higher benefit from consuming renewable energy than that in the *Good State*.

We may interpret β_G and β_S as the ideological positions of the government and the climate scientist, respectively. Recall that we consider two dimensions of economic policy, growth and the environment. If $\beta_S < \beta_G$, then it may be the case where the climate scientist is more biased toward the environment, while the government is more biased toward growth.

2.4. Information Transmission without Election Concerns

First, I consider the case where the government does not have any election concerns regarding climate change policies. We can think of this case as an authoritarian state with regard to climate change policies. Therefore in this variation of the model, I consider only two players, a government (G) and a climate scientist (S).

I assume that β_S is exogenously given. I consider the message space of the climate scientist, $M \equiv \{m_L, m_H\}$, where m_L indicates a message of *Low* probability of the *Bad State* (a comforting message) and m_H indicates a message of *High* probability of the *Bad State* (an alarming message). The timing of the game is as follows:

Stage 1. The climate scientist privately observes the probability of the *Bad State*, $\theta \in \Theta$, and then sends a message $m \in M$ to the government.

Stage 2. The government observes the climate scientist's message m (but not θ) and then chooses $r^*(m)$, its optimal climate change policy.

I define a perfect Bayesian equilibrium, which consists of signaling rules $q(m|\theta)$ for S, optimal climate change policies $r^*(m)$ for G, and the G's posterior belief $\rho(\theta|m)$ such that

(C1) for each $m \in \{m_L, m_H\}$, $r^*(m)$ solves

$$\max_{r \in \mathbb{R}_+} \int_0^1 U^G(r, \theta)\rho(\theta|m)d\theta \tag{7}$$

where $\rho(\theta|m)$ is the government's posterior belief after observing the climate scientist's message m by applying Bayes' rule whenever possible; and

(C2) for each $\theta \in [0, 1]$ and $m^* \in M$, if $q(m^*|\theta) > 0$, m^* solves

$$\max_{m \in M} U^S(r^*(m), \theta). \tag{8}$$

I derive a partially separating equilibrium with a two-step by assuming that f is a uniform distribution over $\Theta = [0, 1]$. As I assume that there exist only two possible messages $m \in \{m_L, m_H\}$, there must exist a cut-off point $x \in \Theta$ such that the climate scientist sends $m(\theta) = m_L$ if $\theta < x$, and $m(\theta) = m_H$ if $\theta \geq x$.

Suppose that the government will update its belief that θ is uniformly distributed over $[0, x)$ if it receives the comforting message m_L; likewise, it will update its belief that θ is uniformly distributed over $[x, 1]$ when it receives the alarming message m_H. That is,

$$\rho(\theta|m) = \frac{q(m|\theta)f(\theta)}{q(m)},$$

where

$$q(m) = \int_0^1 q(m|t)f(t)dt.$$

Lemma 1. *The proportion of renewable energy is higher when the government receives the alarming message m_H (High probability of the Bad State) than when it receives the comforting message m_L (Low probability of the Bad State). That is,*

$$r^*(m_L; x) = 1 - \frac{\bar{\beta}}{2} + \frac{x}{4}(\bar{\beta} - \beta_G), \tag{9}$$

$$\leq r^*(m_H; x) = 1 - \frac{\bar{\beta}}{2} + \frac{x+1}{4}(\bar{\beta} - \beta_G). \tag{10}$$

Proof. See Appendix □

Notice that $r^*(m_L)$ is the government's optimal climate change policy if it receives the comforting message m_L and that $r^*(m_H)$ is its optimal climate change policy if it receives the alarming message m_H. The government responds to the alarming message with higher proportion of renewable energy.

Since the climate scientist's utility function is in a quadratic form and thus is symmetric around her optimal climate change policy $r^S(\theta)$ where

$$r^S(\theta) = arg\max_r U^S(r, \theta) = 1 - \frac{\bar{\beta}}{2} + \frac{\theta}{2}(\bar{\beta} - \beta_S), \tag{11}$$

the climate scientist prefers $r^*(m_L)$ to $r^*(m_H)$ if the midpoint between $r^*(m_L)$ and

$r^*(m_H)$ is higher than its optimal energy policy $r^S(\theta)$. However, she prefers $r^*(m_H)$ to $r^*(m_L)$ if $r^S(\theta)$ is higher than the midpoint. Therefore, for the existence of a partially separating equilibrium with a two-step, the cut-off point $x \in \Theta$ must be the point where $r^S(\theta)$ is exactly equal to the midpoint between $r^*(m_L)$ and $r^*(m_H)$.

Proposition 1. *If $\beta_S \leq \bar{\beta}/4 + 3\beta_G/4$, there exists a partially separating equilibrium with a two-step, where the cut-off point is given by*

$$x = \frac{\frac{1}{2}(\bar{\beta} - \beta_G)}{\bar{\beta} + \beta_G - 2\beta_S} \in \Theta. \tag{12}$$

Proof. See Appendix □

2.4.1. Credibility Gap

Recall that I assumed the climate scientist's ideological position is exogenously given. If the climate scientist's ideological position is perfectly aligned with that of the government, i.e., $\beta_S = \beta_G$, then the cut-off point $x \in \Theta$ becomes $1/2$.

Definition 1. *A credibility gap is the difference between the government's cut-off point x and $1/2$.*

If a government receives a message from a more left-wing climate scientist, i.e., $\beta_{S'} < \beta_G$, then the cut-off point $x \in \Theta$ becomes smaller than $1/2$. That is, a credibility gap is created by the left-wing scientist. Figure 4 illustrates a credibility gap created by the left-wing scientist. To illustrate, suppose that the exogenous climate scientist has an identical ideological position to a left-wing party, and the right-wing government's ideological position is different from that, i.e., $\beta_S = \beta_{LW} < \beta_{RW}$. Then the right-wing government's cut-off point x is smaller than $1/2$. The climate scientist and the left-wing party views being close together creates a credibility gap about the scientist for the right-wing government, and therefore the right-wing government is

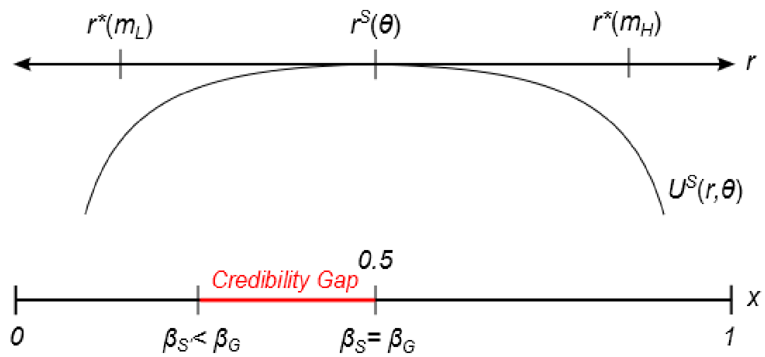

Figure 4: A credibility gap

doubtful about the truthfulness of the scientist's message. The existence of a credibility gap means that a government is less likely to trust that the information being transmitted is unbiased, and thus is doubtful about the veracity of the message sent by the scientist.

Some episodic observations seem to support our theoretical results. For example, many right-wing politicians in the U.S. seem to be skeptical about human-caused climate change, which is strongly supported by climate scientists. As they have gained greater scientific confidence in human-caused climate change, climate scientists' political views on climate change policies have become much closer to those of the left wing. Thus right-wing politicians have become more doubtful about human-caused climate change as investigated by the scientific community.[9] Figure 3 shows the percentage of Americans by political party who believe that the effects of global warming have already begun. In 1998, 46% of Americans in both parties believed that these effects had already begun. However, the gap between the two parties has increased since then: In 2013, only 39% of Republicans believed the effects had already begun, but 67% of Democrats did.

When the climate scientist is more left wing than the government, the climate

[9]Meet the Republicans in Congress who don't believe climate change is real, *The Guardian*, Nov 17th 2014.

scientist becomes more "alarmist": he becomes more likely to send the alarming message m_H as $x < 1/2$. To illustrate, suppose that the climate scientist's ideological position is constant but the ruling party of the government changes from the left wing to the right wing. Then, we would expect that the scientific reports to become more alarming. We may turn to one of Aesop's fables, "The Boy Who Cried Wolf," to illustrate the credibility gap created by the left-wing scientist. Since the boy cried wolf too often, nobody believed him when a wolf actually came.

2.4.2. Social Welfare

Let us consider a social welfare function to examine the optimal ideological position of the climate scientist. I assume a purely utilitarian social welfare function of citizens of a society. I consider the median voter's utility function as follows:

$$U^V(r,\theta) = \theta[-1 + \beta_V + (2-\beta_V)r - r^2] + (1-\theta)[-1 + \bar{\beta} + (2-\bar{\beta})r - r^2], \quad (13)$$

where β_V is the ideological position that measures how the median voter weighs the importance on renewable energy in the *Bad State*.

Assumption 2. $\beta_V \in [0, \frac{\bar{\beta}+\beta_G}{2})$.

The *ex-ante* social welfare function is the summation of all the median voters' *ex-ante* utility function.[10] Assuming that the number of the median voters is given by N, the *ex-ante* social welfare function is the following.

$$W\{E_\theta U^V[r^*(m(\theta)),\theta]\} = N \cdot E_\theta U^V[r^*(m(\theta)),\theta], \quad (14)$$

[10] In the real-world, the number of the median voters outweighs the number of climate scientists and policymakers.

where

$$E_\theta U^V\left[r^*(m(\theta)),\theta\right] = q(m_L)\int_0^x U^V(r^*(m_L),\theta)\rho(\theta|m_L)d\theta + q(m_H)\int_x^1 U^V(r^*(m_H),\theta)\rho(\theta|m_H)d\theta.$$

I present the optimal ideological position of the climate scientist which maximizes the *ex-ante* social welfare in the following theorem.

Theorem 1. *The ex-ante social welfare is maximized with respect to β_S when $\beta_S = \beta_G$, i.e., when there is no credibility gap.*

Proof. See Appendix □

This is a striking result: the *ex-ante* social welfare is maximized if the climate scientist's ideological position is aligned with the government's, not the median voter's. This striking result is due to the fact that a credibility gap reduces the *ex-ante* social welfare. If the climate scientist is to the left of the government, a credibility gap is created, and this reduces the *ex-ante* social welfare. As the credibility gap is created by the left-wing climate scientist, the alarming message is sent "too often". As a result, a "right-wing" policymaker may feel that the "left-wing" climate scientist is sending an alarming message about climate change too often. The policymaker may then discount the alarming message, assuming that it is just exaggeration from the left wing. This may be indeed the case when the state is not bad, i.e., $x \leq \theta < 1/2$. However, when the state *is* truly bad, i.e., $\theta > 1/2$, the scientist cannot credibly communicate the danger. This results in a shortfall of renewable energy, which is very costly to society.

If the ideological positions of the climate scientist and the government could be better aligned, the problem would be mitigated. Indeed, even if the government's ideological position on the environment deviates from the median voter's position, the *ex-ante* social welfare is maximized as long as the climate scientist's position is aligned with the government's, not with the median voter's.

2.4.3. Endogenous Selection of Scientist

I allow the government to choose its climate scientist in the very first stage of the game (Stage 0). I show how the government selects its optimal climate scientist (b_s) when it does not have any election concerns with regard to its climate change policy. The timing of the game is as follows:

Stage 0. The government chooses a climate scientist with β_S.

Stage 1. The climate scientist privately observes the probability of the *Bad State*, $\theta \in \Theta$, and then sends a message $m \in M$ to the government.

Stage 2. The government observes the climate scientist's message m (but not θ) and then chooses $r^*(m)$, its optimal climate change policy.

I define a perfect Bayesian equilibrium, which consists of signaling rules $q(m|\theta)$ for S, the optimal climate scientist β_S^* and optimal climate change policies $r^*(m)$ for G, and the G's posterior belief $\rho(\theta|m)$ such that

(C1) for each $m \in \{m_L, m_H\}$, $r^*(m)$ solves

$$\max_{r\in\mathbb{R}_+} \int_0^1 U^G(r,\theta)\rho(\theta|m)d\theta, \tag{15}$$

where $\rho(\theta|m)$ is the government's updated belief after observing the climate scientist's message m by applying Bayes' rule whenever possible;

(C2) for each $\theta \in [0,1]$ and $m^* \in M$, if $q(m^*|\theta) > 0$, m^* solves

$$\max_{m\in M} U^S(r^*(m),\theta); \text{and} \tag{16}$$

(C3) β_S^* solves

$$\max_{\beta_S \in [0,2]} E_\theta U^G[r^*(m(\theta)), \theta]. \tag{17}$$

Proposition 2. *If the climate scientist is endogenously chosen by the government, the government selects a climate scientist whose ideological position is perfectly aligned with its own position, i.e.,* $\beta_S^* = \beta_G$.

Proof. See Appendix □

We can derive an important implication from Proposition 2. The maximized *ex-ante* social welfare is achieved endogenously if we allow the government to choose its climate scientist. Then it will select a climate scientist whose ideological position agrees with its own position, so the credibility gap will be eliminated.

Corollary 1. *The ex-ante social welfare is endogenously maximized if the government can select a climate scientist perfectly aligned with its own ideological position.*

Proof. Follow from Theorem 1 and Proposition 2. □

This is another striking result. The social welfare is maximized when the government appoints its favorite scientist. The intuition is that when the government appoints a climate scientist, it appoints someone that it trusts not to "cry wolf" too often. This indeed improves the information transmission; in the truly dangerous state, the government will trust the alarming message and implement enough renewable energy. So it is socially optimal for the government to appoint a climate scientist who it feels comfortable with, even if that scientist is a "right-wing extremist".

2.5. Information Transmission with Election Concerns

I consider a case where the government has election concerns with regard to climate change policies. I assume that the political system is a full democracy (where the median voters have the power to replace the regime). If the median voter's ideological position is perfectly aligned with the government, i.e., $\beta_V = \beta_G$, then the government's optimal climate change policies must be also optimal for the median voter. Thus the government does not have any election concerns with regard to climate change policies. By Corollary 1, we can eliminate the credibility gap and maximize the *ex-ante* expected social welfare if we allow the government to select its climate scientist in this case.

However, if the median voter's ideological position is not perfectly aligned with the government's, then the government must have election concerns with regard to climate change policies in a full democracy.

I consider two political parties, a left wing (LW) and a right wing (RW). I assume that the left-wing party puts higher weight on renewable energy than the right-wing party in the *Bad State*. Thus I have the following assumption.

Assumption 3. $\beta_{LW} < \beta_V < \beta_{RW}$.

I assume that the median voter cannot observe the probability of the *Bad State* (θ). However, they can observe the message from the climate scientist, $m \in M$, as well as the government's optimal climate change policies, $r_G(m_L)$ and $r_G(m_H)$ for all $G = \{LW, RW\}$.

Recall that I focus on the case where the government is more right wing than the median voter. Thus I shall suppose that the right-wing party is in power at the beginning of the game. In Stage 0, the right-wing government selects its optimal climate scientist while it considers the following voter constraints (VC).

(VC) β_S^* solves

$$\max_{\beta_S} E_\theta U^{RW}[\hat{r}_{RW}(m(\theta)),\theta]$$

s.t.

$$\int_0^x U^V(\hat{r}_{RW}(m_L),\theta)\rho(\theta|m_L)d\theta \geq \int_0^x U^V(r^*_{LW}(m_L),\theta)\rho(\theta|m_L)d\theta \tag{18}$$

$$\int_x^1 U^V(\hat{r}_{RW}(m_H),\theta)\rho(\theta|m_H)d\theta \geq \int_x^1 U^V(r^*_{LW}(m_H),\theta)\rho(\theta|m_H)d\theta \tag{19}$$

Note that $\hat{r}_{RW}(m_L)$ and $\hat{r}_{RW}(m_H)$ are the constrained optimum when the government has election concerns. It is a commitment of climate change policy to prevent the alternative party from winning the election. The left-hand sides of the voter constraints (18) and (19) are the median voter's expected utility levels from the climate change policies of the current government (the right wing), $\hat{r}_{RW}(m)$, conditional on the message $m \in \{m_L, m_H\}$. So, conditional on the message, the expected utility of the current policy has to be greater than the expected utility from the alternative party's policies, $r^*_{LW}(m_L)$ and $r^*_{LW}(m_H)$, which are the unconstrained optimum specified in Lemma 1. The median voter will choose the alternative party in the next election if he expects strictly higher utility from the climate change policy of the alternative party than that of the current government. Therefore, in order for the current government to maintain its regime, the median voter's expected utility from the current government's climate change policy must be higher or at least equal to the expected utility from the alternative party.

The timing of the game is as follows:

Stage 0. The government chooses a climate scientist with β_S.

Stage 1. The climate scientist privately observes the probability of the *Bad State*, $\theta \in \Theta$, and then sends a message $m \in M$ to the government.

Stage 2. The government observes the climate scientist's message m (but not θ) and

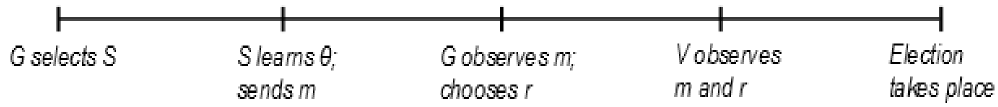

Figure 5: Timing of the game

then announces $\hat{r}_G(m)$, its optimal climate change policy.

Stage 3. The median voter observes both the climate scientist's message m and the government's optimal climate change policy $\hat{r}_G(m)$.

Stage 4. The election takes place. The median voter can either choose the current ruling party; or choose the alternative party if the constraints are not satisfied. If the alternative party takes power, it will choose its optimal climate change policy given m. That is, the new government cannot change the climate scientist and must take the message given.

Note that, in Stage 4, I assume that the new government cannot change the climate scientist (appointed by the current government) and must take the message given. This assumption makes sense because, once climate change is investigated by the climate scientist appointed by the current government, it would be hard for a new scientist to send a different message from the current scientist. As all the data of climate change is already organized, manipulated and presented by the current scientist, there would be little chance to reveal completely new data in the scientific community.[11][12]

I define a perfect Bayesian equilibrium, which consists of signaling rules $q(m|\theta)$ for S, the optimal climate scientist β_S^* and optimal climate change policies $r^*(m)$ for G, and the G's posterior belief $\rho(\theta|m)$ that satisfy **C1**, **C2**, and **VC**.

[11] Even if the alternative party can select its optimal scientist, the climate change data provided the previous scientist cannot be changeable. Namely, the new scientist cannot observe θ.

[12] One may extend our model as follows: in Stage 4, the alternative party can select its optimal climate scientist who can observe θ and send a new message $m \in \{m_L, m_H\} \equiv \tilde{M}$.

I first examine partially separating equilibria where the election concerns do not distort the selection of scientist. I consider two cases. First, if the median voter's ideological position (β_V) is closer to the ruling party than the alternative party, then the voter constraints (18) and (19) are not active. Therefore, the government appoints a scientist whose ideological position agrees with the ruling party, and then announces the unconstrained climate change policy, $r_G^*(m)$, derived in Lemma 1. Second, suppose that the median voter's position is equidistant from both parties. Namely, $\beta_V = (\beta_{LW} + \beta_{RW})/2$. Then, the median voter is indifferent between the two parties because their policies are equally far away from its optimum. Let us assume that he votes for the ruling party when he is indifferent. Then the voter constraints are not active, and thus the ruling party can disregard the election concerns. Therefore, the government appoints a scientist whose ideological position agrees with the government, and then announces the unconstrained climate change policy, $r_G^*(m)$, derived in Lemma 1. Notice that we can eliminate the credibility gap in both cases, i.e., $x = 1/2$.

Proposition 3. *The government (the ruling party) appoints a scientist whose ideological position agrees with its own position, i.e.,* $\beta_S^* = \beta_G$, *and thereby no credibility gap, i.e.,* $x = 1/2$, *in the following two cases:*
(i) the median voter's position is closer to the ruling party; and
(ii) the median voter's position is equidistant between the two parties, i.e., $\beta_V = (\beta_{LW} + \beta_{RW})/2$.

