Public Awareness of Carbon Capture and Storage: A Survey of Attitudes toward Climate Change Mitigation

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Submitted to the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degree of Master of Science in Technology and Policy

at the
Massachusetts Institute of Technology
June 2004

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Abstract

The Carbon Capture and Sequestration Technologies Program in the Laboratory for Energy and the Environment at MIT conducted a survey of public attitudes on energy use and environmental concerns. Over 1,200 people, representing a general population sample of the United States, responded. The survey asked a representative sample of the American public seventeen questions about the environment, global warming, and climate change-mitigation technologies.

The analysis in this thesis uses the survey responses to draw conclusions about the level of public understanding and awareness of global climate change and carbon dioxide capture and storage and to suggest implications for public outreach.

The survey results show that carbon dioxide capture and storage and carbon sequestration are largely unknown to the general public, and there is significant confusion over which environmental issue the technology is intended to address. The environment is not a top priority for the U.S. public, and global warming is not the top environmental concern, even for those concerned about the environment.

The public's willingness to pay to solve global warming increases when an individual is concerned about the environment or believes that immediate action is necessary to address global warming. An experiment within the survey shows that a large portion of the public supports investment in renewable energy technologies but that support decreases when cost information for all climate mitigation technologies is provided.

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Acknowledgments

I am truly indebted to Howard Herzog, who wanted to know what (and if) people think about carbon dioxide capture and storage and trusted me to analyze the data.

I would like to acknowledge the generous support of the Alliance for Global Sustainability and the Carbon Sequestration Initiative at MIT who sponsored the survey described in this thesis and my work here at MIT.

I would like to thank Steve Ansolabehere who led me through the maze of multiple regression analysis and David Reiner who provided insight and excellent reading recommendations. Thanks to Mark de Figueiredo and Gemma Heddle who, along with David, Steve, and Howard, worked hard last summer to put the survey together.

Thanks to all my friends in the corrals – especially plot wizard, Kate Martin, and constant source of distraction, Adam Smith.

A special thanks to those who kept me sane and well fed - my wonderful sisters, Bridgid and Helen, who never stopped me from telling a bad joke, and Mary Gallagher who always seemed to know what I needed here in E40. Thanks to my parents who have supported me throughout my years and always encouraged me to rise to the challenge.

Finally, thank you to Michelle, my once and future closer, your patience with my MIT experience has been unending. We made it!

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Acronyms

CCS	Carbon dioxide capture and storage
CCSTP	Carbon Capture and Sequestration Technologies Program (MIT)
CO_2	Carbon dioxide
EIA	Energy Information Agency
EOR	Enhanced oil recovery
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
LFEE	Laboratory for Energy and the Environment
NGO	Non-governmental organization
USDOE	U.S. Department of Energy

Preface

This thesis reports and analyzes the results of a survey conducted by the Massachusetts Institute of Technology (MIT) Carbon Capture and Sequestration Technologies Program (CCSTP) in October 2003. The survey included questions that asked a representative sample of the American public questions about the environment, global warming, and the technologies available to address global warming. The survey questions focused on technologies available to reduce carbon dioxide (CO_2) emissions from electricity generation and included questions about individual technology preferences and willingness to pay for solutions to global warming.

Specific survey questions tested public awareness and understanding of carbon dioxide capture and storage (CCS), a technology designed to limit the potential for global warming (also called global climate change). CCS involves capture of CO_2 from power plants or industries and storage of the captured CO_2 in deep geologic formations. CO_2 is the primary greenhouse gas resulting from human activities (such as burning fossil fuels for energy or transportation). Scientists consider human-activity derived greenhouse gases the largest potential cause of global warming. CCS has been drawing increased interest from experts in government, academia, industry, and non-governmental organizations (NGOs) over the past 10 years but has not entered a wider public dialogue.[1]

This thesis is divided into seven chapters.

- Chapter 1 introduces the thesis motivation and objectives.
- Chapter 2 provides background on climate change, CO_2 emissions in the United States, and CCS.
- Chapter 3 details the survey design and distribution.
- Chapter 4 reports and analyzes the survey results as they relate to public attitudes and public understanding of broader climate change concepts and specific climate change-mitigation technologies (with an emphasis on CCS).
- Chapter 5 reviews other recent surveys of public attitudes toward CCS.

[1] The second section of Chapter 1 provides a detailed description of CCS.

- Chapter 6 derives lessons for public education and outreach.
- Chapter 7 summarizes the paper and presents ideas for future study.