Proof. See Appendix □

2.5.1. Deliberately Created Credibility Gap

I now examine partially separating equilibria where the ideological position of the median voter is closer to the alternative party. In this case, the government (the ruling party) has fears of losing power at Stage 0 when it chooses its optimal climate scientist. That is, the voter constraints (18) and (19) are strictly binding. In order for the government (the ruling party) to win the election at Stage 4, the government announces the constrained optimum policy, $\hat{r}_G(m_L)$ and $\hat{r}_G(m_H)$, which are stronger than the unconstrained policies derived in Lemma 1, i.e., more aggressive renewable energy policies.[13] The fears of losing power cause a distortion of the government's optimal climate change policy.

The policy distortion causes another distortion in Stage 0. That is, the government does not appoint a scientist whose ideological position agrees with its own position. As a result, a credibility gap is created between the government and the climate scientist. Recall that we focus on the case where the government is more right-wing than the median voter. In Stage 0, the right-wing government knows that it must announce the constrained optimum policy, which is stronger than its unconstrained policy in Stage 2. The distortion of climate change policies causes the right-wing government to appoint a more right-wing climate scientist than itself at Stage 0, i.e., $\beta_S^* > \beta_{RW}$. Intuitively, the right-wing government has a political incentive to distort the communication with the scientific community, because it knows that it will have to respond to an alarming message with stronger climate change policies than it would like. Thus, the government's election concerns cause it to deliberately create a credibility gap by appointing a scientist whose ideological position differ from its own. This is in sharp contrast to the case where the government has no election concerns and therefore can choose its unconstrained optimal response to the scientists message – in the unconstrained case it prefers to minimize the credibility gap by appointing a scientist with the same ideological position as itself. Thus, we have a surprising result: election concerns may be the cause of a credibility gap in a democratic society, and this leads to distorted climate change policies.

Proposition 4. *If the ideological position of the median voter is closer to that of the*

[13]The constrained optimum climate change policies are weaker than the unconstrained policies, i.e., less aggressive renewable energy policies, when the left wing is the ruling party of the government.

alternative party,

(i) the right-wing government appoints a more right-wing climate scientist, $\beta_S^* > \beta_{RW}$*;*

(ii) the right-wing government commits to higher proportions of renewable energy than the unconstrained policies derived in Lemma 1. That is, the constrained policies are

$$\hat{r}_{RW}(m_L; x) = 1 - \frac{\bar{\beta}}{2} + \frac{x}{4}(\bar{\beta} - 2\beta_V + \beta_{LW});$$
$$\hat{r}_{RW}(m_H; x) = 1 - \frac{\bar{\beta}}{2} + \frac{x+1}{4}(\bar{\beta} - 2\beta_V + \beta_{LW}).$$

Proof. See Appendix □

The right-wing government commits to a climate scientist more inclined to the right wing, i.e., $\beta_S^* > \beta_{RW}$, because it knows that it will have to commit to higher levels of renewable energy (the constrained optimum policies); and it becomes less likely to receive the alarming message as $x > 1/2$. In Stage 3, it commits to higher levels of renewable energy than those derived in Lemma 1. The commitment of higher renewable energy is due to the fact that the right-wing government has fears of losing power. The median voter and the left-wing party being close together raises fears of losing power in the next election at Stage 4. The fears of losing power lead the government to commit to higher levels of renewable energy, which will make it win the next election at Stage 4. That is, the right-wing party's commitment of climate change policies must be at least as good as the alternative party's policy. Figure 6 shows the distortion of climate change policy due to the fears of losing power for the right-wing government.[14]

These results are interesting. The fears of losing power, which arises from the fact that the ideological position of the median voter is closer to the alternative party, are the cause of a credibility gap in a democratic country. Although we cannot achieve

[14] In the case where the left wing is in power at the beginning of the game and the median voter is closer to the right wing, the results are the reverse of the Proposition 4: the government appoints a more left-wing climate scientist, i.e., $\beta_S^* < \beta_{LW}$; and the government commits to lower levels of renewable energy than the unconstrained policies specified in Lemma 1. That is, the constrained

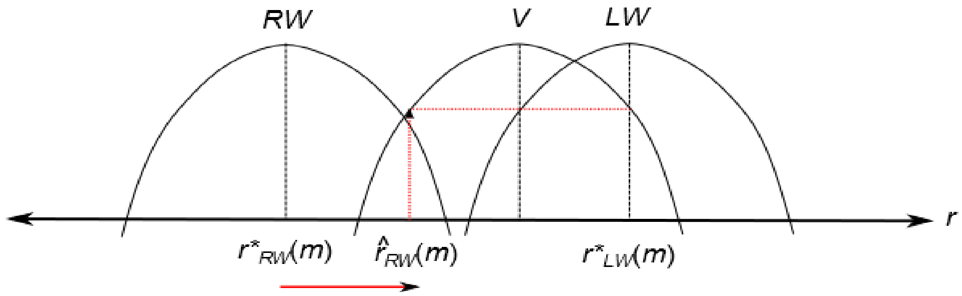

Figure 6: Distortion of climate change policies due to fears of losing power

the maximized *ex-ante* social welfare if the government has the fears of losing power, we can achieve more moderate climate change polices compared to the case without the fears.

We may find anecdotal evidence of Proposition 4 in the Bush administration. George W. Bush, former president of the U.S., appointed Dr. John Marburger as the head of the White House Office of Science and Technology Policy. Dr. Marburger served as the presidential science adviser for Bush's entire time in office, and defended Bush administration policies which were often criticized by most scientists. As soon as Bush took office in 2001, his administration pulled out of the Kyoto Protocol. Dr. Marburger was widely criticized for defending these policies on climate change, particularly his defense against an assertion by the National Academy of Sciences that political influence was contaminating the scientific research in government agencies. He defended the Bush Administration from accusation that the Bush administration had distorted scientific information that would conflict with its policy preferences, especially on climate change policy and stem cell research. In 2004, a number of leading

policies are

$$\hat{r}_{LW}(m_L) = 1 - \frac{\bar{\beta}}{2} + \frac{x}{4}(\bar{\beta} - 2\beta_V + \beta_{RW});$$
$$\hat{r}_{LW}(m_H) = 1 - \frac{\bar{\beta}}{2} + \frac{x+1}{4}(\bar{\beta} - 2\beta_V + \beta_{RW}).$$

Proof. See Appendix □

scientists released a statement in which they charged the Bush administration with widespread and unprecedented "manipulation of the process through which science enters into its decisions." There is a series of evidence that the Bush administration has deliberately distorted the communication with the scientific community. [15]

Corollary 2. *Political institutions affect the government's climate change policies:*
(i) In the case where the government does not have any fears of losing power (the voter constraints are non-binding or weakly binding), we can eliminate the credibility gap and maximize the ex-ante social welfare;
(ii) In the case where the government has the fears of losing power (the voter constraints are strictly binding), the credibility gap is deliberately created by a distortion in selection a climate scientist while we achieve more moderate climate change polices.

Proof. Follow from Propositions 3 and 4. □

Figure 7 graphically illustrates a credibility gap between the government and the climate scientist. If the government has no fears of losing power, then it can appoint a climate scientist whose ideological position agrees with its own position. Thus the credibility gap is eliminated, which is the forty-five degree line where $\beta_G = \beta_S$, so $x = 1/2$. If the government has the fears of losing power, the right-wing government commits to a more right-wing climate scientist to ensure re-election; and the left-wing government commits to a more left-wing climate scientist to ensure re-election. As a result, a credibility gap is created by election concerns, between the government and the climate scientist.

[15]The *New York Times* Obituary, July 29, 2011; John H. Marburger, Bush Science Advisor, Dies at 70
The *Union of Concerned Scientists* Scientific Integrity in Policy Making, An Investigation of the Bush Administration's Misuse of Science, March 2004; Further Investigation, July 2004
The *Union of Concerned Scientists* 2004 Scientist Statement on *Restoring Scientific Integrity to Federal Policy Making*

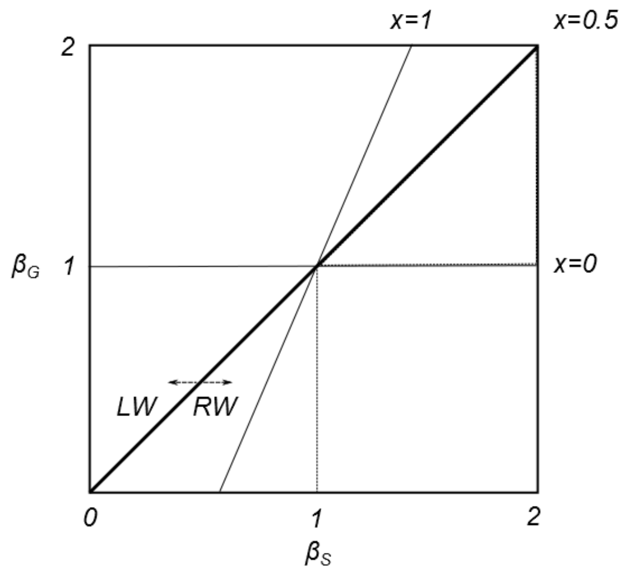

Figure 7: A credibility gap created by distortion in selection of scientist (when $\bar{\beta} = 1$)

2.5.2. Uninformed Voters

The public perception of climate change is also a critical factor in determining climate change policies. Even in a democratic society, an unconcerned public can cause policymakers neglect climate change warnings from the scientific community if policymakers' ideological position is different from the climate scientists.

I consider the case where the median voter observes the government's optimal climate change policy $\hat{r}_G(m)$, but do not observe the climate scientist's message m in Stage 4. In this case, the median voter can infer from the government's optimal climate change policy $\hat{r}_G(m_H)$ (or $\hat{r}_G(m_L)$) that the probability of the *Bad State* is high (or low). However, they do not directly observe which message was sent from the climate scientist. Thus the government can deviate from the optimal policy that it should choose in accordance with the message from the climate scientist, if it is profitable for the government. Note that I do not solve for an equilibrium here; however, I show that the government can deviate to out of the equilibrium path if the median voter does not observe the climate scientist's message.

Proposition 5. *We cannot achieve climate change policies accordant with the climate scientist when the median voter is uninformed. The right-wing government deviates from $\hat{r}_{RW}(m_H)$ to $\hat{r}_{RW}(m_L)$ but not in the opposite direction.*[16]

Proof. See Appendix □

As in Schultz's 1995 model in which voters do not directly observe the true state of the world, the government's optimal climate change policy may not reflect the true probability of the *Bad State* if the voters do not directly observe the message from the climate scientist. This is the cost of a society in which voters do not monitor research on climate change: climate change policy may not be aligned with the true state of climate change. In order to achieve a climate change policy in accordance with climate scientists, the public must be aware of the true state of climate change investigated by those scientists, and they should take the government's climate change policy into consideration when they vote.

Theoretical Prediction Recall that under my hypothesis, the ruling governments' preferences for climate change policy are not high as compared to their alternative parties and the median voters. Furthermore, the preference of the median voters is much closer to that of the alternative party. Therefore, in a democratic country, Corollary 2 suggests that the government, for fears of losing power, will implement more moderate climate change policies closer to the median voters' preference. That is, elections may at least partly mitigate the problem of the biased government preferences. More sharply, I obtain the prediction that countries with more democratic political institutions will have climate change policies more targeted towards renewable energy.

[16] The left-wing government deviates from $\hat{r}_{LW}(m_L)$ to $\hat{r}_{LW}(m_H)$ but not in the opposite direction.

2.6. Conclusion

The subject of climate change is by nature complex and full of uncertainties, and these complications often result in discordant climate change policies. I incorporate some of them into our game-theoretic model to examine why climate change policies are sometimes discordant, and suggest a solution to achieve accordant climate change policies.

I develop a game-theoretic model of the three parties associated with climate change: the government, the climate scientist, and the median voter. The climate scientist tells the government about the state of climate change. Since the governments cannot verify the truthfulness of scientific reports, the scientist's message is considered "cheap talk".

In the basic model, where all preferences are exogenous and the government has no election concerns, I show that a credibility gap between a climate scientist and a government is created if their preference for what policy to enact is not perfectly aligned with the government. If the government is allowed to select its climate scientist, then it would select a climate scientist whose preference agrees with its own preference. Then we can eliminate the credibility gap and maximize the *ex-ante* social welfare. I show a striking result: the *ex-ante* social welfare is maximized if and only if the preference of the scientist is perfectly aligned with the government, not the median voter. This is due to the fact that a credibility gap reduces the *ex-ante* social welfare.

I show that election concerns may be the cause of the credibility gap in a democratic society. The right-wing government has a political incentive to distort the communication with the scientific community, because it knows that it will have to respond to an alarming message with stronger climate change policies than it would like when it has binding election concerns. My contribution from our research to this literature is that I theoretically showed that climate change denial can be a rational behavior in a democratic society.

From my model, I obtain a theoretical prediction that countries with more democratic political institutions will implement climate change policies more targeted towards renewable energy. If the government's preference for climate policy is not high as compared to that of its alternative party and the median voters, the preference of the median voters being closer to the alternative party raises fears of losing power for the government. The fears of losing power lead the government to implement much stronger climate change policy to win the election. This democratic procedure of implementing climate policy will be more likely to occur in countries with higher level of democracy.

Additionally, I show that if voters cannot observe the message from the climate scientist, then the climate change policy that a government puts into place may be discordant with the recommendations of the climate scientist. The right wing government deviates to the climate change policy accordant with the comforting message when the climate scientist sends the alarming message. The left wing government deviates to the climate change policy accordant with the alarming message when the climate scientist sends the comforting message. This is the cost of a society in which voters do not monitor research on climate change: climate change policy may not be aligned with the true state of climate change. In order to achieve a climate change policy in accordance with climate scientists, the public must be aware of the true state of climate change investigated by those scientists, and they should take the government's climate change policy into consideration when they vote.

My research presents a theoretical model that shows how a climate scientist affects domestic political decisions on climate change policies. One may argue that climate change policies are inherently related with international positive externalities, so one should include another player in the model to see how a scientist affects a climate game between two different players. I leave that for the future research.

2.7. Appendix

Proof of Lemma 1. In Stage 2, the government solves

$$\max_{r\in\mathbb{R}_+}\int_0^1 U^G(r,\theta)\rho(\theta|m)d\theta = -\int_0^1 \theta(\beta_G-\bar{\beta}-(\beta_G-\bar{\beta})r)\rho(\theta|m)d\theta-(1-\bar{\beta})+(2-\bar{\beta})r-r^2,$$

$$\text{where} \int_0^1 \theta\rho(\theta|m)d\theta = \begin{cases} x/2, & \text{if } m(\theta)=m_L \\ (x+1)/2, & \text{if } m(\theta)=m_H. \end{cases}$$

Note that there is a unique interior solution to this maximization problem due to the strict concavity of $U^G(r,\theta)$ in r. From the first-order condition, we obtain

$$r^*(m_L;x) = 1-\frac{\bar{\beta}}{2}+\frac{x}{4}(\bar{\beta}-\beta_G), \quad (20)$$

$$r^*(m_H;x) = 1-\frac{\bar{\beta}}{2}+\frac{x+1}{4}(\bar{\beta}-\beta_G). \quad (21)$$

Thus, $r^*(m_L;x) < r^*(m_H;x)$ if $\bar{\beta} > \beta_G$ and $x > 0$.■

Proof of Proposition 1. In Stage 1, the climate scientist solves

$$\max_{m\in\Omega} U^S(r^*(m),\theta) = \theta[\beta_S-\bar{\beta}-(\beta_S-\bar{\beta})r^*(m)]-1+\bar{\beta}+(2-\bar{\beta})r^*(m)-r^*(m)^2$$

$$\text{s.t.} \quad r^*(m) = \begin{cases} r^*(m_L), & \text{if } m(\theta)=m_L \\ r^*(m_H), & \text{if } m(\theta)=m_H. \end{cases}$$

Note that the climate scientist faces a binary decision in Stage 1. She can choose either m_L or m_H. Due to the quadratic form of $U^S(r^*(m), \theta)$ in r,

$$U^S(r^*(m_L), \theta) \leq U^S(r^*(m_H), \theta), \quad \text{if} \quad r^S(\theta) \geq \frac{r^*(m_L) + r^*(m_H)}{2}$$
$$U^S(r^*(m_L), \theta) \geq U^S(r^*(m_H), \theta), \quad \text{if} \quad r^S(\theta) \leq \frac{r^*(m_L) + r^*(m_H)}{2}.$$

Thus, in order for a partially separating equilibrium with a two-step to exist, x must be the point where

$$r^S(x) = \frac{r^*(m_L) + r^*(m_H)}{2}, \tag{22}$$

which is equivalent to

$$1 - \frac{\bar{\beta}}{2} + \frac{x}{2}(\bar{\beta} - \beta_S) = 1 - \frac{\bar{\beta}}{2} + \frac{x}{4}(\bar{\beta} - \beta_G) + \frac{1}{8}(\bar{\beta} - \beta_G).$$

Solving for x, we obtain

$$x = \frac{\frac{1}{2}(\bar{\beta} - \beta_G)}{\bar{\beta} + \beta_G - 2\beta_S}. \tag{23}$$

Since $\beta_G < \bar{\beta}$ by Assumption 1, and x must be strictly positive,

$$\beta_S < \frac{\bar{\beta} + \beta_G}{2}.$$

Furthermore, it must be that $x \leq 1$. Thus

$$\beta_S \leq \frac{\bar{\beta} + 3\beta_G}{4}. \tag{24}$$

■

Proof of Theorem 1. The social planner solves

$$\max_{b_s} W\{E_\theta U^V[r^*(m(\theta)),\theta]\} = N \cdot E_\theta U^V[r^*(m(\theta)),\theta],$$

where

$$E_\theta U^V[r^*(m(\theta)),\theta] = q(m_L)\int_0^x U^V(r^*(m_L),\theta)\rho(\theta|m_L)d\theta + q(m_H)\int_x^1 U^V(r^*(m_H),\theta)\rho(\theta|m_H)d\theta$$

$$r^*(m_L) = 1 - \frac{\bar\beta}{2} + \frac{x}{4}(\bar\beta - \beta_G),$$

$$r^*(m_H) = 1 - \frac{\bar\beta}{2} + \frac{x+1}{4}(\bar\beta - \beta_G),$$

$$x = \frac{\frac{1}{2}(\bar\beta - \beta_G)}{\bar\beta + \beta_G - 2\beta_S}.$$

Note that

$$\begin{aligned} E_\theta U^V[r^*(m(\theta)),\theta] &= q(m_L)\int_0^x U^V(r^*(m_L),\theta)\rho(\theta|m_L)d\theta + q(m_H)\int_x^1 U^V(r^*(m_H),\theta)\rho(\theta|m_H)d\theta \\ &= x\{\frac{x}{2}[\beta_V - \bar\beta - (\beta_V - \bar\beta)r^*(m_L)] - 1 + \bar\beta + (2-\bar\beta)r^*(m_L) - r^*(m_L)^2\} \\ &+ (1-x)\{\frac{x+1}{2}[\beta_V - \bar\beta - (\beta_V - \bar\beta)r^*(m_H)] - 1 + \bar\beta + (2-\bar\beta)r^*(m_H) - r^*(m_H)^2 \end{aligned}$$

From the first-order condition with respect to β_S,

$$-(1-\frac{\bar\beta}{2})x' + \frac{1}{4}(4 - \frac{3}{2}\bar\beta - \frac{\beta_V}{2})x' + \frac{x}{2}(\frac{\beta_V}{2} - \frac{\bar\beta}{2})x' = 0,$$

where $x' = \frac{dx}{d\beta_S} = \frac{\bar\beta - \beta_G}{(\bar\beta + \beta_G - 2\beta_S)^2} > 0$.

Thus we obtain

$$x = \frac{\frac{1}{2}(\bar\beta - \beta_V)}{\bar\beta - \beta_V} = \frac{1}{2}. \tag{25}$$

Since $x = \frac{\frac{1}{2}(\bar{\beta}-\beta_G)}{\bar{\beta}+\beta_G-2\beta_S}$,

$$x = \frac{\frac{1}{2}(\bar{\beta}-\beta_G)}{\bar{\beta}+\beta_G-2\beta_S^*} = \frac{1}{2}.$$

Thus $\beta_S^* = \beta_G$. ■

Proof of Proposition 2. In Stage 0, the government solves

$$\max_{\beta_S \in [0,2]} q(m_L) \int_0^x U^G(r^*(m_L), \theta)\rho(\theta|m_L)d\theta + q(m_H) \int_x^1 U^G(r^*(m_H), \theta)\rho(\theta|m_H)d\theta$$
$$= x\{\frac{x}{2}[\beta_G - \bar{\beta} - (\beta_G - \bar{\beta})r^*(m_L)] - 1 + \bar{\beta} + (2-\bar{\beta})r^*(m_L) - r^*(m_L)^2\}$$
$$+ (1-x)\{\frac{x+1}{2}[\beta_G - \bar{\beta} - (\beta_G - \bar{\beta})r^*(m_H)] - 1 + \bar{\beta} + (2-\bar{\beta})r^*(m_H) - r^*(m_H)^2\}$$

where $r^*(m_L) = 1 - \frac{\bar{\beta}}{2} + \frac{x}{4}(\bar{\beta} - \beta_G)$,

$$r^*(m_H) = 1 - \frac{\bar{\beta}}{2} + \frac{x+1}{4}(\bar{\beta} - \beta_G),$$
$$x = \frac{\frac{1}{2}(\bar{\beta}-\beta_G)}{\bar{\beta}+\beta_G-2\beta_S}.$$

From the first-order condition with respect to β_S,

$$-(1-\frac{\bar{\beta}}{2})x' + \frac{1}{4}(4 - \frac{3}{2}\bar{\beta} - \frac{\beta_G}{2})x' + \frac{x}{2}(\frac{\beta_G}{2} - \frac{\bar{\beta}}{2})x' = 0,$$

where $x' = \frac{dx}{d\beta_S} = \frac{\bar{\beta}-\beta_G}{(\bar{\beta}+\beta_G-2\beta_S)^2} > 0$.

Thus we obtain

$$x = \frac{\frac{1}{2}(\bar{\beta}-\beta_G)}{\bar{\beta}-\beta_G} = \frac{1}{2}. \tag{26}$$

Since $x = \frac{\frac{1}{2}(\bar{\beta}-\beta_G)}{\bar{\beta}+\beta_G-2\beta_S}$,

$$x = \frac{\frac{1}{2}(\bar{\beta}-\beta_G)}{\bar{\beta}+\beta_G-2\beta_S^*} = \frac{1}{2}.$$

Thus $\beta_S^* = \beta_G$. ■

Proof of Proposition 3. Suppose that the right wing is the ruling party of the government. If the voter constraint (18) is non-binding or weakly binding,

$$[\frac{x}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{RW}(m_L)-r^*_{LW}(m_L)]-[r^*_{RW}(m_L)^2-r^*_{LW}(m_L)^2]\geq 0. \quad (27)$$

The above constraint (28) becomes

$$2-\bar{\beta}+\frac{x}{2}(\bar{\beta}-\frac{\beta_{LW}+\beta_{RW}}{2})\geq 2-\bar{\beta}+\frac{x}{2}(\bar{\beta}-\beta_V). \quad (28)$$

Thus $\beta_V \geq \frac{\beta_{LW}+\beta_{RW}}{2}$.

If the voter constraint (19) is non-binding or weakly binding,

$$[\frac{x+1}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{RW}(m_H)-r^*_{LW}(m_H)]-[r^*_{RW}(m_H)^2-r^*_{LW}(m_H)^2]\geq 0. \quad (29)$$

The above constraint (30) becomes

$$2-\bar{\beta}+\frac{x+1}{2}(\bar{\beta}-\frac{\beta_{LW}+\beta_{RW}}{2})\geq 2-\bar{\beta}+\frac{x+1}{2}(\bar{\beta}-\beta_V). \quad (30)$$

Thus $\beta_V \geq \frac{\beta_{LW}+\beta_{RW}}{2}$.

In Stage 0, the right wing government solves the following constrained maximization problem:

$$\begin{aligned}
&\max_{\beta_S\in[0,2]} q(m_L)\int_0^x U^{RW}(\hat{r}_{RW}(m_L),\theta)\rho(\theta|m_L)d\theta+q(m_H)\int_x^1 U^{RW}(\hat{r}_{RW}(m_H),\theta)\rho(\theta|m_H)d\theta \\
&\quad = x\{\frac{x}{2}[\beta_{RW}-\bar{\beta}-(\beta_{RW}-\bar{\beta})\hat{r}_{RW}(m_L)]-1+\bar{\beta}+(2-\bar{\beta})\hat{r}_{RW}(m_L)-r^*_{RW}(m_L)^2\} \\
&\quad + (1-x)\{\frac{x+1}{2}[\beta_{RW}-\bar{\beta}-(\beta_{RW}-\bar{\beta})\hat{r}_{RW}(m_H)]-1+\bar{\beta}+(2-\bar{\beta})\hat{r}_{RW}(m_H)-\hat{r}_{RW}(m_H)^2\} \\
&\text{s.t.}\quad [\frac{x}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_L)-\hat{r}_{RW}(m_L)]-[r^*_{LW}(m_L)^2-\hat{r}_{RW}(m_L)^2]\leq 0 \\
&\quad [\frac{x+1}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_H)-\hat{r}_{RW}(m_H)]-[r^*_{LW}(m_H)^2-\hat{r}_{RW}(m_H)^2]\leq 0.
\end{aligned}$$

Form the Lagrangian function:

$$\mathcal{L} = q(m_L)\int_0^x U^{RW}(\hat{r}_{RW}(m_L),\theta)\rho(\theta|m_L)d\theta + q(m_H)\int_x^1 U^{RW}(\hat{r}_{RW}(m_H),\theta)\rho(\theta|m_H)d\theta$$
$$-\lambda_1\{[\frac{x}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_L)-\hat{r}_{RW}(m_L)]-[r^*_{LW}(m_L)^2-\hat{r}_{RW}(m_L)^2]\}$$
$$-\lambda_2\{[\frac{x+1}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_H)-\hat{r}_{RW}(m_H)]-[r^*_{LW}(m_H)^2-\hat{r}_{RW}(m_H)^2]\}. \tag{31}$$

Note that the voter constraints (18) and (19) are not active. Therefore, from the first-order condition, we obtain: $\lambda_1 = 0$ and $\lambda_2 = 0$: $\beta^*_S = \beta_{RW}$.

Likewise, $\beta^*_S = \beta_{LW}$ in the case where the left wing is the ruling party and $\beta_V \leq \frac{\beta_{LW}+\beta_{RW}}{2}$ (the constraints (22) and (23) are non-binding or weakly binding). ■

Proof of Proposition 4. Suppose that the right wing is in power at the beginning of the game. Note that the constraints (18) and (19) are strictly binding if $\beta_V < \frac{\beta_{LW}+\beta_{RW}}{2}$.

At the constrained optimum $\hat{r}_{RW}(m_L)$ and $\hat{r}_{RW}(m_H)$, it must be that

$$[\frac{x}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_L)-\hat{r}_{RW}(m_L)]-[r^*_{LW}(m_L)^2-\hat{r}_{RW}(m_L)^2]=0 \tag{32}$$
$$[\frac{x+1}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_H)-\hat{r}_{RW}(m_H)]-[r^*_{LW}(m_H)^2-\hat{r}_{RW}(m_H)^2]=0, \tag{33}$$

where $r^*_{LW}(m_L)$ and $r^*_{LW}(m_H)$ are the unconstrained optimum specified in Lemma 1.

Solving (33) and (34) for $\hat{r}_{RW}(m_L)$ and $\hat{r}_{RW}(m_H)$, respectively, yields

$$\hat{r}_{RW}(m_L) = 1-\frac{\bar{\beta}}{2}+\frac{x}{4}(\bar{\beta}-2\beta_V+\beta_{LW}); \tag{34}$$
$$\hat{r}_{RW}(m_H) = 1-\frac{\bar{\beta}}{2}+\frac{x+1}{4}(\bar{\beta}-2\beta_V+\beta_{LW}). \tag{35}$$

In Stage 0, the right wing government solves the following constrained maximization problem:

$$\max_{\beta_S\in[0,2]} q(m_L)\int_0^x U^{RW}(\hat{r}_{RW}(m_L),\theta)\rho(\theta|m_L)d\theta + q(m_H)\int_x^1 U^{RW}(\hat{r}_{RW}(m_H),\theta)\rho(\theta|m_H)d\theta$$

$$= x\{\frac{x}{2}[\beta_{RW}-\bar{\beta}-(\beta_{RW}-\bar{\beta})\hat{r}_{RW}(m_L)] - 1 + \bar{\beta} + (2-\bar{\beta})\hat{r}_{RW}(m_L) - \hat{r}_{RW}(m_L)^2\}$$

$$+ (1-x)\{\frac{x+1}{2}[\beta_{RW}-\bar{\beta}-(\beta_{RW}-\bar{\beta})\hat{r}_{RW}(m_H)] - 1 + \bar{\beta} + (2-\bar{\beta})\hat{r}_{RW}(m_H) - \hat{r}_{RW}(m_H)^2\}$$

$$\text{s.t.}\quad [\frac{x}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_L)-\hat{r}_{RW}(m_L)] - [r^*_{LW}(m_L)^2 - \hat{r}_{RW}(m_L)^2] \leq 0$$

$$[\frac{x+1}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_H)-\hat{r}_{RW}(m_H)] - [r^*_{LW}(m_H)^2 - \hat{r}_{RW}(m_H)^2] \leq 0.$$

Form the Lagrangian function:

$$\mathcal{L} = q(m_L)\int_0^x U^{RW}(\hat{r}_{RW}(m_L),\theta)\rho(\theta|m_L)d\theta + q(m_H)\int_x^1 U^{RW}(\hat{r}_{RW}(m_H),\theta)\rho(\theta|m_H)d\theta$$
$$-\lambda_1\{[\frac{x}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_L)-\hat{r}_{RW}(m_L)] - [r^*_{LW}(m_L)^2-\hat{r}_{RW}(m_L)^2]\}$$
$$-\lambda_2\{[\frac{x+1}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_H)-\hat{r}_{RW}(m_H)] - [r^*_{LW}(m_H)^2-\hat{r}_{RW}(m_H)^2]\}. \tag{36}$$

From the first-order condition, we obtain the following solution β_S^*, λ_1^*, and λ_2^* such that

(i)

$$[\frac{x}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_L)-\hat{r}_{RW}(m_L)] - [r^*_{LW}(m_L)^2-\hat{r}_{RW}(m_L)^2] = 0$$
$$[\frac{x+1}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r^*_{LW}(m_H)-\hat{r}_{RW}(m_H)] - [r^*_{LW}(m_H)^2-\hat{r}_{RW}(m_H)^2] = 0,$$

where $x = \frac{\frac{1}{2}(\bar{\beta}-\beta_{RW})}{\bar{\beta}+\beta_{RW}-2\beta_S^*}$ and $\hat{r}_{RW}(m_L)$ and $\hat{r}_{RW}(m_H)$ are the constrained maximum.

(ii) $\lambda_1^* = \frac{(\bar{\beta}-\beta_{RW})^2(x-\frac{1}{2})}{(\beta_{RW}-\beta_{LW})xx'(\bar{\beta}-\beta_V)(1-x)} > 0$. Note that it must be that $\beta_S^* > \beta_{RW}$ (equivalently, $x > \frac{1}{2}$) since the denominator of λ_1^* is always strictly positive.

(iii) $\lambda_2^* = \frac{(\bar{\beta}-\beta_{RW})^2(x-\frac{1}{2})}{(\beta_{RW}-\beta_{LW})x'[\frac{3}{2}(\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})x^2+\frac{1}{2}(2-\frac{\beta_V}{2}-\frac{\bar{\beta}}{2})x-1+\frac{\beta_V}{2}]} > 0.$

Note that $\lambda_2^* > 0$ if $x > \frac{1}{2}$ and

$$\frac{1}{2} \leq \frac{-\frac{1}{2}(2-\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})+\sqrt{\frac{1}{4}(2-\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})^2+6(1-\frac{\beta_V}{2})(\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})}}{3(2-\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})} < x. \tag{37}$$

Notice that the numerator of λ_2^* is positive only if $x > \frac{1}{2}$, and the denominator of λ_2^* is positive only if the condition (38) is satisfied.

In sum, it must be that $\beta_S^* > \beta_{RW}$ (equivalently, $x > \frac{1}{2}$). ■

Suppose that the left wing is the ruling party of the government. Note that the voter constraints (18) and (19) are strictly binding if $\beta_V > \frac{\beta_{LW}+\beta_{RW}}{2}$.

At the constrained optimum $\hat{r}_{LW}(m_L)$ and $\hat{r}_{LW}(m_H)$, it must be that

$$[\frac{x}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r_{RW}^*(m_L)-\hat{r}_{LW}(m_L)]-[r_{RW}^*(m_L)^2-\hat{r}_{LW}(m_L)^2]=0 \tag{38}$$

$$[\frac{x+1}{2}(\bar{\beta}-\beta_V)+(2-\bar{\beta})][r_{RW}^*(m_H)-\hat{r}_{LW}(m_H)]-[r_{RW}^*(m_H)^2-\hat{r}_{LW}(m_H)^2]=0, \tag{39}$$

where $r_{RW}^*(m_L)$ and $r_{RW}^*(m_H)$ are the unconstrained optimum specified in Lemma 1.

Solving (39) and (40) for $\hat{r}_{LW}(m_L)$ and $\hat{r}_{LW}$, yields

$$\hat{r}_{LW}(m_L) = 1-\frac{\bar{\beta}}{2}+\frac{x}{4}(\bar{\beta}-2\beta_V+\beta_{RW}); \tag{40}$$

$$\hat{r}_{LW}(m_H) = 1-\frac{\bar{\beta}}{2}+\frac{x+1}{4}(\bar{\beta}-2\beta_V+\beta_{RW}). \tag{41}$$

In Stage 0, the left wing government solves the following constrained maximization problem:

$$\max_{\beta_S \in [0,2]} q(m_L) \int_0^x U^{LW}(\hat{r}_{LW}(m_L), \theta)\rho(\theta|m_L)d\theta + q(m_H) \int_x^1 U^{LW}(\hat{r}_{LW}(m_H), \theta)\rho(\theta|m_H)d\theta$$
$$= x\{\frac{x}{2}[\beta_{LW} - \bar{\beta} - (\beta_{LW} - \bar{\beta})\hat{r}_{LW}(m_L)] - 1 + \bar{\beta} + (2 - \bar{\beta})\hat{r}_{LW}(m_L) - \hat{r}_{LW}(m_L)^2\}$$
$$+ (1 - x)\{\frac{x+1}{2}[\beta_{LW} - \bar{\beta} - (\beta_{LW} - \bar{\beta})\hat{r}_{LW}(m_H)] - 1 + \bar{\beta} + (2 - \bar{\beta})\hat{r}_{LW}(m_H) - \hat{r}_{LW}(m_H)^2\}$$
$$\text{s.t.} \quad [\frac{x}{2}(\bar{\beta} - \beta_V) + (2 - \bar{\beta})][r^*_{RW}(m_L) - \hat{r}_{LW}(m_L)] - [r^*_{RW}(m_L)^2 - \hat{r}_{LW}(m_L)^2] \leq 0$$
$$[\frac{x+1}{2}(\bar{\beta} - \beta_V) + (2 - \bar{\beta})][r^*_{RW}(m_H) - \hat{r}_{LW}(m_H)] - [r^*_{RW}(m_H)^2 - \hat{r}_{LW}(m_H)^2] \leq 0.$$

Form the Lagrangian function:

$$\mathcal{L} = q(m_L) \int_0^x U^{LW}(\hat{r}_{LW}(m_L), \theta)\rho(\theta|m_L)d\theta + q(m_H) \int_x^1 U^{LW}(\hat{r}_{LW}(m_H), \theta)\rho(\theta|m_H)d\theta$$
$$- \lambda_1\{[\frac{x}{2}(\bar{\beta} - \beta_V) + (2 - \bar{\beta})][r^*_{RW}(m_L) - \hat{r}_{LW}(m_L)] - [r^*_{RW}(m_L)^2 - \hat{r}_{LW}(m_L)^2]\}$$
$$- \lambda_2\{[\frac{x+1}{2}(\bar{\beta} - \beta_V) + (2 - \bar{\beta})][r^*_{RW}(m_H) - \hat{r}_{LW}(m_H)] - [r^*_{RW}(m_H)^2 - \hat{r}_{LW}(m_H)^2]\}. \tag{42}$$

From the first-order condition, we obtain the following solution β_S^*, λ_1^*, and λ_2^* such that

(i)

$$[\frac{x}{2}(\bar{\beta} - \beta_V) + (2 - \bar{\beta})][r^*_{RW}(m_L) - \hat{r}_{LW}(m_L)] - [r^*_{RW}(m_L)^2 - \hat{r}_{LW}(m_L)^2] = 0$$
$$[\frac{x+1}{2}(\bar{\beta} - \beta_V) + (2 - \bar{\beta})][r^*_{RW}(m_H) - \hat{r}_{LW}(m_H)] - [r^*_{RW}(m_H)^2 - \hat{r}_{LW}(m_H)^2] = 0,$$

where $x = \frac{\frac{1}{2}(\bar{\beta} - \beta_{LW})}{\bar{\beta} + \beta_{LW} - 2\beta_S^*}$ and $\hat{r}_{LW}(m_L)$ and $\hat{r}_{LW}(m_H)$ are the constrained maximum.

(ii) $\lambda_1^* = \frac{(\bar{\beta} - \beta_{LW})^2(x - \frac{1}{2})}{(\beta_{LW} - \beta_{RW})xx'(\bar{\beta} - \beta_V)(1 - x)} > 0$. Note that it must be that $\beta_S^* < \beta_{LW}$ (equivalently, $x < \frac{1}{2}$) since the denominator of λ_1^* is always strictly negative.

(iii) $\lambda_2^* = \frac{(\bar{\beta} - \beta_{LW})^2(x - \frac{1}{2})}{(\beta_{LW} - \beta_{RW})x'[\frac{3}{2}(\frac{\bar{\beta}}{2} - \frac{\beta_V}{2})x^2 + \frac{1}{2}(2 - \frac{\beta_V}{2} - \frac{\bar{\beta}}{2})x - 1 + \frac{\beta_V}{2}]} > 0$.

Note that $\lambda_2^* > 0$ if $x < \frac{1}{2}$ and

$$\frac{-\frac{1}{2}(2-\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})+\sqrt{\frac{1}{4}(2-\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})^2+6(1-\frac{\beta_V}{2})(\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})}}{3(2-\frac{\bar{\beta}}{2}-\frac{\beta_V}{2})} < x < \frac{1}{2}. \tag{43}$$

Notice that the numerator of λ_2^* is negative only if $x < \frac{1}{2}$, and the denominator of λ_2^* is negative only if the condition (44) is satisfied.