As research moves forward and public officials develop policies to address global warming, the survey results and analyses found in this thesis can help in the development of public outreach and education.

1. MOTIVATION AND OBJECTIVES

Researchers in the MIT Laboratory for Energy and the Environment (LFEE) have been studying a global climate change mitigation technology called carbon dioxide capture and storage (CCS) since 1989 under the auspices of a program currently called the Carbon Capture and Sequestration Technologies Program (CCSTP). In 1997, researchers in the program authored a U.S. Department of Energy (USDOE) White Paper that explored the state of knowledge of CCS and proposed a direction for study and funding (Herzog et al., 1997). That same year, Statoil, an international oil and gas company based in Norway, began what remains the largest commercial CCS project in the world. The project (called Sleipner) is based on a natural gas platform in the North Sea off the coast of Norway and was initiated to avoid a carbon emission tax imposed by the Norwegian government. It involves the separation of CO_2 from natural gas as it is removed from a reservoir underneath the sea. Statoil then transports the natural gas to market and injects the CO_2 into a separate reservoir deep under the seabed. Geologists monitor the injection reservoir to ensure that the CO_2 stays underground and to understand the mechanisms by which the CO_2 moves within the reservoir (Heinrich et al., 2004).

Industrial, academic, and government researchers have developed experimental and demonstration programs around the world to test the technical feasibility of CCS. The largest projects in North America include the University of Texas Bureau of Economic Geology Frio Brine Project in southern Texas; the Weyburn CO_2 Project in Saskatchewan, Canada, near the U.S. border; the USDOE Teapot Dome Project in Wyoming; and Battelle Memorial Institute Mountaineer Power Plant Project in West Virginia (Friedmann, 2003; Heinrich et al., 2004). These projects focus on development of the siting, injection, and monitoring technologies needed to guarantee the effectiveness of CCS at preventing CO_2 from entering the atmosphere.

As the research and development of CCS as a technologically and economically feasible global climate change mitigation option continues, the MIT CCSTP has begun research into the non-technical and non-economic barriers to the use of CCS. Recent and ongoing work focuses on regulatory barriers, political barriers, and legal barriers (de Figueiredo,

2003; Heddle, 2003; Heinrich et al., 2004; Reiner and Herzog, 2004). An area that has been gaining increased attention from researchers in the United States, Europe, and Japan has been public acceptance of and attitudes toward CCS (Huijts, 2003; Itaoka, 2004; Palmgren et al., 2004; Shackley et al., 2004). The survey discussed and analyzed in this document is an attempt to better understand public attitudes toward global climate change and climate change-mitigation technologies with an emphasis on CCS and technologies to reduce the potential impact of electricity generation on climate.

1.1. Public Opinion

A Harris Poll published in October 2002[2] reported that 85 percent of adult Americans had seen, heard, or read about global warming. Of those, 74 percent said that they believed in "the theory that carbon dioxide and other gases will lead to global warming and an increase in average temperatures" (Harris Interactive, 2002). A recent study by researchers at the University of Oklahoma supports the conclusion that a large percentage of the American public recognizes and believes global warming could be a problem (Leiserowitz, 2003). Despite this apparent widespread recognition of global warming, a number of studies have shown that the public is confused about what causes global warming and is unsure about what society should do to address it. The studies suggest that the public concern over global warming (even among those who recognize global warming as a problem) is lower than other environmental concerns, such as water and air pollution (Bostrom et al., 1994; Kempton et al., 1995; The Polling Report, 2004).

Public opinion and public acceptance of climate change-mitigation technologies is important because global climate change is an extraordinarily complex problem without a clear scientific or political solution. Proposed solutions to global climate change involve costs to society and sacrifices by the public. Ways to address climate change usually include technological leaps in energy production, more expensive energy sources, energy efficiency measures, and lifestyle changes to consume less energy. The costs and

[2] Conducted Sept. 19-23, 2002. N=1,011 adults nationwide. Margin of error ± 3. The Polling Report (2004) Environment The Polling Report, Inc. Accessed April, 2004. http://www.pollingreport.com/enviro.htm. (Accessed April 2004)

uncertainties of global climate change make it difficult to garner political support. Policymakers not only have to decide how to address the scientific and technical uncertainties of global climate change but they also have to decide how to respond to public uncertainty and skepticism about the need for action.