In sum, it must be that $\beta_S^* < \beta_{LW}$ (equivalently, $x < \frac{1}{2}$). ■

Proof of Proposition 5. The maximizer of the government's *ex-ante* utility function $E_\theta U^G[r^*(m(\theta)), \theta]$ is

$$\begin{aligned} arg \max_r E_\theta U^G[r^*(m(\theta)), \theta] = q(m_L) \int_0^x U^G(r^*(m_L), \theta)\rho(\theta|m_L)d\theta \\ + q(m_H) \int_x^1 U^G(r^*(m_H), \theta)\rho(\theta|m_H)d\theta = 1 - \frac{\beta_G + \bar{\beta}}{4}. \end{aligned} \tag{44}$$

In the case where the constraints are non-binding or weakly binding, notice that

$$\begin{aligned} r^*(m_L) = 1 - \frac{\bar{\beta}}{2} + \frac{x}{4}(\bar{\beta} - \beta_G) \leq 1 - \frac{\beta_G + \bar{\beta}}{4}, \\ r^*(m_H) = 1 - \frac{\bar{\beta}}{2} + \frac{x+1}{4}(\bar{\beta} - \beta_G) \geq 1 - \frac{\beta_G + \bar{\beta}}{4}. \end{aligned}$$

Since $E_\theta U^G[r^*(m(\theta)), \theta]$ is in a quadratic form and the government prefers $r^*(m_L)$ to $r^*(m_H)$ if

$$1 - \frac{\beta_G + \bar{\beta}}{4} - r^*(m_L) = \frac{1-x}{4}(\bar{\beta} - \beta_G) \leq \frac{x}{4}(\bar{\beta} - \beta_G) = r^*(m_H) - 1 + \frac{\beta_G + \bar{\beta}}{4}, \tag{45}$$

which is equivalent to $x \geq \frac{1}{2}$. That is, the government prefers $r^*(m_L)$ to $r^*(m_H)$ if $x \geq \frac{1}{2}$ and vice versa. Note that $x = \frac{1}{2}$ when the constraints (18) and (19) are non-binding or weakly binding. Thus the government does not have any incentive to deviate from the given message. ■

In the case where the right wing is in power at the beginning of the game, and the constraints (18) and (19) are strictly binding (equivalently, $\beta_V < \frac{\beta_{LW}+\beta_{RW}}{2}$), the government deviates from $\hat{r}_{RW}(m_H)$ to $\hat{r}_{RW}(m_L)$ at Stage 3 since

$$\hat{r}_{RW}(m_H) - 1 + \frac{\beta_{RW} + \bar{\beta}}{4} - 1 + \frac{\beta_{RW} + \bar{\beta}}{4} - \hat{r}_{RW}(m_L) = -\beta_V + \frac{\beta_{LW} + \beta_{RW}}{2} > 0.$$

In the case where the left wing is in power at the beginning of the game, and the constraints (18) and (19) are strictly binding (equivalently, $\beta_V > \frac{\beta_{LW}+\beta_{RW}}{2}$), the government deviates from $\hat{r}_{LW}(m_L)$ to $\hat{r}_{LW}(m_H)$ at Stage 3 since

$$\hat{r}_{LW}(m_H) - 1 + \frac{\beta_{LW} + \bar{\beta}}{4} - 1 + \frac{\beta_{LW} + \bar{\beta}}{4} - \hat{r}_{LW}(m_L) = -\beta_V + \frac{\beta_{LW} + \beta_{RW}}{2} < 0.$$

■

Chapter 3

How Democracy Matters for Environmental Policy: Evidence from International and U.S. Panel Data

3.1. Introduction

Social choice theory tells us that the crucial necessary condition for democracy is simply a shared understanding that democracy will function in the society.[17] To avoid catastrophic climate change and other environmental disaster, it is crucial to implement environmental policies at a suitable time and place. Thus, it is important to understand how decision-making regarding climate change and environmental policies works in a democracy.

According to a national poll on climate change conducted by Stanford University, Resource for the Future, and the *New York Times* in 2015, social concerns about climate change has been steadily high. As of 2015, 53% of U.S. citizens thought that the government *should* do more than a moderate amount about climate change, but only 15% of citizens thought that the government *was* currently doing more than a moderate amount to deal with climate change.[18]

Park (2015) provides a theoretical model that shows how election concerns matter for climate change and/or environmental policies in a democracy.[19] If median voters perceive an alarming message about climate change from a climate scientist, then even

[17] "Fundamentals of Social Choice Theory," Myerson (2013).

[18] Figures 1-2 show the results of Global Warming National Poll conducted by SSRS from January 7-22, 2015, organized by Resource For the Future, the *New York Times*, and Stanford University.

[19] "Cheap Talk and Climate Change: A Theory of Discordant Climate Change Policies," Park (2015)

a right-wing (pro-growth) politician will be forced to choose an aggressive climate change policy to avoid losing the election. This deviation from its unconstrained policy (without election concerns) is costly to the politician, so he prefers to appoint a climate scientist who is unlikely to send an alarming message, i.e., one with more right-wing views.[20] Intuitively, the right-wing politician has a political incentive to distort the communication with the scientific community, because he knows that he will have to respond to an alarming message with stronger climate change policies than it would like. Thus, a politician with election concerns deliberately creates a credibility gap by appointing a scientist whose preferences differ from its own. [21] This is in sharp contrast to the case where the politician has no election concerns and therefore can choose his unconstrained optimal response to the scientist's message. In the unconstrained case he prefers to minimize the credibility gap by appointing a scientist with the same preference as himself.

Nevertheless, he shows that there will be more renewable energy when the government has election concerns than when it does not. Thus, we obtain a theoretical prediction that countries with more democratic political institutions will have climate change policies more targeted towards renewable energy. I test this theoretical prediction with an international panel data in the period of 1980-2012. I find that a one-unit increase in the Polity II index is associated with approximately 12-13% increase in the proportion of electricity due to renewable energy, which indicates that countries with higher levels of democracy implement stronger climate change policies. At the same time, I find that a one-unit increase in the Polity II index is associated with approximately 3% decrease in the carbon dioxide (CO2) emissions per capita, which means that countries with higher levels of democracy produce lower carbon dioxide

[20]In the opposite case when a left-wing government is in power, the climate change policy distortion causes the government to commit to a more left-wing climate scientist, which means that it is more likely to receive an alarming message.

[21]For anecdotal evidence, see The *Union of Concerned Scientists* 2004 Scientist Statement on *Restoring Scientific Integrity to Federal Policy Making* for further details.

emissions per capita. The empirical findings from the international panel data show that "democracy is good for the environment," because it is positively related with climate change policy. To explain the empirical findings in line with the theoretical model, it may force the right-wing (pro-growth) politicians to be more responsive to the environmental preferences of the median voters.

I further study how the population environmental preferences, as measured by the LCV scores, influence state governors to become more concerned about the environment in the U.S. This would be especially important for Republican governors, if we assume that Democrat voters are concerned about the environment while Republican voters are not. The voters who are not concerned about the environment are likely to be indifferent about environmental policy. However, an environmental policy is likely to be important for the voters who are concerned about the environment.[22] I assume that Democrat voters (the left wing) are concerned about the environment and a politician's choice on environmental policy is important for them, while Republican voters (the right wing) are not concerned about the environment and they are indifferent about environmental policy. Democrat politicians would have great environmental preferences like the Democrat voters, so they are likely to implement strong environmental policies. The politicians of interest is Republicans. Even though the Republican voters are not concerned about the environment and they are indifferent about environmental policy, Republican politicians may have an incentive to respond to the environmental preferences of Democrat voters to attract the median voters and win the elections. Therefore, I examine how state governors are sensitive to the environmental preferences of population.

I analyze a U.S. panel data in the period of 1971-2007. I find the Republican state governors increase the environmental expenditure per capita by approximately 1.5 percent as the Democrat LCV scores increase by 1 percent; and they increase the

[22] List and Sturm (2006) argue that electoral incentives are important determinant of policy choice on "secondary" policy issues such as environmental policy.

environmental expenditure per capita by 4.8 percent as the Republican LCV scores decrease by 1 percent. That is, Republican governors respond positively to the LCV scores of the Democrats, but not to Republican LCV scores. These empirical findings can be explained in line with the theoretical model. First, the Democrat governors do not significantly respond to a change in the environmental preferences of their residents. The Democrat governors may not be sensitive to a change in their residents' environmental preferences since they already have strong environmental preferences to implement strong environmental policies. Second, the Republican governors do significantly respond to a change in the environmental preferences of their residents. I find that they positively respond to an increase in the Democrats' environmental preferences. To be specific, the Republican governors increase the environmental expenditure per capita by approximately 1.5 percent as the Democrats LCV increases by 1 percent. The Republican governors positively respond to the environmental preferences of the Democrat voters to attract the median voters and win the elections. I consider one-dimensional space of the voters regarding environmental policy. Let us assume that half of the voters are Republicans (the right wing) who are not concerned about the environment and feel indifferent about environmental policy, and another half of the voters are Democrats (the left wing) who are concerned about th environment and feel important about environmental policy. Suppose that the median voters are 10 percent of the voters in the middle of the space. The Republican governors win the elections since they positively responded to the environmental preferences of the Democrat voters and attracted the median voters (see Figure 4). This empirical finding is consistent with Park's theoretical prediction that countries with more democratic institutions are more likely to have more stringent environmental policy. The right-wing politicians (Republicans) will not have any incentive to respond to the Democrat voters' environmental preferences if they do not have any election concerns. In a full democracy such as the U.S. where the median voters have power to replace to regime, the politicians have political incentive to respond to the median voters' preferences to win the elections.

I review the related literature in Section 2. The international panel analysis is discussed in Section 3. I analyze the U.S. panel data in Section 5. I conclude in Section 6.

3.2. Related Literature

A country's political system may influence its climate change policies in our theoretical model. There are several empirical research on the relationship between environmental policies and political systems. Hassler and Krussel (2012) construct a model to quantify how key features of heterogeneity between different regions of the world affect those regions' preferences for different climate change policies. They show that in the absence of international transfer mechanisms, Pareto-improving policies to curb climate change may not exist. Fredriksson and Neumayer (2013) study the relationship between countries' democratic capital stocks and climate change policies. Using data for 87 countries starting from as far back as the year 1800, they show that larger democratic capital stocks are associated with more stringent climate change polices. Congleton (1992) provides a simple model to show how different political institutions affect the enactment of environmental regulations. He finds empirical evidence that political institutions play a significant role to the pollution control policies. Winslow (2005) presents empirical evidence to support the existence of a relationship between democracy and one aspect of environmental quality, urban air pollution. The relationship between environmental quality and democracy is explored empirically using a regression analysis of urban air concentrations of three pollutants, sulfur dioxide (SO2), suspended particulate matter (SPM) and smoke, and two measures of democracy, the Freedom House Index and Polity III. The results suggest a significant and robust negative linear relationship between these pollutant concentrations and democracy level: the higher the level of democracy, the lower the ambient pollution level. My contribution to this literature is that I provided a rigorous game-theoretic model to theoretically explain those empirical results, and another empirical result consistent with the previous literature.

Public perception of climate change is one of the key factors in determining climate change policies in our model. Leiserowitz (2006) argues the importance of public perception of climate change in the socio-economic political context. The direction of climate change policy (for example, public support or opposition to climate change policies such as carbon taxes or clean energy subsidies) is substantially influenced by public perceptions of climate change. Lorenzoni and Pidgeon (2006) survey how climate change is conceptualized in the Europe and the U.S., and conclude that awareness of climate change is widespread but that it is considered less important than other personal or social issues. Furthermore, the public showed limited understanding of the causes of, and the solutions to, climate change.

My study is related with List and Sturm (2006). They explore to what extent secondary policy issues are influenced by electoral incentives. They develop a two-dimensional political agency model, in which a politician decides on both a frontline policy issue and a secondary policy issue. The model predicts when the incumbent should manipulate the secondary policy to attract voters. They test the model by using panel data on environmental policy choices in the U. S. states. They find that there are strong effects of electoral incentives: In states with a large group of green voters, they find that governors advance less environmentally friendly policies once they face a binding term limit. They observe the opposite pattern in states with a small environmental constituency, where governors advance much greener policies once they can no longer be reelected. These results suggest that governors reverse policies, which they have undertaken purely to attract voters once they face a binding term limit.

3.3. Democracy and Climate Change Policy

I test a theoretical prediction that countries with more democratic political institutions will have climate change policies more targeted towards renewable energy. I first describe the data, then the econometric strategy, and finally discuss the estimation results.

3.3.1. Data

I use data on climate change polices from International Energy Statistics of the U.S. Energy Information Administration for 154 countries in the period of 1980-2012. I collect the proportion of electricity generation due to renewable energy of 154 countries in the period of 1980-2012. The renewable energy resources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action. I also examine whether the level of democracy has any relationship with an environmental outcome. I use carbon dioxide (CO2) emissions per capita (measured in metric tons) from the World Bank Open Data. Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.

My key explanatory variable is each country's political regime characteristic. I use data on political regime characteristics from the Polity IV data set (Marshall et al., 2014). They constructed an index ranging 0 to 10 for each regime (democracy and autocracy). I use the difference between the two indexes (Polity II index) following previous literature (Baliga et al., 2011 among many others). The Polity II index ranges from -10 to 10, where more democratic countries have a higher index.

To control for any confounding factors influencing use of renewable energy (e.g., more accumulated technology, higher preferences for clean environment, and etc.), I include each country's GDP per capita. Developed countries with higher GDP per capita would have accumulated higher levels of clean technology to generate electricity

Table 1: Summary Statistics: International Panel, 1980-2012

Variable	Mean	Std.	Min	Max	Obs.
Renewable Ratio	0.2977	0.3397	0	2.7419	7020
CO2 per capita	4.5208	6.5484	0.00058	68.7007	5671
Polity II Index	1.8052	7.2179	-10	10	5079
GDP per capita	9023.28	13781.71	69.57	87772.69	5079
Annual Mean Temperature	18.9448	8.6380	-17.5	29.8	6632
% below 5m Elevation	7.7692	15.6302	0	99.9999	6270

CO2 per capita in metric tons; GDP per capita in constant 2005 US$;
Annual mean temperature in Celsius.

from renewable energy sources. Therefore, they would use renewable energy at a cheaper cost than developing countries with low GDP per capita. Then it is possible that they use larger proportions of renewable energy than developed countries. On the other hand, it is possible that developed countries would use smaller proportions of renewable energy because of the increasing marginal cost of generating electricity from renewable energy. Even though developed countries have accumulated more stocks of clean technology, they may face a higher marginal cost of generating electricity from renewable energy since developed countries consume higher levels of energy per capita. In any case, I control for them by including GDP per capita. I collect data on GDP per capita (constant 2005 US$) from the World Bank Open Data.

Furthermore, I control for each country's climate vulnerability. I collect annual mean temperature of each country from Climatic Research Unit, University of East Anglia. They provide open database for climate records such as mean, max, min temperatures, number of days with ground frozen by country from 1901 to present. Furthermore, I collect data on the percentage of land below 5 meters of elevation from the World Bank Open Data.

3.3.2. Econometric Methodology

I use linear panel-data models to estimate the relationship between the proportion of electricity generation due to renewable energy and political regime characteristics, GDP per capita, mean temperature, and the percentage of land below 5 meters of elevation. The regression equation is the following:

$$R_{it} = \alpha_0 + \alpha_1 Polity_{it} + \alpha_2 GDP_{it} + \alpha_3 Meantemp_{it} + \alpha_4 Below5Elev_{it} + \delta_i + \gamma_t + \epsilon_{it}, \quad (46)$$

where R_{it} is the log of the proportion of total electricity generation due to renewable energy in each country (i) and year (t), $Polity_{it}$ is the Polity II index of each country and year, and GDP_{it} is the log of GDP per capita in each country and year, δ_i and γ_t denote the country and year fixed-effects, respectively, and ϵ_{it} is the error term.

3.4. Empirical Results

First, in specifications (1)-(4), I estimate a linear panel-data model using the pooled OLS with the year fixed-effects and the robust standard errors clustered by country, to examine any cross-country relationship between the proportion of renewable energy and political regime characteristics. I include the country fixed-effects in specification (5)-(6). In specification (4) and (6), I include the quadratic term of GDP per capita.

I find strong empirical evidence that supports the theoretical prediction: The level of democracy has a significant and positive relationship with the government's climate change policy. The governments implement stronger climate change policies as their political institutions are closer to a full democracy. Table 2 shows the regression results of this climate change policy analysis.

In specification (1), I include only two control variables, the log of GDP per capita and mean temperature in each country and year. I estimate that a one degree Celsius increase in annual mean temperature is associated with approximately 12

Table 2: Proportion of Renewable Energy

	Pooled OLS				Fixed-Effects	
	(1)	(2)	(3)	(4)	(5)	(6)
PolityII Index	0.121***	0.136***	0.116***	0.116***	0.007	0.005
	(0.0396)	(0.0455)	(0.0395)	(0.0388)	(0.0228)	(0.023)
GDP per capita	-0.683***	-0.318	-0.559**	0.756	0.453	1.597
	(0.228)	(0.221)	(0.249)	(1.633)	(0.590)	(2.561)
GDP p.c. squared				-0.083		-0.078
				(0.100)		(0.148)
Mean Temperature	-0.119***		-0.109**	-0.115***	0.0588	0.065
	(0.0427)		(0.0469)	(0.0495)	(0.0683)	(0.069)
% Below 5m Elev.		-0.109**	-0.0930**	-0.090**		
		(0.0543)	(0.0463)	(0.0467)		
Constant	4.752**	-0.00276	3.945	-0.978	-7.740	-11.912
	(2.323)	(1.728)	(2.529)	6.391	(4.732)	(11.062)
N	4567	4554	4525	4525	4525	4524
adj. R^2	0.117	0.104	0.143	0.147	0.037	0.041

Standard errors are clustered by country and in parentheses.
All columns include year fixed-effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

percent decrease in the proportion of electricity due to renewable energy with the 1% significance level. I estimate that a one-unit increase in the Polity II index is associated with approximately 12 percent increase in the proportion of electricity due to renewable energy with the 1% significance level.

In specification (2), I include another control variable, the percentage of land below 5 meters of elevation, instead of mean temperature. The estimated effects of the Polity II index increases to approximately 14 percent with 1% significance level. The coefficient on the percentage of land below 5 meters of elevation is negative. I estimate that a one percentage point increase in the proportion of land below 5 meters of elevation is associated with approximately 11 percent decrease in the proportion of electricity due to renewable energy with the 5% significance level.

In specification (3), I include all three control variables. The coefficient on the GDP per capita is positive and statistically significant: a one percent increase in GDP per capita is associated with approximately 56 percent decrease in the proportion of electricity due to renewable energy. I estimate that a one-unit increase in the Polity II index is associated with approximately 12 percent increase in the proportion of electricity due to renewable energy with the 1% significance level. A one degree Celsius increase in the annual mean temperature is estimated to be associated with approximately 11 percent decrease in the proportion of electricity due to renewable energy with 5% significance level. Furthermore, a one percentage point increase in the proportion of land below 5 meters of elevation is associated with approximately percent decrease in the proportion of electricity due to renewable energy with the 5% significance level. This empirical finding is interesting. The Alliance of Small Island States (AOSIS) is a group of 43 low-lying and small island countries that are particularly vulnerable to sea-level rise. The AOSIS countries share the view that climate change is a major threat to their survival, and speak a common statement in negotiations at the UNFCCC. Unlike their common interests to avoid catastrophic climate change, they tend to use larger proportions of electricity due to fossil fuels.

Finally, in specification (5) I examine the same panel data with the country fixed-effects to see if any within-country variations have significant effects. Surprisingly, within-country variations in political regime characteristics are not significantly correlated with the proportion of electricity generation due to renewable energy. The theoretical model may explain the intuition behind this empirical result. It may be the case that, in many countries, the governments' preferences of climate change policy are not high as compared to their alternative parties and the median voters. Furthermore, the preferences of the median voters are much closer to that of the alternative party. In a democratic country, the median voters and the alternative party being close together should raise fears of losing power for the government. The fears of losing power should lead the government to implement climate change policies closer to the median voters' preference. That is, the election concerns make the government to implement much stronger climate change policies than its preferred policies. However, this democratic procedure of implementing climate change policies will work only if the median voters actually observe and care about the government's climate change policy. Otherwise, there must be a deviation from an aggressive climate change policy to a loose one. Thus, we may interpret this result as the governments' deviation in climate change policies.