Frequently, policymakers in the government and the energy industry are able to make decisions about research allocation and facility placement without much public attention. As such, general public opinions about specific technologies do not usually influence decisions (Conn, 1983). When the public becomes involved, it is usually in the form of local public opposition to project siting. This form of public involvement can significantly impact decisions. Lack of knowledge can increase public apprehension toward new technologies, especially technologies that have the potential to disrupt their local environment (such as the siting of gas pipelines or wind turbines).

Given the complexities of decision-making processes, survey data can provide information for policymakers and decision makers who face difficult choices about how to address global climate change. Survey data can show favorable or unfavorable attitudes toward ideas, general levels of knowledge, and fears or concerns; it is less accurate at predicting actual behavior or explaining reasons for opinions (Conn, 1983). The survey analyses that form the basis of this thesis establish a foundation for decision makers interested in general levels of public knowledge of climate change and climate change mitigation.

1.2. Objectives

This thesis analyzes public opinion of energy and the environment focusing on responses to a survey designed by researchers in the CCSTP at MIT. The survey asked a representative sample of the American public seventeen questions about the environment, global warming, and climate change-mitigation technologies. The analysis in this thesis uses the survey responses to answer the following questions:

- What is the level of public understanding of global warming[3] and carbon dioxide capture and storage (or carbon sequestration)?
- What are public attitudes toward global warming and climate change-mitigation technologies?
- What is public willingness to pay to solve global warming?
- What is the effect of information (national energy usage and price data) on public preferences?
- What lessons do the survey results suggest for public outreach campaigns?

[3] The survey uses "global warming" when referring to the possible consequences of increased greenhouse gases in the atmosphere. While the term global climate change is the more widely used descriptor in the scientific community, the survey designers believe that the public is more familiar with the term global warming.

2. BACKGROUND

The earth's climate is constantly changing. Scientists who study ice core samples from Antarctica and Greenland are able to estimate the average global temperature over thousands of years and can show fluctuations that have marked shifts into and out of ice ages. While these temperature changes are not the only sign or effect of climate change, they are well correlated and easier to estimate than other signs of climate change (such as changes in the frequency of storm events or the annual amount of rainfall) (IPCC, 2001b).

There are a number of processes that scientists believe influence the climate. There are natural processes that affect climate over centuries (like gradual shifts in Earth's rotation) and sudden processes that affect climate almost instantaneously (like large volcanic eruptions). Over decades, it appears that increasing the amount of greenhouse gases in the atmosphere can alter the climate. Over the past two centuries, greenhouse gas emissions resulting from human activities (anthropogenic greenhouse gases) have been entering and staying in the atmosphere. The pre-industrial atmospheric concentration of CO_2, one of the primary anthropogenic greenhouse gases, was 280 parts per million (ppm); today's atmospheric concentration of CO_2 is over 360 ppm (IPCC, 2001b). The increased atmospheric concentrations of greenhouse gases have led to concern about global warming. The concern is that anthropogenic emissions of greenhouse gases may be driving average global temperatures higher than previously recorded or estimated. The climate change associated with that temperature rise may be extraordinarily difficult to handle. Besides temperature, the climate change threats include more intense precipitation events, increased drying and risk of drought, and increased tropical cyclone peak wind (IPCC, 2001b).

2.1. Greenhouse Gases

Greenhouse gases are an essential part of the atmosphere; they work to trap and reflect energy from the sun. The earth's surface radiates energy from the sun as infrared energy. Greenhouse gases absorb some of the infrared energy and radiate it back towards the earth (Jacoby et al., 1998). This process keeps the earth at a life-sustaining temperature.

The main greenhouse gases are water vapor, CO_2, methane, nitrous oxide, tropospheric ozone, HFCs, PFCs, SF_6, halons, and CFCs. Water vapor and clouds are responsible for the majority of the absorbed and reflected energy on Earth (Jacoby et al., 1998). Water vapor is not considered an anthropogenic greenhouse gas since human activity has little direct effect on its atmospheric concentrations (although human activities that increase other greenhouse gases may indirectly increase the atmospheric concentrations of water vapor) (EIA, 2003b). CO_2, methane, and nitrous oxide are responsible for a smaller fraction of the absorbed and reflected energy. However, CO_2, methane, and nitrous oxide are currently entering the atmosphere at rates greatly enhanced by human activities. These greenhouse gases have atmospheric lifetimes on the scale of tens to hundreds of years, as a result they tend to accumulate in the atmosphere. As they reach higher atmospheric concentrations, the greenhouse gases absorb and radiate more energy. This process increases average global temperatures. The temperature increases are driving the threat of global climate change (Karl and Trenberth, 2003).