Table 3: CO2 Emissions per Capita

	Pooled OLS				Fixed-Effects	
	(1)	(2)	(3)	(4)	(5)	(6)
PolityII Index	-0.032***	-0.026***	-0.031***	-0.032***	0.001	-0.001
	(0.009)	(0.008)	(0.009)	(0.009)	(0.003)	(0.003)
GDP per capita	0.946***	0.989***	0.946***	3.345***	0.820***	1.708***
	(0.045)	(0.038)	(0.046)	(0.333)	(0.074)	(0.407)
GDP p.c. squared				-0.151***		-0.060**
				(0.021)		(0.027)
Mean Temperature	-0.025**		-0.022**	-0.033***	-0.051***	-0.046***
	(0.010)		(0.011)	(0.009)	(0.014)	(0.014)
% of Below 5m Elev.		0.003	0.006	0.012		
		(0.007)	(0.009)	(0.008)		
Constant	-6.556***	-7.394***	-6.637***	-15.609***	-4.987***	-8.217***
	(0.496)	(0.317)	(0.519)	(1.285)	(0.607)	(1.666)
N	4418	4405	4378	4378	4378	4378
adj. R^2	0.793	0.812	0.795	0.841	0.763	0.799

Standard errors are clustered by country and in parentheses.
All columns include year fixed-effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Next, I examine a climate change outcome measure, which is CO2 emissions per capita in each country and year. Table 3 shows the regression results of this outcome analysis.

In specifications (1)-(4), I examine the pooled OLS analysis with the year fixed-effects and the robust standard errors clustered by country. I estimate that a one-unit increase in the PolityII index is associated with 3 percent decrease in the CO2 emissions per capita. These results are consistent with the results from the previous analysis: countries with more democratic political institutions tend to use higher proportions of renewable energy; and at the same time, they are likely to produce lower CO2 emissions per capita. A one degree Celsius higher mean temperature is estimated to be associated with approximately 2 percent decrease in CO2 emissions per capita. However, the percentage of land below 5 meters of elevation is not significantly associated with the CO2 emissions per capita.

Finally, in specification (5)-(6), I examine the same panel data with the country fixed-effects to see if any within-country variation has significant effects. The results are consistent with the previous analysis. A within-country change in political regime characteristics does not have any significant effects on the CO2 emissions per capita. However, I find that the GDP per capita is positively and significantly associated with the CO2 per capita. I estimate that a one percent increase in the GDP per capita is associated with 82 percent increase in the CO2 emissions per capita with the 1% significance level.

To sum up, the empirical findings from the international panel data show that "democracy is good for the environment," because it is positively related with climate change policy and negatively related with the CO2 emissions. To explain the empirical findings in line with the theoretical model, it may force the right-wing (pro-growth) politicians to be more responsive to the environmental preferences of the median voters. In the next section, I examine the responsiveness of the U.S. state governors to the environmental preferences of their population.

3.5. State Preferences and Environmental Policy

In Section 3, I argued that the positive relationship between democracy and environmental policies may be due to "pro-growth" politicians choosing stronger environmental policies to avoid losing the elections. In this Section, I investigate this hypothesis further by examining how state governors are sensitive to the environmental preferences of population. Of special interest are states with Republican governors, since these are hypothesized to be more pro-growth. I first describe the data, then the econometric methodology, and finally discuss the estimation results.

3.5.1. Data

I collect the state environmental expenditure data in 50 U.S. states in the period of 1971-2007. They are expenditure on "fish and game," "forestry," and "natural resources." "Fish and game" is expenditure for conservation and development of fish and game resources through regulation, protection, and propagation. "Forestry" is expenditure on conservation, development and promotion of forests and forest products. It includes forest fire prevention and forest fire-fighting activities. Lastly, "natural resources" is expenditure on conservation, promotion, and development of natural resources, such as soil, water, forests, minerals, and wildlife. It includes irrigation, drainage, flood control, forestry and fire protection, soil reclamation, soil and water conservation, fish and game programs, and agricultural fairs. These measures are deflated to 1982-1984 dollars. I use the sum of the three categories of expenditure in per capita amounts to measure each state government's environmental policy. The data is from the Census of State Governments reports.

As a proxy for the environmental preference of residents in each state, I use the League of Conservation Voters (LCV) score. The LCV scores are the politicians' scores about the votes on the most important environmental issues of the year, such as global warming, environmental health and safety protections and etc. The LCV scores

Table 4: Summary Statistics: US Panel

Variable	Mean	Std.	Min	Max	Obs.
Environmental Expenditure per capita	122.055	196.447	0.103	2016.337	1849
Personal Income per capita	14278	3341	7050	30914	1849
Population	9254.17	33311.6	316	303785	1849
LCV scores	46.2542	16.0205	8.6617	84.47318	1849
Republican LCV scores	32.5786	15.9661	-.80575	87.7306	1731
Democrat LCV scores	60.1736	15.8362	10.3163	96.4662	1727

Environmental expenditure per capita in US$ and state personal income per capita in US$; Population in thousands.

are the proportion of the time that the member of Congress voted with the LCV's position on legislation with environmental consequences (see Sigman, 2003). The League of Conservation Voters publishes an annual report on the LCV scores every year since 1971. The politicians scored by the LCV are the congressional delegation from each state. Therefore, it is likely that politicians with high LCV scores are the delegation from states where residents have favorable environmental preferences. I collect the nominal LCV scores of each state from the website of the LCV and convert them to the real terms for a time consistent measure of environmental preferences.[23] The LCV score is the average score of senators and representatives in each year and state, which I assume the environmental preferences of the median voters in each year and state. The Republican LCV score is the average score of Republican senators and representatives in each year and state; and the Democrat LCV score is the average score of Democrat senators and representatives in each year and state.

The key explanatory variable is each state governor's party affiliation, which is equal to 1 if the governor is affiliated with Republican party, and 0 otherwise. I collect this data from the National Governors Association. To capture the theoretical argument that the Republican governors may have an incentive to respond to the environmental preferences of the Democrat voters, I extend the econometric model

[23] The scales underlying the nominal LCV scores can shift and stretch since the set of votes used to score is not constant over time and across chambers. Groseclose et al. (1999) provides a method to convert the scores.

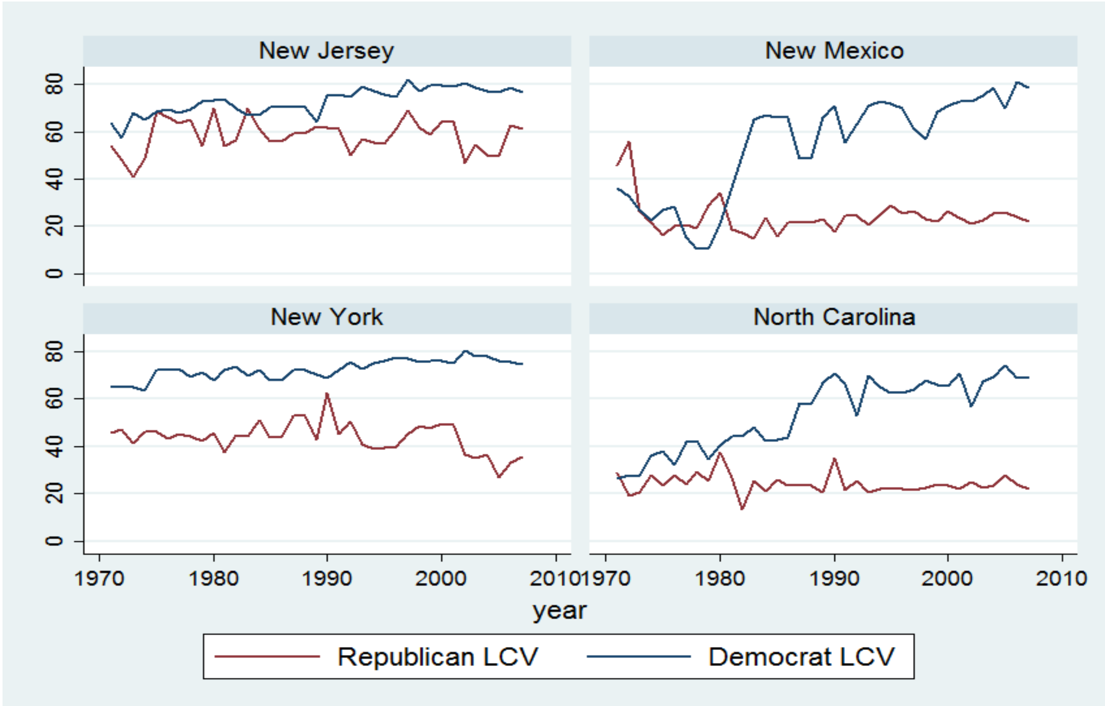

Figure 8: Real LCV Scores by Party

by interacting this variable with the LCV score in each year and state. As the previous literature,[24] I control for total state population and state personal income per capita.

3.5.2. Econometric Methodology

I use linear panel-data models with state and year fixed effects to estimate the relationship between the state environmental expenditure and the state environmental preferences (LCV scores), and the LCV scores interacted with the state governor's party affiliation, the state personal income per capita, and the state population. The regression equation is the following:

$$ENV_{it} = \beta_0 + \beta_1 RLCV_{it} + \beta_2 DLCV_{it} + \beta_3 RLCV \times REP_{it} + \beta_4 DLCV \times REP_{it} + \beta_5 X_{it} + \delta_i + \gamma_t + \epsilon_{it}, \quad (47)$$

[24]See List and Sturm (2006) and Besley and Case (1995, 2003)

where ENV_{it} is the log of the environmental expenditure in each state (i) and year (t), $RLCV_{it}$ is the log of real LCV score of Republicans in each state and year, $DLCV_{it}$ is the log of real LCV score of Democrats in each state and year. The regressor of primary interest is the interaction between the LCV scores and the governor's party affiliation, which is equal to one if the governor is affiliated with Republican party, and zero otherwise. X_{it} is the vector of state population demographic characteristics: the state population and the state personal income per capita. δ_i and γ_t denote the country and year fixed effects, respectively, and ϵ_{it} is the error term.

I try four different specifications. Specifications (1) and (2) analyze the sample of the period 1971-2007. The early 1970s is considered to be when environmental concerns arise in the U.S., due to the fact that the Environmental Protection Agency was founded and the first Earth day (see List and Sturm, 2006) was designated. Figure 3 shows the LCV scores by party in four states, NJ, NM, NY, and NC. Compared to 1970s, it seems that each party' s political stance regarding the environmental issues becomes more distinct in 1980s: Democrats are more concerned about the environment than Republicans. Thus, specifications (3) and (4) analyze the reduced sample of the period 1985-2007.

3.5.3. Empirical Results

In specification (4) where the sample period is 1985-2007, I estimate with the 5% significance level that, for a one percent increase in the Republican LCV, we will see approximately 9.9 percent less environmental expenditure per capita in Republican states over and above any effect we see in Democrat states. In this case, a one percent increase in the Republican LCV leads to approximately 4.8 percent less expenditure in Republican states. At the same time, I estimate with the 10% significance level that, for a one percent increase in the Democrat LCV, we will see approximately 7.2 percent more environmental expenditure per capita in Republican States over and above any effect we see in Democrat states. In this case, a one percent increase in the Democrat LCV leads to approximately 1.5 percent more expenditure in Republican states.

In Democrat states, I estimate that a one percent increase in the Republican LCV is associated with approximately 5.1 percent increase in the environmental expenditure per capita; and a one percent increase in the Democrat LCV is associated with approximately 5.7 percent decrease in the environmental expenditure per capita. Note that these two coefficients are not statistically significant.

Table 5: Environmental Preferences by Party on Environmental Expenditure per Capita

	(1) 1971-	(2) 1971-	(3) 1985-	(4) 1985-
Republican LCV	-0.0116	-0.00866	-0.00091	0.0512
	(0.0370)	(0.0407)	(0.0386)	(0.0474)
Democrat LCV	-0.0268	-0.0355	-0.0131	-0.0568
	(0.0434)	(0.0505)	(0.0447)	(0.0538)
Rep LCV × Republican State		-0.0123		-0.0994**
		(0.0401)		(0.0451)
Dem LCV × Republican State		0.0142		0.0715*
		(0.0335)		(0.0383)
State Personal Income	0.0731	0.0742	0.0700	0.0648
	(0.0583)	(0.0586)	(0.0679)	(0.0656)
State Population	-0.993***	-0.993***	-1.008***	-1.006***
	(0.0085)	(0.0086)	(0.0080)	(0.0078)
Constant	11.29***	11.30***	11.35***	11.40***
	(0.582)	(0.585)	(0.634)	(0.621)
N	1606	1606	979	979
adj. R^2	0.970	0.970	0.980	0.980

Standard errors are clustered by state and in parentheses.
All columns include state and year fixed-effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.5.4. Discussion

I interpret these empirical findings as follows. First, the Democrat governors do not significantly respond to a change in the environmental preferences of their residents. The Democrat governors may not be sensitive to a change in their residents' environmental preferences since they already have strong environmental preferences to implement strong environmental policies. Second, the Republican governors do significantly respond to a change in the environmental preferences of their residents. I find that they positively respond to an increase in the Democrats' environmental preferences. To be specific, the Republican governors increase the environmental expenditure per capita by approximately 1.5 percent as the Democrats LCV increases by 1 percent.

To interpret these results, consider a representative democracy with a multi-dimensional policy space. The majority of voters are interested in "frontline" policy issues such as the level of government spending and the degree of income distribution, and they often have an opposing idea about the frontline policy issues with each other. However, it is less likely that the majority voters are interested in "secondary" policy issues such as environmental policy. While there is a group of voters who are not concerned about the environment, there is another group of voters who are seriously concerned about the environment. The voters who are not concerned about the environment are likely to be indifferent about environmental policy. However, an environmental policy is likely to be important for the voters who are concerned about the environment.[25] I assume that Democrat voters (the left wing) are concerned about the environment and a politician's choice on environmental policy is important for them, while Republican voters (the right wing) are not concerned about the environment and they are indifferent about environmental policy. Democrat politi-

[25] List and Sturm (2006) argue that electoral incentives are important determinant of policy choice on "secondary" policy issues such as environmental policy.

cians would have great environmental preferences like the Democrat voters, so they are likely to implement strong environmental policies. The politicians of interest is Republicans. Even though the Republican voters are not concerned about the environment and they are indifferent about the environment policy, Republican politicians may respond to the environmental preferences of the Democrat voters to attract the median voters and win the elections.

The Republican governors positively respond to the environmental preferences of the Democrat voters to attract the median voters and win the elections. I consider one-dimensional space of the voters regarding environmental policy. Let us assume that half of the voters are Republicans (the right wing) who are not concerned about the environment and feel indifferent about environmental policy, and another half of the voters are Democrats (the left wing) who are concerned about th environment and feel important about environmental policy. Suppose that the median voters are 10 percent of the voters in the middle of the space. The Republican governors win the elections since they positively responded to the environmental preferences of the Democrat voters and attracted the median voters (see Figure 4).

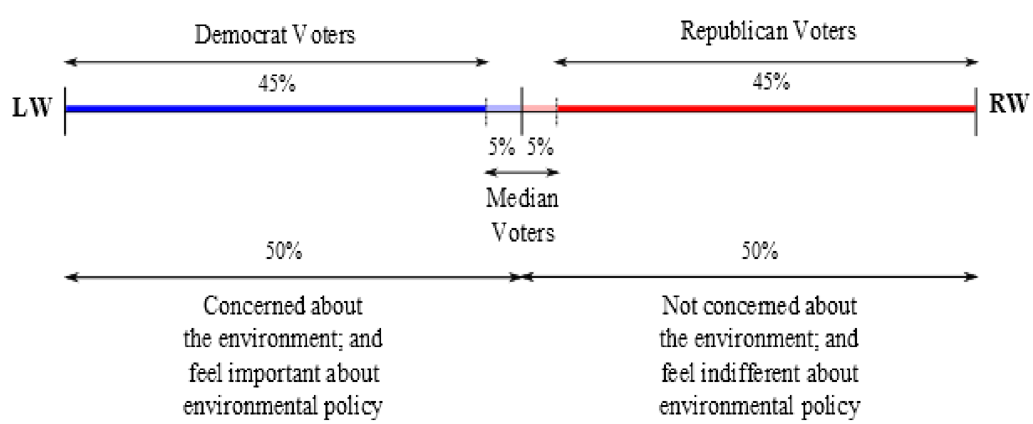

Figure 9: One-Dimensional Space of the Environmental Preferences of the Voters

Lastly, I examine how the governors respond to the median voters' environmental preferences. To measure the environmental preferences of the median voters, I use the averages of the LCV scores of both parties. Table 6 provides the empirical results.

Table 6: Environmental Preferences on Environmental Expenditure per Capita

	(1) 1971-	(2) 1971-	(3) 1985-	(4) 1985-
LCV	-0.120	-0.122*	-0.0358	-0.0280
	(0.0738)	(0.0729)	(0.0611)	(0.0603)
LCV × Republican State		0.00186		-0.0116**
		(0.00479)		(0.00567)
State Personal Income per capita	0.0141	0.0137	-0.00273	-0.00119
	(0.0605)	(0.0606)	(0.0762)	(0.0726)
State Population	-0.993***	-0.993***	-1.005***	-1.004***
	(0.00707)	(0.00707)	(0.00688)	(0.00658)
Constant	12.17***	12.17***	11.98***	11.95***
	(0.339)	(0.337)	(0.342)	(0.337)
N	1850	1850	1150	1150
adj. R^2	0.969	0.969	0.979	0.979

Standard errors are clustered by state and in parentheses.
All columns include state and year fixed-effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

First, although it is statistically insignificant, the LCV scores are negatively related with the state environmental expenditure. Specifically, a one percent increase in the LCV score is associated with approximately 12 percent decrease in the state environmental expenditure in the period of 1971-2007; and it is associated with approximately 3 percent decrease in the period of 1985-2007. In specification (4) where the sample period is 1985-2007, the coefficient on the interaction term is negative and statistically significant. Specifically, for a one percent increase in the LCV, we will see approximately 1.2 percent smaller environmental expenditure per capita in Republican states over and above any effect we see in Democrat States. In this case, a one percent increase in the LCV leads to approximately $2.8 + 1.2 = 4$ percent less expenditure in Republican states. This is puzzling: the states where the environmental preferences of the median voters increase should see more stringent environmental policies; However, I find the opposite. It is possible that the averaged LCV scores do not accurately measure the median voters preferences.

3.6. Concluding Remarks

The theoretical model shows that Political institutions affect the government's climate change policies: In the case where the government has the fears of losing power (the median voter is closer to the alternative party), we achieve stronger environmental polices. In the analysis of international panel data of 1980-2012, I find that a one-unit increase in the Polity II index is associated with approximately 11-13 percent increase in the proportion of electricity due to renewable energy. I also find that a one-unit increase in the Polity II index is associated with approximately 3 percent decrease in the CO2 emissions per capita. That is, countries with more democratic institutions practice more environment-friendly policies; and they also produce lower CO2 emissions.

I further study how the population environmental preferences, as measured by the LCV scores, influence state governors to become more concerned about the environment in the U.S. This would be especially important for Republican governors, if we assume that Democrat voters are concerned about the environment while Republican voters are not. The voters who are not concerned about the environment are likely to be indifferent about environmental policy. However, an environmental policy is likely to be important for the voters who are concerned about the environment.[26] I assume that Democrat voters (the left wing) are concerned about the environment and a politician's choice on environmental policy is important for them, while Republican voters (the right wing) are not concerned about the environment and they are indifferent about environmental policy. Democrat politicians would have great

[26] List and Sturm (2006) argue that electoral incentives are important determinant of policy choice on "secondary" policy issues such as environmental policy.

environmental preferences like the Democrat voters, so they are likely to implement strong environmental policies. The politicians of interest is Republicans. Even though the Republican voters are not concerned about the environment and they are indifferent about environmental policy, Republican politicians may have an incentive to respond to the environmental preferences of Democrat voters to attract the median voters and win the elections. Therefore, I examine how state governors are sensitive to the environmental preferences of population.

I analyze a U.S. panel data in the period of 1971-2007. I find the Republican state governors increase the environmental expenditure per capita by approximately 1.5 percent as the Democrat LCV scores increase by 1 percent; and they increase the environmental expenditure per capita by 4.8 percent as the Republican LCV scores decrease by 1 percent. That is, Republican governors respond positively to the LCV scores of the Democrats, but not to Republican LCV scores. These empirical findings can be explained in line with the theoretical model. First, the Democrat governors do not significantly respond to a change in the environmental preferences of their residents. The Democrat governors may not be sensitive to a change in their residents' environmental preferences since they already have strong environmental preferences to implement strong environmental policies. Second, the Republican governors do significantly respond to a change in the environmental preferences of their residents. I find that they positively respond to an increase in the Democrats' environmental preferences. To be specific, the Republican governors increase the environmental expenditure per capita by approximately 1.5 percent as the Democrats LCV increases by 1 percent. The Republican governors positively respond to the environmental preferences of the Democrat voters to attract the median voters and win the elections. I consider one-dimensional space of the voters regarding environmental policy. Let us assume that half of the voters are Republicans (the right wing) who are not concerned about the environment and feel indifferent about environmental policy, and another half of the voters are Democrats (the left wing) who are concerned about th environment and feel important about environmental policy. Suppose that the median voters are 10 percent of the voters in the middle of the space. The Republican governors win the elections since they positively responded to the environmental preferences of the Democrat voters and attracted the median voters (see Figure 4). This empirical finding is consistent with Park's theoretical prediction that countries with more democratic institutions are more likely to have more stringent environmental policy. The right-wing politicians (Republicans) will not have any incentive to respond to the Democrat voters' environmental preferences if they do not have any election concerns. In a full democracy such as the U.S. where the median voters have power to replace to regime, the politicians have political incentive to respond to the median voters' preferences to win the elections.

Chapter 4

Climate Politics between Asymmetric Countries and Scientific Communication

4.1. Introduction

Climate scientists express a strong consensus that climate change over the past century is very likely anthropogenic, or due to human activity. Ninety-seven percent or more of climate scientists support the significance of anthropogenic climate change (see the NASA Global Climate Change website for further details). Although the consensus about climate change is strong within the worldwide scientific community, it seems that how this alarming message about climate change influences the political arena differs significantly by region. For instance, in the United States, it appears that skeptical messages about climate change are often more powerful than alarming messages about climate change. Less than three percent of scientists create the skeptical messages about climate change, but in the political arena, these skeptical messages are powerful enough to compete with alarming message issued by the remaining 97% (Dunlap and McCright, 2011). In Europe, however, climate change has been seriously dealt with the political arena since the associated risks were uncovered by science, with the European Union taking more political actions against climate change than the US.[27] The fundamental reason for this difference may be different levels of damage from climate change and/or different benefits from actions against climate change. Unlike the US, the EU has numerous member countries especially vulnerable to climate change, such as Sweden, Denmark, Finland, Greenland, and

[27] "[O]nly the EU has accepted binding commitments under the Kyoto Protocol, which the U.S. signed, but refused to ratify." *Climate policies in the EU and USA: Different approaches, Convergent outcomes?,* European Parliamentary Research Service, Gregor Erbach

Iceland. They are mostly Northern European countries lying close to the Arctic, which makes them more sensitive to damage from climate change, such as melting glaciers and rising surface temperature.[28]

To study how the scientists (a third party) influence international climate politics between asymmetric countries, I extend the strategy of manipulating conflict developed by Baliga and Sjöström (2012) with asymmetric players, and apply it to climate-change politics between two asymmetric decision-makers under incomplete information. I consider two asymmetric countries, A and B. Climate change presents a greater risk of damage to country A than country B. In country $i \in \{A, B\}$, a decision-maker called player i chooses either a *progressive* (P) or a *conservative* (C) action. Player i can be interpreted as the median voter or some other pivotal decision-maker in country i. The progressive action may be developing renewable energy sources, increasing the use of them, or developing/adopting technology to mitigate greenhouse gases. The conservative action may be burning more fossil fuels rather than using renewable energy, passing legislation to protect the fossil fuel industry, pulling out of an international climate agreement. Player i's choice may also involve selecting an agent who will take either progressive or conservative action toward climate change. For example, the median voter in the US must decide whether to support Democrats (who traditionally enact more progressive climate change policies) or Republicans (who traditionally do not).

In my model, a third-party player, a scientist (player S), sends a publicly observed cheap-talk message[29] before players A and B make their decisions. An example of a cheap-talk message might be the exposure to the media of the risks of climate change.

[28]Rising one Celsius degree from 0 to 1 is more detrimental than rising from from 25 to 26. The Intergovernmental Panel on Climate Change (IPCC) summary for policymakers, released in 2014, states that "[C]limate change is causing permafrost warming and thawing in high latitude regions and in high-elevation regions (high confidence)."

[29]Note that the messages from scientists are not verifiable by the decision-makers. Therefore, the messages themselves are talk-costless, nonbinding, and nonverifiable claims, which make the game a cheap-talk game.

The scientist is from country A, and can hold a range of influential positions there. For instance, he could be the leader of the skepticism movement, or alternatively, an insider at the center of politics, such as the head of the White House of Science and Technology Policy. The true preference of the scientist is commonly known. I consider two cases: a conservative (contrarian) scientist who wants player A to choose C, and a progressive scientist who wants player A to choose P. Both kinds of scientists want player B to choose P.

For a scientist's cheap-talk to matter, it must convey information. In my model, the cheap-talk message conveys information about player A's type. For simplicity, I assume that the scientist knows player A's true type, because as a political insider in country A, he would typically know more about the preference of player A than player B.

My main interest is in *communication equilibria*, where the scientist's cheap-talk is effective in the sense of influencing the equilibrium decisions of players A and B. I show the existence of such equilibria. Under some assumptions, there is even a *unique* communication equilibrium. Importantly, I find that even if multiple communication equilibria exist, they always have the same structure and the same welfare implications.

If cheap-talk is effective, then some message m_0 will make player B more likely to choose C. A conservative scientist is willing to send message m_0 only if player A also becomes more likely to choose C. Such co-varying actions must be the property of strategic complements. On the other hand, a progressive scientist is willing to send m_0 only if player A becomes more likely to choose P. Such negative correlation occurs when actions have the property of strategic substitutes. This argument implies that if the underlying game has the property of strategic complements, then only a conservative scientist can communicate effectively. By sending message m_0, the conservative scientist triggers an unwanted (by players A and B) spiral of climate change skepticism, making both players A and B more likely to choose C. Conversely, if the underlying game has the property of strategic substitutes, then only a progressive scientist can communicate effectively. By sending message m_0, the progressive scientist makes player B more likely to choose C and causes player A to choose P.

With the property of strategic complements, message m_0 can be interpreted as a "skeptical" message on climate change from the conservative scientist. This occurs only when player A is a "left moderate" who would have chosen P in the communication-free equilibrium. The skeptical message causes him to choose C instead. In contrast, skeptical messages are counter-productive when player A is a dominant strategy conservative (who always chooses C anyway). Thus, the absence of a skeptical message is actually "bad news" about player A's type in the sense that the conditional probability that player A is a dominant strategy conservative increases. This "bad news" makes player B more likely to choose C than in the communication-free equilibrium.

These arguments imply that, with strategic complements, players A and B are more likely to choose C in the communication equilibrium (whether or not a skeptical message occurs) than in the communication-free equilibrium. Because each decision-maker always wants the other to choose P, the communication-free equilibrium interim Pareto dominates the communication equilibrium for players A and B. Eliminating the conservative scientist would make all types of players A and B strictly better off. This includes player A's most conservative types, whose preferences are aligned with the conservative scientist. When preferences are aligned in this way, the scientist will not behave conservatively, but this itself alarms player B. Without the conservative scientist, climate change skepticism would not be inflamed in this way.

With the property of strategic substitutes, message m_0 can be interpreted as an "alarming" message sent by the progressive scientist. This occurs only when player A is "right moderate" who would have chosen C in the communication-free equilibrium. In the communication equilibrium, following an alarming message from the scientist, player B becomes more conservative, and player A more progressive. In fact, whether or not an alarming message occurs, player B is more likely to choose C in the communication equilibrium than in the communication-free equilibrium, and this unambiguously makes player A worse off. Thus, player A would like to ban alarming messages if he could. On the other hand, because they induce player A to choose P, alarming messages make player B better off.

My theoretical model is directly related to the work of Baliga and Sjöström (2012). Those authors examined how an extremist can influence political decision-making by sending publicly observed messages. They showed that a publicly observed cheap-talk message sent by one country's extremist can influence another country's political decisions. Specifically, an extremist can increase the likelihood of conflict between two different countries. The main difference between my model and theirs is that the decision-makers in my model are asymmetric. I examine how the third party can influence the asymmetric decision-makers in different environments. The likelihood of both players choosing progressive action on climate change decreases if actions have the property of strategic complements and the scientist is conservative. If actions have the property of strategic substitutes, a progressive scientist can send alarming messages that cause the decision-maker with greater climate change damage to be more progressive. Furthermore, I show that there does not exist any communication equilibrium for either kind of scientist, for any other combination of player types.

The basic model is discussed in Section 2. I analyze communication equilibria in Section 3. I conclude in Section 4.

4.2. The Model

4.2.1. The Game without Cheap Talk

I consider two decision-makers of countries $i \in \{A, B\}$. Players A and B are the pivotal decision-makers of countries A and B, respectively. They simultaneously choose either a *progressive* (pro-environment, renewable-energy advocative) action P or a *conservative* (pro-growth, fossil-fuel advocative) action C. The payoff for player $i \in \{A, B\}$ is given by the following payoff matrix, where the row and the column represent the payoffs for players A and B, respectively.

	Progressive	*Conservative*
P	$\mu_A - c_A,\ \mu_B - c_B$	$\mu_A - d_A - c_A,\ \mu_B - d_B$
C	$\mu_A - d_A,\ \mu_B - d_B - c_B$	$-d_A,\ -d_B$

Note that d_i captures the damage to player i of one of the two players choosing a conservative course of action. I assume that the level of damage is asymmetric between the two players. A conservative action causes damage from climate change, such as an increase in the land surface temperature, melting glaciers in the Arctic, and rising sea levels. But the the level of damage may differ across countries. μ_i captures the benefit from being progressive, which arises from actions for preventing climate change, such as mitigation of greenhouse gases and developing renewable energy sources. I assume that μ_i is asymmetric between the two countries. Note that $\mu_i \in \{A, B\}$ and $d_i \in \{A, B\}$ are common knowledge.

Notice that c_i is the cost for player $i \in \{A, B\}$ to take the progressive action P, referred to as his type. Neither player knows the other player's type. The two types, c_A and c_B, are random variables independently drawn from the distributions $F_A(c)$ and $F_B(c)$, respectively. Let $F_i \in \{A, B\}$ denote the continuous cumulative distribution function, with support $[\underline{c}, \overline{c}]$, and where $F_i'(c) > 0$ for all $c \in (\underline{c}, \overline{c})$. When players choose an action, player A knows c_A but not c_B, while player B knows c_B but not c_A.

Player i is considered a *dominant strategy progressive* if P is a dominant strategy ($d_i \geq c_i$ and $\mu_i \geq c_i$ with at least one strict inequality). Player i is considered a *dominant strategy conservative* if C is a dominant strategy ($d_i \leq c_i$ and $\mu_i \leq c_i$ with at least one strict inequality). Player i is a *coordination type* if P is a best response to P and C is a best response to C ($\mu_i \leq c_i \leq d_i$). Player i is an *opportunistic type* if C is a best response to P and P is a best response to C ($d_i \leq c_i \leq \mu_i$). Note that when both players are coordination types, the actions P and C have the properties of strategic complements, and when both players are opportunistic, P and C have the properties of strategic substitutes. Assumption 1 states that the support of F_i is big enough to include dominant strategy types of both kinds.

Assumption 1. $\underline{c} < \mu_i < \overline{c}$ *and* $\underline{c} < d_i < \overline{c}$ *for all* $i \in \{A, B\}$*.*

Suppose that player i thinks player j will choose P with probability p_j. Player i's expected payoff from choosing P is $\mu_i - c_i - d_i(1 - p_j)$, while his expected payoff from C is $\mu_i p_j - d_i$. Thus, if he chooses P instead of C, his *net* gain is

$$\mu_i - c_i + (d_i - \mu_i)p_j. \tag{48}$$

A *strategy* for player i is a function $\sigma_i : [\underline{c}, \overline{c}] \to \{P, C\}$, which specifies an action $\sigma_i(c_i) \in \{P, C\}$ for each cost type $c_i \in [\underline{c}, \overline{c}]$. In a Bayesian Nash equilibrium (BNE), all types maximize their expected payoff. Therefore, $\sigma_i(c_i) = P$ if the expression in (1) is positive, and $\sigma_i(c_i) = C$ if it is negative. If the expression (1) is zero, then type c_i is indifferent. For convenience, I assume that the player chooses P in this case.

Player i uses a *cutoff strategy* if there is a *cutoff point* $x \in [\underline{c}, \overline{c}]$ such that $\sigma_i(c_i) = P$ if and only if $c_i \leq x$. Because the expression (1) is monotone in c_i, all BNE must be in cutoff strategies. Therefore, we can restrict our attention to cutoff strategies without loss of generality. Any such strategy can be identified by its cut-off point $x \in [\underline{c}, \overline{c}]$. As there are dominant strategy progressives and conservatives by Assumption 1, all

BNE must be interior: each player chooses P with probability strictly between 0 and 1.

If player j uses cutoff point x_j, the probability that he plays P is $p_j = F_j(x_j)$. Therefore, using (1), player i's best response to player j's cutoff x_j is to choose the cutoff $x_i = \Gamma(x_j)$, where

$$\Gamma_i(x) = \mu_i + (d_i - \mu_i)F_j(x). \tag{49}$$

The function Γ_i is the best-response function for player i's cutoff strategy. The best-response functions generate a unique equilibrium which is ensured by Assumption 2.

Assumption 2. $F_i'(c) < |\frac{1}{d_i - \mu_i}|$ *for all* $c \in (\underline{c}, \overline{c})$.

If F_i happens to be uniform, then there is maximal uncertainty (for a given support) and Assumption 2 is redundant. More precisely, with a uniform distribution, $F_i'(c) = \frac{1}{\overline{c} - \underline{c}}$, so Assumption 1 implies $F_i'(c) < |\frac{1}{d_i - \mu_i}|$. Note that Assumption 2 is much weaker than uniformity.

Theorem 2. *The game without cheap-talk has a unique Bayesian Nash equilibrium.*

Proof. See Appendix. □

Theorem 1 shows that–as long as Assumptions 1 and 2 hold, and whether players are coordination types or opportunistic types–there exists a unique BNE, which I refer to as the *communication-free BNE*. In equilibrium, player A chooses P if $c_i < \overline{y}$, and player B chooses P if $c_i < \overline{x}$, where $(\overline{x}, \overline{y})$ is the unique equilibrium point of $\Gamma_A(x)$ and $\Gamma_B(y)$ in $[\underline{c}, \overline{c}]$. The asymmetry of the game implies that each player uses a different cutoff point. Since $\overline{x} < \overline{y}$, player A is more likely to be progressive than player B. Note that the player who uses the lower cutoff in the communication-free equilibrium will be the player with the lower value for d. The equilibrium can be

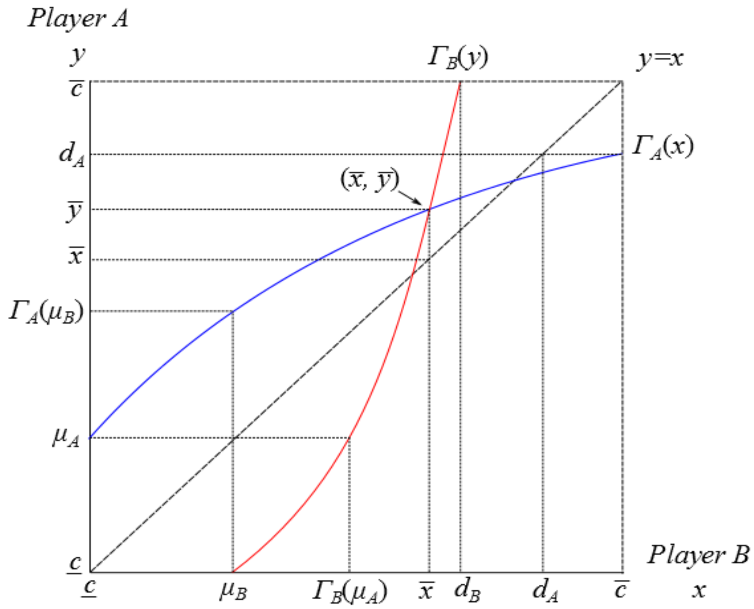

Figure 10: The Game with Coordination Types: Communication-Free Equilibrium

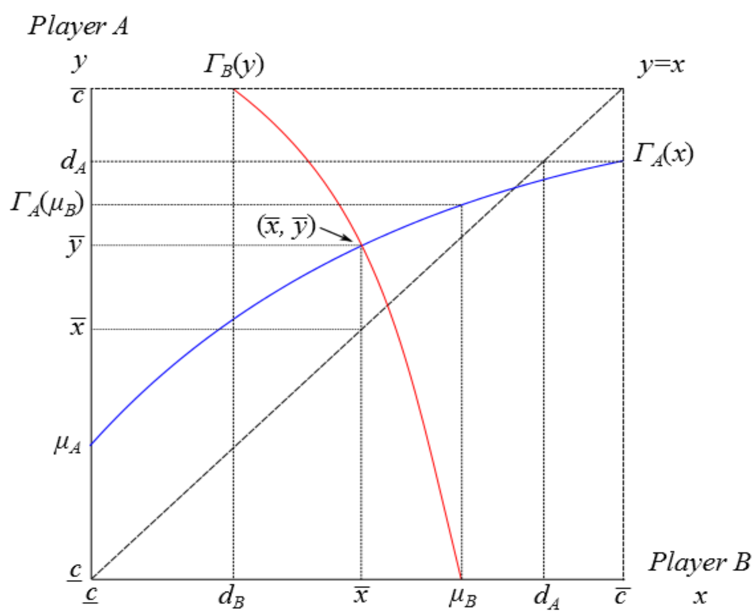

Figure 11: The Game with a Coordination type and an Opportunistic Type: Communication-Free Equilibrium

reached via iterated deletion of dominated strategies, and captures the escalating spiral of fear discussed by Shelling (1960) and Jervis (1976).

4.2.2. Cheap Talk

Now a third player, player S, is introduced. Player S is a scientist. His payoff function is identical to player A's, with one exception: player S's cost type c_S differs from player A's cost type c_A. Thus, player S's payoff is obtained by setting $c_i = c_S$ in the payoff matrix. There is no uncertainty about c_S. Formally, c_S is common knowledge among the three players.

Player S knows c_A, but not c_B. (More accurately, the scientist might receive some signal about player A's type; to avoid unnecessary complications, I assume that the signal is perfect, so that player S knows c_A.)

I consider two possibilities. First, if player S is a *progressive* (renewable-energy advocative) scientist, then $c_S < 0$. To put it differently, $(-c_S) > 0$ represents a *benefit* the progressive scientist enjoys if player A is progressive. When both players are opportunistic types, the progressive scientist is guaranteed a strictly positive payoff no matter what player A chooses; this payoff is however higher when player A chooses P. So the scientist always wants player A to choose P. On the other hand, when both players are coordination types, he gets a strictly positive payoff if player A chooses P, but a strictly negative payoff if player A chooses C; therefore the scientist always wants player A to choose P.

Second, if player S is a *conservative* scientist (fossil-fuel advocative), then $c_S > \mu_A + d_A$. The highest payoff the conservative scientist can obtain if player A chooses P is $\mu_A - c_S$, while the lowest payoff he can obtain when player A chooses C is $-d_A > \mu_A - c_S$. Therefore, he always wants player A to choose C. Notice that, holding player A's action fixed, the scientist (whether renewable-energy or fossil-fuel advocative) is better off if player B chooses P.

Before players A and B play the game, player S sends a publicly observed cheap-talk message, $m \in M$, where M is his message space. The time line is as follows.

1. The cost type c_i is determined for each player $i \in \{A, B\}$. Players A and S

learn c_A. Player B learns c_B.