Scientists generally agree about the mechanisms of the greenhouse effect. The primary scientific debate is the speed and extent of the climate's response to increased greenhouse gas concentrations. Some processes within the atmosphere might act to dampen the speed of climate change while others might accelerate it (Jacoby et al., 1998). A growing consensus of scientists and researchers agree that there is strong evidence that the global community needs to take action to reduce human activity greenhouse gas emissions.

The Third Assessment Report of Working Group I of the IPCC, records the evidence of recent climate change. During the twentieth century, the global average surface temperature increased by about 0.6 °C. In the Northern Hemisphere, this temperature change is likely to have been the largest of any century in the past 1,000 years. Since the late 1960s, there has been about a 10 percent decrease in the extent of snow cover. In the twentieth century, global average sea level rose between 0.1 and 0.2 meters (IPCC, 2001b).

To consider options for slowing the accumulation of greenhouse gases, policymakers must consider the source of emissions. By weight, CO_2 is the most emitted greenhouse gas. In 2002, sources in the United States emitted 5,796 million metric tons of CO_2 compared to 27 million metric tons of methane and 1.1 million metric tons of nitrous oxides (EIA, 2003b). Because of differences in lifetimes and radiative efficiency, scientists consider different greenhouse gases to have different impacts on climate. To compare the effect of CO_2 on the climate to the effect of other greenhouse gases on the climate, scientists developed a unit of comparison called global warming potential (GWP). GWP allows scientists to convert all gases to CO_2 equivalents for comparison. For example, for a 100-year time horizon, scientists calculate that CO_2 has a reference impact of 1 while methane has an impact of 23 and nitrous oxide has an impact of 296 (IPCC, 2001a). This means that one molecule of methane has an impact on global warming equivalent to 23 molecules of CO_2 and one molecule of nitrous oxide has an impact on global warming equivalent to 296 molecules of CO_2. On this basis, CO_2 accounts for 84 percent of the total amount of greenhouse gas emissions in the U.S. (USEPA, 2003).

Worldwide efforts to control global climate change have included all of the greenhouse gases but have focused on trying to reduce emissions of CO_2.

2.2. Carbon Dioxide Emissions in the United States

The IPCC states that the combustion of fossil fuels for energy is the major source of anthropogenic CO_2 and will likely continue to be over the next century. The concentrations of CO_2 in the atmosphere have increased by 31 percent since 1750 (IPCC, 2001b). Of the total CO_2 emissions in the United States in 2002, approximately 98 percent resulted from the combustion of fossil fuels (coal, petroleum, and natural gas). Industrial processes, including gas flaring and cement production, accounted for the other 2 percent (EIA, 2003b).

Fossil fuel combustion for electricity generation is the largest contributor to CO_2 emissions from the United States followed by fossil fuel combustion for transportation.

In 2002, electricity generation accounted for 39 percent of CO_2 emissions in the United States while transportation accounted for about 32 percent (EIA, 2003b). Researchers studying electricity generation currently focus on a portfolio of options that include increased energy efficiency, renewable energy sources (solar power, wind power, etc.), nuclear power, and CCS (Anderson and Newell, 2003).

2.3. Carbon Dioxide Capture and Storage (CCS)

CCS[4] is a technological solution to the potential environmental problem of emitting CO_2 into the atmosphere. CCS is the capture and secure storage of CO_2 that would otherwise be emitted to or remain in the atmosphere (Herzog and Golomb, 2004).

In most scenarios, researchers plan to capture CO_2 from the off-gases of large industrial stationary sources, such as electric power plants and oil and gas refineries. After capture, the CO_2 is compressed, transported by tanker or through pipelines, and stored in underground formations (geologic storage) or in the deep ocean (ocean storage) (Anderson and Newell, 2003). Most policymakers do not currently consider ocean sequestration politically viable after the failures to start a test project off the coasts of Hawaii and Norway (Hawkins, 2001; de Figueiredo, 2003). The failure of this major ocean sequestration study highlights the importance of public opinion in the research of CCS.

Scientists are also studying carbon uptake in trees and soils. This form of carbon storage, called terrestrial sequestration, is a valuable option for sequestration but it is primarily a form of indirect sequestration. Terrestrial sequestration removes CO_2 from the atmosphere and does not capture CO_2 at the source.