2. Player S sends a (publicly observed) cheap-talk message $m \in M$.

3. Players A and B simultaneously choose P or C.

Cheap-talk is *effective* if there is a positive measure of types that choose different actions at time 3 than they would have done in the unique communication-free equilibrium. A Perfect Bayesian Equilibrium (PBE) with effective cheap-talk is a *communication equilibrium*. Clearly, if player A and B maintain their prior beliefs at time 3, then they must act just as in the communication-free equilibrium. Therefore, for cheap-talk to be effective, player S's message must reveal some information about player A's type.

A strategy of player S is a function $m : [\underline{c}, \overline{c}] \to M$, where $m(c_A)$ is the message sent by player S when player A's type is c_A. Without loss of generality, I assume that each player $j \in \{A, B\}$ uses a conditional cut-off strategy: for any message $m \in M$, there is a cut-off $c_j(m)$ such that if player j hears message m, then he chooses P if and only if $c_j \leq c_j(m)$.

Lemma 1. *In the communication equilibrium, we can assume without loss of generality that M contains only two messages, $M = \{m_0, m_1\}$, where $c_B(m_1) > c_B(m_0)$.*

Proof. See Appendix. □

Notice that this lemma holds for any player type, and for any kind of scientist. It does not require Assumption 2.

4.3. Communication Equilibrium with Cheap-Talk

4.3.1. Conservative Cheap-Talk

I consider the case where both players are coordination types, $d_i > \mu_i$ for all $i \in \{A, B\}$. Suppose player S is a conservative scientist, $c_S > \mu_A + d_A$, and both players are coordination types. I will construct a communication equilibrium, where the conservative scientist S uses cheap-talk to decrease the likelihood of progressive cooperation on climate change below the level where it would be in the communication-free equilibrium. It is surprising that player S can do this, because c_S is commonly known. That is, it is commonly known that player S wants player B to choose P and player A to choose C. To understand the equilibrium intuitively, it helps to recall that $M = \{m_0, m_1\}$ by Lemma 1, where $c_B(m_1) > c_B(m_0)$, and to interpret message m_0 as a "skeptical attitude" towards climate change and message m_1 as a "no skeptical attitude" towards climate change.

Say that player A is a *susceptible type* if he chooses C following the message m_0, but P following m_1. The set of susceptible types is

$$S \equiv (c_A(m_0), c_A(m_1)].$$

The proof of Lemma 1 showed that if $m(c_A) = m_0$, then type c_A must be susceptible. Since the skeptical attitude makes player B more likely to choose C, player S will only send m_0 if it causes player A to change his action from P to C. On the other hand, player S wants player A to choose C and therefore strictly prefers to send m_0 whenever player A is susceptible. That is, it is optimal for player S to set $m(c_A) = m_0$ if and only if $c_A \in S$. Accordingly, message m_0 signals that player A will choose C. As argued in the proof of Lemma 1, this implies that $c_B(m_0) = \mu_B$. Therefore, if m_0 is sent then player B will choose P with probability $F_B(\mu_B)$, so player A prefers P if and only if

$$-c_A + (1 - F_B(\mu_B))\mu_A \geq F_B(\mu_B)(-d_A),$$

which is equivalent to $c_A \leq \Gamma_A(\mu_B)$. Thus, player A uses cut-off point $c_A(m_0) = \Gamma_A(\mu_B)$, where Γ_A is defined by (2).

It remains only to consider how players A and B behave when player S shows a non-skeptical attitude (message m_1). Let $y^* = c_A(m_1)$ and $x^* = c_B(m_1)$ denote the cutoff points in this case. Therefore, if m_1 is sent then player B will choose P with probability $F_B(x^*)$, so player A prefers P if and only if

$$-c_A + (1 - F_B(x^*))\mu_A \geq F_B(x^*)(-d_A),$$

which is equivalent to $c_A \leq \Gamma_A(x^*)$. Thus, $y^* = \Gamma_A(x^*)$. When player B hears message m_1, he knows that player A is not the susceptible type. That is, c_A is either below $\Gamma_A(\mu_B)$ or above y^*, and player A chooses P in the former case and C in the latter case. Therefore, player B prefers P if and only if

$$-c_B + \frac{1 - F_A(y^*)}{1 - F_A(y^*) + F_A(\Gamma_A(\mu_B))}\mu_B \geq \frac{1 - F_A(\Gamma_A(\mu_B))}{1 - F_A(y^*) + F_A(\Gamma_A(\mu_B))}(-d_B). \qquad (50)$$

Inequality (4) is equivalent to $c_B \leq \Omega_B(y^*)$, where

$$\Omega_B(y) \equiv \frac{[1 - F_A(y)]\mu_B + F_A(\Gamma_A(\mu_B))d_B}{[1 - F_A(y)] + F_A(\Gamma_A(\mu_B))}.$$

Thus, $x^* = \Omega_B(y^*)$.

To summarize, any communication equilibrium must have the following form. Player S sets $m(c_A) = m_0$ if and only if $c_A \in S = (\Gamma_A(\mu_B), y^*]$. Player A's cutoff points are $c_A(m_0) = \Gamma_A(\mu_B)$ and $c_A(m_1) = y^*$. Player B's cutoff points are $c_B(m_0) = \mu_B$ and $c_B(m_1) = x^*$. Moreover, x^* and y^* must satisfy $y^* = \Gamma_A(x^*)$ and $x^* = \Omega_B(y^*)$. Conversely, if such x^* and y^* exist, then they define a communication equilibrium. Figure 3 shows a graphical illustration of a communication equilibrium.

By Assumption 2, Γ_i is increasing with a slope less than one. Since $F_i(\underline{c}) = 0$ and $F_i(\bar{c}) = 1$, $\Gamma_i(\underline{c}) = \mu_i > \underline{c}$ and $\Gamma_i(\bar{c}) = d_i < \bar{c}$. Furthermore,

$$\Gamma_i(d_i) - \mu_i = F_j(d_i)(d_i - \mu_i) < d_i - \mu_i.$$

Therefore,

$$\Gamma_i(d_i) < d_i. \tag{51}$$

Also,

$$\Gamma_i(\mu_j) = \mu_i(1 - F_j(\mu_j)) + d_i F_j(\mu_j) > \mu_i, \tag{52}$$

as $d_i > \mu_i$. Let $(\overline{x}, \overline{y})$ be the unique communication-free equilibrium point in $[\underline{c}, \bar{c}]$. Clearly, $\mu_B < \Gamma_B(\mu_A) < \overline{x}$ and $\mu_A < \Gamma_A(\mu_B) < \overline{y}$ (see Figure 3).

Notice that

$$\Omega_B'(y) = \frac{F_A'(y)(d_B - \mu_B)F_A(\Gamma_A(\mu_B))}{\{[1 - F_A(y)] + F_A(\Gamma_A(\mu_B))\}^2},$$

so Ω_B is increasing. It is easy to check that $\Gamma_B(y) > \Omega_B(y)$ whenever $y \in (\Gamma_A(\mu_B), \bar{c})$.

Moreover,

$$\Omega_B(\bar{c}) = \Gamma_B(\bar{c}) = d_B$$

and

$$\Omega_B(\Gamma_A(\mu_B)) = \Gamma_B(\Gamma_A(\mu_B)) > \Gamma_A(\mu_B),$$

where the inequality follows from (6) and the fact that Γ_B is increasing. These properties are drawn in Figure 3. Notice that the curve $x = \Omega_B(y)$ lies to the left of the curve $x = \Gamma_B(y)$ for all $y \in (\Gamma_A(\mu_B), \bar{c})$, but that the two curves intersect when $y = \Gamma_A(\mu_B)$ and $y = \bar{c}$.

As shown in Figure 3, the two curves $x = \Omega_B(y)$ and $y = \Gamma_A(x)$ must intersect at some (x^*, y^*), and it must be true that

$$\mu_A < \Gamma_A(\mu_B) < x^* < \overline{x} < y^* < \overline{y}. \tag{53}$$

By construction, $y^* = \Gamma_A(x^*)$ and $x^* = \Omega_B(y^*)$. Thus, a communication equilibrium exists. Both players A and B are strictly more likely to choose C in a communication equilibrium than in the communication-free equilibrium. To see this illustrated, notice that in the communication-free equilibrium, player A's cutoff is $\overline{y}$ and player B's cutoff is $\overline{x}$. By (7), the cut-off points are strictly lower in the communication equilibrium; namely, $x^* < \overline{x}$ and $y^* < \overline{y}$. Thus, whenever a player would have chosen C in the communication-free equilibrium, he necessarily chooses C in the communication equilibrium. Moreover, after any message, there are types (of each player) who choose C, but who would have chosen P in the communication-free equilibrium. It follows that all types of player A and B are made worse off by communication, because each wants the other player to choose P.

For player S, the welfare comparison across equilibria is ambiguous, because cheap-talk makes both players A and B more likely to choose C. There are three specific cases. First, if either $c_A \leq \Gamma_A(\mu_B)$ or $c_A > \overline{y}$, then player A's action is the same in the communication equilibrium and in the communication-free equilibrium, but player B is more likely to choose C in the former, making player S worse off. Second, if $y^* < c_A < \overline{y}$, then player A would have chosen P in the communication-free equilibrium. In the communication equilibrium, there is the skeptical message when $y^* < c_A < \overline{y}$, but player A plays C rather than P, because player B is more likely to choose C. Third, if $\Gamma_A(\mu_B) < c_A \leq y^*$, then the skeptical message causes player A to play C, rather than P in the communication-free equilibrium. Player S gets a strictly higher payoff when player A chooses C no matter what player B chooses. Thus, player S is better off if player A switches to C.

The communication equilibrium is *unique* if the two curves $x = \Omega_B(y)$ and $y = \Gamma_A(x)$ have a unique intersection. This would be true, for example, if F were concave, because in this case both Ω_B and Γ_A would be concave. However, uniqueness also obtains without concavity, if a "conditional" version of Assumption 2 holds. Intuitively, after m_1 is sent player B knows that player A's type is either below $\Gamma_A(\mu_B)$ or above y^*. Thus, the continuation equilibrium must be the equilibrium of a "conditional" game (without communication) where it is commonly known that player A's type distribution has support $[\underline{c}, \Gamma_A(\mu_B)] \cup (y^*, \bar{c}]$ and density

$$g(c) \equiv \frac{F_A'(c)}{1 - F_A(y^*) + F_A(\Gamma_A(\mu_B))}$$

on this support. Furthermore, following m_1, player A's type y^* must be indifferent between choosing P and C. That is, in the "conditional" game, the cut-off type is y^*. Recall that Assumption 2 guarantees uniqueness in the "unconditional" communication-free game. The analogous condition which guarantees uniqueness in the "conditional" game is $g(y^*) < 1/(d_i - y)$. Thus, the "conditional" game has a unique equilibrium if the following "conditional" version of Assumption 2 holds:

$$\frac{F_A'(y)}{1 - F_A(y) + F_A(\Gamma_A(\mu_B))} < \frac{1}{d_i - \mu_i} \tag{54}$$

for all $y \in (\underline{c}, \bar{c})$. This implies, since $0 < \Gamma_A'(x) < 1$, that the two curves intersect only once, as indicated in Figure 2. Thus, as before, the requirement for uniqueness is that the distribution is sufficiently diffuse. In summary:

Theorem 3. *Suppose that player S is a conservative scientist and both players A and B are coordination types. A communication equilibrium exists. All types of players A and B prefer the communication-free equilibrium to any communication equilibrium. Player S is better off in the communication equilibrium if and only if $\Gamma_A(\mu_B) < c_A < \overline{y}$. If (8) holds for all $y \in (\underline{c}, \bar{c})$, then there is a unique communication equilibrium.*

In the communication-free equilibrium, the probability of progressive cooperation on climate change, in the sense that the outcome is PP, is $F_B(\overline{x})F_A(\overline{y})$. In the communication equilibrium, PP happens with probability $\Gamma_A(\mu_B)F_B(x^*) < F_B(\overline{x})F_A(\overline{y})$. Thus, progressive cooperation on climate change is less likely in the communication equilibrium than in the communication-free equilibrium.

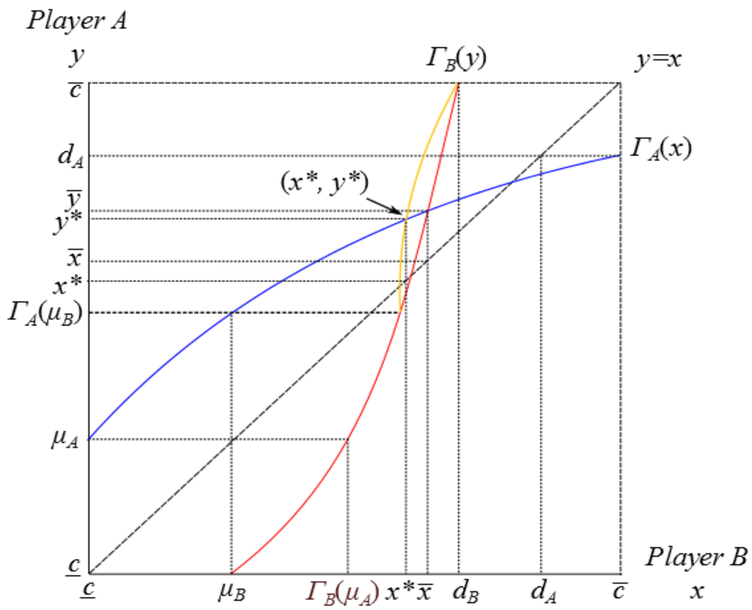

Figure 12: The Game with Coordination Types: Communication Equilibrium

To understand how the cut-off points can be uniformly higher with cheap-talk, we again interpret message m_1 as being a non-skeptical attitude towards climate change and message m_0 as being a skeptical attitude towards climate change. A spiral of skepticism occurs when player A is a coordination type, $c_A \in (\Gamma_A(\mu_B), y^*]$, who would have played P in the communication-free equilibrium. Now he plays C instead, and so does player B (except if he is a dominant strategy progressive). The players choose conservative actions following a skeptical attitude (m_0) because they think the other will choose a conservative action. The fact that a skeptical attitude does not show also deters cooperation, but for a different reason. In the "curious incident of the dog in the night-time" from Sir Arthur Conan Doyle's short story "Silver Blaze," , the dog did not bark at an intruder because the dog knew him well. Similarly, when player A's preferences are aligned with the conservative scientist, there is no skeptical attitude. Hence, a scientist who does not "bark" signals the possibility that player A is a dominant strategy conservative. This information makes player B want to choose C. Accordingly, the communication equilibrium has less cooperation on climate change than the communication-free equilibrium, no matter what message is sent.

4.3.2. Progressive Cheap-Talk

In this section, I consider the case of strategic substitutes, i.e., $d_i < \mu_i$ for all $i \in \{A, B\}$. Suppose player S is a progressive scientist and both players A and B are opportunistic types. I will construct a communication equilibrium where the progressive scientist S sends informative messages. Again, it is surprising that this can be done because c_S is commonly known. To understand the communication equilibrium intuitively, it helps to again recall Lemma 1, but now interpret message m_0 as "alarming" about climate change and message m_1 as "not alarming". Intuitively, the alarming message will make player B more conservative, and player A alert and chooses P.

Again, say that player A is a susceptible type if his action depends on which message is sent. But now, susceptible types switch from C to P when they hear message m_0. That is, the set of susceptible types is

$$S \equiv (c_A(m_1), c_A(m_0)].$$

The proof of Lemma 1 showed that if $m(c_A) = m_0$ then type c_A must be susceptible. Intuitively, since the alarming message makes player B more likely to choose C, player S would not engage in an alarming message unless player A is a susceptible type. Conversely, whenever player A is a susceptible type, the progressive scientist will engage in the alarming message, since he wants player A to choose P. Therefore, $m(c_A) = m_0$ if and only if $c_A \in S$. Accordingly, message m_0 signals that player A will choose P. As argued in the proof of Lemma 1, this implies that $c_B(m_0) = d_B$, and player A's best response to this cut-off point is $c_A(m_0) = \Gamma_A(d_B)$.

It remains only to consider how players A and B behave when the message is not alarming (m_1). Let $y^* = c_A(m_1)$ and $x^* = c_B(m_1)$ denote the cutoff points used in this case. Arguing as for the case of strategic complements, the cut-off points must satisfy $y^* = \Gamma_A(x^*)$ and $x^* = \tilde{\Omega}_B(y^*)$, where

$$\tilde{\Omega}_B(y) = \frac{[1 - F_A(\Gamma_A(d_B)]\mu_B + F_A(y)d_B}{[1 - F_A(\Gamma_A(d_B)] + F_A(y)}.$$

As shown in Figure 4, (x^*, y^*) is an intersection of the two curves $x = \tilde{\Omega}_B(y)$ and $y = \Gamma_A(x)$. With strategic substitutes, Assumption 2 implies

$$-1 < \Gamma_A'(x) < 0.$$

Furthermore, $\Gamma_A(\underline{c}) = \mu_A < \bar{c}$ and $\Gamma_A(\bar{c}) = d_A > \underline{c}$, and

$$\Gamma_A(d_B) - d_A = (1 - F_B(d_B))(\mu_A - d_A)$$

where

$$0 < (1 - F_B(d_B))(\mu_A - d_A) < \mu_A - d_A.$$

Therefore,

$$d_A < \Gamma_A(d_B) < \mu_A. \tag{55}$$

Let $(\overline{x}, \overline{y})$ be the unique communication-free equilibrium in $[\underline{c}, \bar{c}]$. Clearly, $d_A < \overline{x} < \overline{y} < \mu_A$ (see Figure 4).

Figure 4 shows three curves: $x = \tilde{\Omega}_B(y)$, $y = \Gamma_A(x)$, and $x = \Gamma_B(y)$. The curves $y = \Gamma_A(x)$ and $x = \Gamma_B(y)$ intersect at the unique communication-free equilibrium, $(\overline{x}, \overline{y})$. It is easy to check that $\Gamma_B(y) > \tilde{\Omega}_B(y)$ whenever $y \in (\underline{c}, \Gamma_A(d_B))$. Moreover,

$$\tilde{\Omega}_B(\underline{c}) = \Gamma_B(\underline{c}) = \mu_B$$

and

$$\tilde{\Omega}_B(\Gamma_A(d_B)) = \Gamma_B(\Gamma_A(d_B)) < \Gamma_A(d_B),$$

where the inequality follows from the fact that Γ_B is decreasing. Consider now (x^*, y^*) such that $y^* = \Gamma_A(x^*)$ and $x^* = \tilde{\Omega}_B(y^*)$, i.e., the intersection of the two curves $y = \Gamma_A(x)$ and $x = \tilde{\Omega}_B(y)$. Figure 4 reveals that there exists $(x^*, y^*) \in [\underline{c}, \bar{c}]^2$ such that $y^* = \Gamma_A(x^*)$ and $x^* = \tilde{\Omega}_B(y^*)$, and

$$d_B < d_A < x^* < \overline{x} < \overline{y} < y^* < \Gamma_A(d_B) < \mu_A. \tag{56}$$

Thus, a communication equilibrium exists. What impact does an alarming messages have on the probability of progressive cooperation on climate change? In the communication-free equilibrium, $\overline{x}$ and $\overline{y}$ are the cutoffs of players B and A, respectively. Now, (9) reveals that with alarming communication, player B's cutoff points x^* and d_B are strictly lower than $\overline{x}$. Thus, any communication makes player B more conservative, no matter what message is actually sent. On the other hand, player A's cutoff points y^* and $\Gamma_A(d_B)$ are strictly higher than $\overline{y}$. Thus, communication makes player A more progressive, no matter what message is actually sent. Since one player becomes more progressive and the other less, it is not possible to unambiguously say if communication is good or bad for progressive cooperation on climate change.

The welfare effects, however, are unambiguous. As player A is more likely to play P in the communication equilibrium, player B is made better off. Conversely, as player B is more likely to play C, player A is made worse off. The progressive scientist is made better off by the alarms, because they prevent player A from choosing C. On the other hand, the "dog that did not bark" effect makes player B more likely to choose C when there are alarms, and this makes player S worse off.

Finally, consider whether the communication equilibrium is unique. Using the same argument as before, we must impose a "conditional" version of Assumption 2.

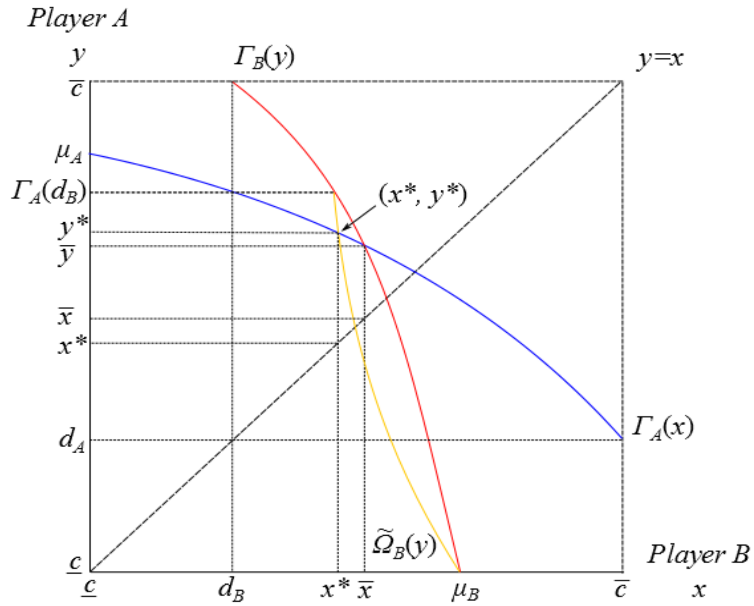

Figure 13: The Game with Opportunistic Types: Communication Equilibrium

Specifically,

$$\frac{F_A'(c)}{1 - F_A(\Gamma_A(d_B)) + F_A(y)} < \frac{1}{\mu_i - d_i} \tag{57}$$

for all $y \in (\underline{c}, \bar{c})$. It can be checked that (11) implies $-1 < \tilde{\Omega}_B'(y) < 0$. In this case, since $-1 < \Gamma_A'(x) < 0$, the two curves intersect only once, as indicated in Figure 4. In summary:

Theorem 4. *Suppose that player S is a progressive scientist and both players are opportunistic types. A communication equilibrium exists. All of player A's types prefer the communication-free equilibrium to the communication equilibrium. All of player B's types have the opposite preference. Player S is better off in the communication equilibrium if and only if* $\bar{y} < c_A < \Gamma_A(d_B)$*. If (11) holds for all* $y \in (\underline{c}, \bar{c})$ *then there is a unique communication equilibrium.*

4.3.3. Ineffective Cheap-Talk

Theorem 5. *There does not exist any communication equilibrium for either kind of scientist, for any other combination of player types.*

Proof. See Appendix. □

In a communication equilibrium, let m_1 be the message that induces player B to play P for a larger set of realizations of c_B, and m_0 to be the message that induces player B to play P for a smaller set of realizations of c_B.

Given C_S, let a_A^S be the generic action that a scientist always prefers A to choose (only the cases in which this preference is constant across a_B^S are considered). Let a_A^{-S} be player A's other action.

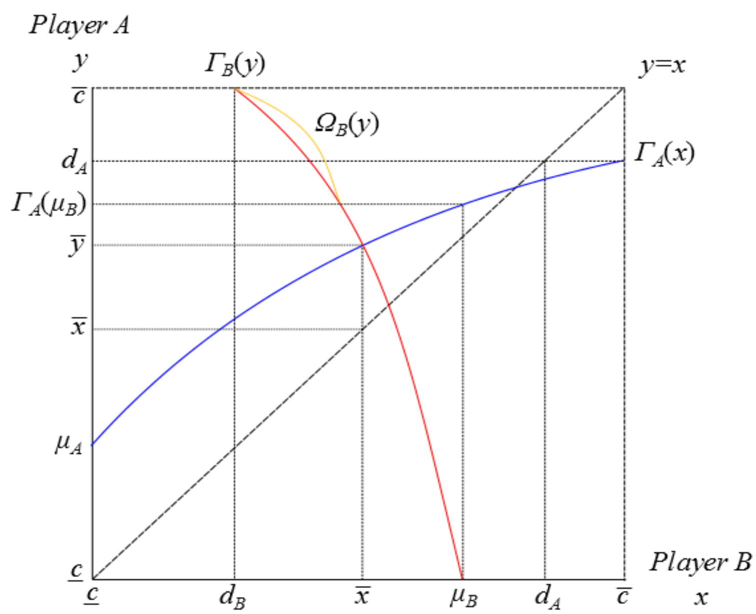

Figure 14: The Game with a Coordination Type and an Opportunistic Type: No Communication Equilibrium

Since the scientist always prefers that player B plays P, a necessary condition for equilibrium is that for all types c_A such that a scientist sends m_0, it must be the case that all such types play a_A^S when m_0 is sent, but would play a_A^{-S} if m_1 were sent.

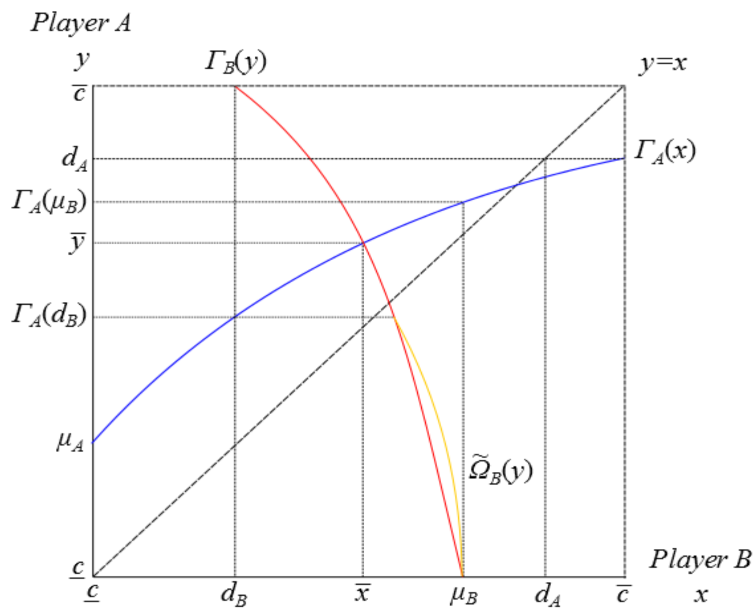

Figure 15: The Game with a Coordination Type and an Opportunistic Type: No Communication Equilibrium

However, since message m_0 being sent guarantees that player A will play a_A^S in equilibrium, this is only consistent with m_0 resulting in player B choosing C more often if C is player B's best response to a_A^S. In particular, after m_0, player B chooses C for all realizations of c_B except for those such that P is dominant for player B.

Given player B choosing C, player A having a type such that playing a_A^S is optimal after m_0, but a_A^{-S} is optimal after m_1, is possible only if a_A^S is player A's best response when player B plays C, but a_A^{-S} is player A's best response when player B plays P.

To summarize, we need: for a_A^S to be a scientist's preferred action for player A; when player A does not have a dominant action, a_A^S is player A's best response when player B chooses C; and when player A chooses a_A^S, player B's best response is C, except when P is dominant for player B.

Thus, since $a_A^S \in \{P, C\}$, there are only two possibilities for a communication equilibrium: First, the scientist prefers that player A chooses P (progressive scientist); P is player A's best response when player B chooses C; C is player B's best response when player A chooses P; or a scientist prefers that player A chooses C (conservative scientist); C is player A's best response when player B chooses C; C is player B's best response when player A chooses C.

4.4. Conclusion

I extend the strategy of manipulating conflict developed by Baliga and Sjöström (2012) and apply it to climate-change politics between two asymmetric decision-makers under incomplete information. The decision-makers choose progressive or conservative actions towards climate change. A decision-maker from a country with greater damage from climate change is more likely to be progressive than a country with lesser damage. Climate scientists can manipulate this decision-making by sending publicly observed cheap-talk messages. The likelihood of both players choosing progressive action on climate change decreases if both players are "coordination" types and the scientist is conservative. The conservative scientist can cause this by sending skeptical messages that trigger a spiral of climate change skepticism. This reduces the welfare of both decision-makers. If both players are opportunistic types, a progressive scientist can send alarming messages that cause the decision-maker from the country with greater damage from climate change to be more progressive. This reduces his welfare but benefits the other decision-maker. I show that there does not exist any communication equilibrium for either kind of scientist, for any other combination of player types.

For future research, one may extend the game by allowing incomplete information in other parameters, such as benefits from actions against climate change or damage from climate change.

4.5. Appendix

Proof of Theorem 2. Equilibria must be in cutoff strategies, and must be interior by Assumption 1. The best-response function Γ_i, defined by (2), is continuous, with $\Gamma_i(\underline{c}) = \mu > \underline{c}$ and $\Gamma_i(\overline{c}) = d_i < \overline{c}$; therefore it has an equilibrium point $(\overline{x}, \overline{y})$ where $\overline{x} \in [\underline{c}, \overline{c}]$ and $\overline{y} \in [\underline{c}, \overline{c}]$ are the cutoff point of player B and player A, respectively. Note that $\overline{x} < \overline{y}$ since $d_A > d_B$. If players A and B use cut-offs $\overline{y}$ and $\overline{x}$, respectively, the strategies form a BNE. It remains to show this BNE is unique. Notice that $\Gamma_i'(x) = (d_i - \mu_i)F'(x)$, so the best-response function is upward (downward) sloping if actions are strategic complements (substitutes). In either case, a well-known sufficient condition for uniqueness is that best-response functions have slope strictly less than one in absolute value. Assumption 2 implies that $0 < \Gamma_i'(x) < 1$ if $d_i > \mu_i$, and $-1 < \Gamma_i < 0$ if $d_i < \mu_i$. Hence, the best-response functions cross at most once and there is a unique equilibrium. The sufficient condition for uniqueness of the equilibrium also holds even if the players are of different types. Namely, if player A is a coordination type ($\mu_A < d_A$) and player B is an opportunistic type ($d_B < \mu_B$), the best-response functions have slope strictly less than one in absolute value as long as Assumption 2 holds. ■

Proof of Lemma 1. Suppose strategy μ_B is a part of a BNE. Because unused messages can simply be dropped, I may assume that for any $m \in M$, there is c_A such that $m(c_A) = m$. Now consider any two messages m and m'. If $c_B(m) = c_B(m')$, then the probability player B plays P is the same after m and m', and this means that each type of player A also behaves the same after m as after m'. Clearly, if all players behave the same after m and m', having two separate messages m and m' is redundant. Hence, without loss of generality, we can assume $c_B(m) \neq c_B(m')$ whenever $m \neq m'$.

Whenever player A is a dominant strategy type, player S will send whatever message maximizes the probability that player B plays P. Call this message m_1. Thus,

$$m_1 = \arg\max_{m \in M} c_B(m). \tag{58}$$

Message m_1 is the *unique* maximizer of $c_B(m)$, since $c_B(m) \neq c_B(m')$ whenever $m \neq m'$.

Player S cannot always send m_1, because then messages would not be informative and cheap-talk would be ineffective (contradicting the definition of a communication equilibrium). However, since message m_1 uniquely maximizes the probability that player B chooses P, player S must have some other reason for choosing $m(c_A) \neq m_1$. Specifically, if player S is a progressive scientist (who wants player A to choose P), then it must be that type c_A would choose C following m_1 but P following $m(c_A)$; conversely if player S is a conservative scientist (who wants player A to choose C), then it must be that type c_A would choose P following m_1 but C following $m(c_A)$. This is the only way that player S can justify sending any other message than m_1.

Thus, if player S is a progressive scientist, then whenever he sends a message $m_0 \neq m_1$, player A will play P. Player B therefore responds with P whenever $c_B < d_B$. That is, $c_B(m_0) = d_B$. However, $c_B(m) \neq c_B(m')$ whenever $m \neq m'$, so m_1 is unique. Thus, $M = \{m_0, m_1\}$.

Similarly, if player S is a conservative scientist, then whenever he sends a message $m_0 \neq m_1$, player A will play C. Player B's cutoff point must therefore be $c_B(m_0) = \mu_B$. Again, this means $M = \{m_0, m_1\}$. ■

Proof of Theorem 5. I first show that if player S is a progressive scientist, $c_S < 0$, then he cannot communicate effectively when actions are strategic complements. From Lemma 1, $M = \{m_0, m_1\}$ with $c_B(m_1) > c_B(m_0)$. Thus, player B is more likely to choose P after m_1 than after m_0. The progressive scientist wants both players A and B to play P, so he would only choose m_0 if such a message causes player A to play P. Formally, if $m(c_A) = m_0$, then we must have $c_A < c_A(m_0)$, so that type c_A chooses P when he hears message m_0. But if $c_A < c_A(m_0)$ for all c_A such that $m(c_A) = m_0$, then player B expects player A to play P for sure when player B hears m_0, so player B's cut-off point must be $c_B(m_0) = d_B$. However, with $d_B > \mu_B$, types above d_B are dominant strategy types who always play C, so it is a contradiction for $c_B(m_1) > d_B$. Thus, if player S is a progressive scientist and the game has strategic complements ($d_i > \mu_i$), then cheap-talk cannot be effective. ■

A communication equilibrium does not exist if player S is a conservative scientist, player A has strategic complements ($\mu_A < d_A$), and player B has strategic substitutes ($d_B < \mu_B$). Any communication equilibrium must have the following form. Player S sets $m(c_A) = m_0$ if and only if $c_A \in S = (\Gamma_A(\mu_B), y^*]$. Player A's cutoff points are $c_A(m_0) = \Gamma_A(\mu_B)$ and $c_A(m_1) = y^*$. Player B's cutoff points are $c_B(m_0) = \mu_B$ and $c_B(m_1) = x^*$. Moreover, x^* and y^* must satisfy $y^* = \Gamma_A(x^*)$ and $x^* = \Omega_B(y^*)$. I show that such x^* and y^* do not exist.

By Assumption 2, Γ_A is increasing and Γ_B is decreasing with a slope less than one. Since $F(\underline{c}) = 0$ and $F(\overline{c}) = 1$, $\Gamma_A(\underline{c}) = \mu_A \geq \underline{c}$, $\Gamma_A(\overline{c}) = d_A \leq \overline{c}$, $\Gamma_B(\underline{c}) = \mu_B \leq \overline{c}$, and $\Gamma_B(\overline{c}) = d_A \geq \underline{c}$. Furthermore,

$$\Gamma_A(d_A) - \mu_A = F_B(d_A)(d_A - \mu_A) < d_A - \mu_A,$$

$$\Gamma_B(d_B) - \mu_B = F_A(d_B)(d_B - \mu_B) > d_B - \mu_B.$$

Therefore, $\Gamma_A(d_A) < d_A$ and $\Gamma_B(d_B) > d_B$. Also,

$$\Gamma_A(\mu_B) = \mu_A(1 - F_B(\mu_B)) + d_A F_B(\mu_B) > \mu_A, \tag{59}$$

$$\Gamma_B(\mu_A) = \mu_B(1 - F_A(\mu_A)) + d_B F_A(\mu_A) < \mu_B. \tag{60}$$

Let $(\overline{x}, \overline{y})$ be the unique communication-free equilibrium point in $[\underline{c}, \overline{c}]$. Clearly,

$\overline{x} < \Gamma_B(\mu_A) < \mu_B$ and $\mu_A < \overline{y} < \Gamma_A(\mu_B)$ (see Figure 5).

Notice that

$$\Omega_B'(y) = \frac{F_A'(y)(d_B - \mu_B)F_A(\Gamma_A(\mu_B))}{\{[1 - F_A(y)] + F_A(\Gamma_A(\mu_B))\}^2},$$

so Ω_B is decreasing. It is easy to check that $\Gamma_B(y) < \Omega_B(y)$ whenever $y \in (\Gamma_A(\mu_B), \bar{c})$.

Moreover,

$$\Omega_B(\bar{c}) = \Gamma_B(\bar{c}) = d_B$$

and

$$\Omega_B(\Gamma_A(\mu_B)) = \Gamma_B(\Gamma_A(\mu_B)) < \Gamma_A(\mu_B)$$

where the inequality follows from (6) and the fact that Γ_B is decreasing. Notice that the curve $x = \Omega_B(y)$ lies to the right of the curve $x = \Gamma_B(y)$ for all $y \in (\Gamma_A(\mu_B), \bar{c})$, but that the two curves intersect when $y = \Gamma_A(\mu_B)$ and $y = \bar{c}$. Thus, a communication equilibrium does not exist. ■

A conservative scientist cannot communicate effectively when actions are strategic substitutes. From Lemma 1, $M = \{m_0, m_1\}$ with $c_B(m_1) > c_B(m_0)$. Thus, player B is more likely to choose P after m_1 than after m_0. The conservative scientist wants player A (but not player B) to play C, so he would only choose m_0 if this message causes player A to play C. But if player A plays C for sure after m_0, player B's cutoff point must be $c_B(m_0) = \mu_B$. However, with $d_B < \mu_B$, types above μ are dominant strategy types who always play C, so it is a contradiction for $c_B(m_1) > \mu_B$. Thus, if player S is a conservative scientist and the game has strategic substitutes ($d_i < \mu_i$), then cheap-talk cannot be effective. ■

A communication equilibrium does not exist if player S is a progressive scientist, player A has strategic complements ($\mu_A < d_A$), and player B has strategic substitutes ($d_B < \mu_B$). In a communication equilibrium, the cut-off points must satisfy $y^* =$

$\Gamma_A(x^*)$ and $x^* = \tilde{\Omega}_B(y^*)$, where

$$\tilde{\Omega}_B(y) = \frac{[1 - F_A(\Gamma_A(d_B)]\mu_B + F_A(y)d_B}{[1 - F_A(\Gamma_A(d_B)] + F_A(y)}.$$

(x^*, y^*) must be an intersection of the two curves $x = \tilde{\Omega}_B(y)$ and $y = \Gamma_A(x)$. With strategic substitutes, Assumption 2 implies

$$0 < \Gamma'_A(x) < 1.$$

Furthermore, $\Gamma_A(\underline{c}) = \mu_A > \underline{c}$ and $\Gamma_A(\bar{c}) = d_A < \bar{c}$, and

$$\Gamma_A(d_B) - d_A = (1 - F_B(d_B))(\mu_A - d_A)$$

where

$$\mu_A - d_A < (1 - F_B(d_B))(\mu_A - d_A) < 0.$$

Therefore,

$$\mu_A < \Gamma_A(d_B) < d_A. \tag{61}$$

Let $(\overline{x}, \overline{y})$ be the unique communication-free equilibrium in $[\underline{c}, \bar{c}]$. Clearly, $\mu_A < \overline{x} < \overline{y} < d_A$ (see Figure 6).

Figure 6 shows three curves: $x = \tilde{\Omega}_B(y)$, $y = \Gamma_A(x)$, and $x = \Gamma_B(y)$. The curves $y = \Gamma_A(x)$ and $x = \Gamma_B(y)$ intersect at the unique communication-free equilibrium, $(\overline{x}, \overline{y})$. It is easy to check that $\Gamma_B(y) < \tilde{\Omega}_B(y)$ whenever $y \in (\underline{c}, \Gamma_A(d_B))$. Moreover,

$$\tilde{\Omega}_B(\underline{c}) = \Gamma_B(\underline{c}) = \mu_B$$

and

$$\tilde{\Omega}_B(\Gamma_A(d_B)) = \Gamma_B(\Gamma_A(d_B)) < \Gamma_A(d_B)$$

where the inequality follows from the fact that Γ_B is decreasing. These properties are drawn in Figure x. Notice that the curve $x = \tilde{\Omega}_B(y)$ lies to the right of the curve $x = \Gamma_B(y)$ for all $y \in (\underline{c}, \Gamma_A(d_B))$, but that the two curves intersect when $y = \underline{c}$ and $y = \Gamma_A(d_B)$. Thus, a communication equilibrium does not exist. $\blacksquare$

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