[4] Throughout this paper, the term carbon dioxide capture and storage (CCS) is used when discussing the technologies associated with capturing carbon dioxide from stationary sources and storing it in geologic formations. The survey used both "carbon sequestration" and "carbon capture and storage" when referring to the same technologies. The survey also uses "carbon sequestration" to mean "using trees to absorb carbon dioxide from the atmosphere." The differences in terminology are a result of the recent increased interest in the field and the difficulties associated with bringing the language of multiple countries and scientific disciplines together.

The most promising uses of geologic CCS involve the capture and storage of CO_2 from stationary sources with large volumes or pure streams. The most viable candidate for storage are underground geologic formations such as depleted oil and gas reservoirs, brine formations, and deep, unmineable coal seams. Current research of geologic storage includes devising methods for ensuring long-term storage. As mentioned in Chapter 1, there are a number of commercial, demonstration, and experimental projects currently underway around the world.

The technologies and practices associated with geologic CCS have been in commercial operation within various industries for 10 to 50 years. The oil industry, in a process called enhanced oil recovery (EOR), has been injecting CO_2 into oil formations to recover additional oil since the 1970s. Today, there are 84 such projects around the world, 72 in the United States. A network of CO_2 pipelines in the western United States has developed to connect many of the EOR projects to natural sources of CO_2. In Canada, some oil and gas producers have been successfully injecting a waste gas, hydrogen sulfide, into underground formations. The injection process, called Acid Gas Injection, helps the companies meet stricter hydrogen sulfide emission restrictions adopted by the Canadian government in 1989. Making these projects particularly relevant to CCS, many of the hydrogen sulfide streams contain CO_2, some with concentrations as high as 90 percent CO_2 by volume (Heinrich et al., 2004).

Current research and demonstration projects focus on the integration of the available technologies for capture, transport, underground injection, and storage of CO_2 from power plants. One of the main differences between EOR and CCS is that the former are not currently concerned about the long-term fate of the injected CO_2. It is important for CCS researchers to develop technologies for monitoring to ensure that the CO_2 stays out of the atmosphere and away from freshwater sources.

3. SURVEY DESIGN AND DISTRIBUTION

Researchers at MIT and the University of Cambridge in collaboration with staff at Knowledge Networks, a consumer information company specializing in Internet-based public opinion surveys, designed the survey to ask a broad range of questions about energy and the environment while maintaining an underlying goal of learning about attitudes and understanding of CCS. The survey included seventeen questions plus an additional three demographic questions. Knowledge Networks provided another 24 supplementary demographic variables from their database. The demographic variables included respondent characteristics such as age, location, education level, and income level. Four of the survey questions referred specifically to carbon capture and storage or carbon sequestration. Initial versions of the survey included more questions about CCS, but the focus shifted to reduce respondent bias toward or away from CCS. Appendix A of this thesis includes the survey questions and answers.

Besides designing the survey to gather information on current public attitudes and understanding of CCS, the researchers intended to gauge public concern for environmental issues and global climate change in relation to other policy issues (e.g., health care, terrorism); to gain a sense of the attractiveness of carbon dioxide capture and storage relative to other options for addressing climate change; and to provide a basis upon which to develop a public outreach strategy. The survey designers also intend to use survey responses to generate trending data for use in follow-on surveys.

Knowledge Networks has recruited an online research panel designed to be representative of the entire U.S. population and conducts their surveys using the Internet. Knowledge Networks recruits households for their membership panel using a probability sampling technique called random digit dialing. Selected households are provided free hardware and Internet access. Each household receives identical hardware, even if they already own a computer. When drawing a random sample to complete a survey, Knowledge Networks draws from this large, national membership panel.

For the MIT CCSTP Survey, an Internet-based survey had four design advantages over the alternative methods, phone or face-to-face. First, a face-to-face survey was prohibitively costly, at least 10 times the cost of the Internet survey. Second, Internet surveys have much higher response rates than phone surveys. Seventy percent of the people sampled responded to the MIT CCSTP survey within two weeks. The typical phone survey with a similar cost structure has a non-response rate of about 70 percent. Third, ensuring a higher response rate in a phone survey would have increased costs substantially. Fourth, Internet surveys are ideal for providing information in graphics and text format, especially compared to reading text over the phone. The Internet also makes it easy to randomize the order of questions to prevent an answering bias based on the order of responses (Deutch et al., 2003).

To correct for known deviations from the general population, Knowledge Networks develops sample weights to allow extrapolation. The data analyses in Chapter 4 are performed with appropriate sample weights and controlling for demographic factors.

Knowledge Networks sent out the survey on September 24, 2003 and concluded the survey on October 13, 2003. They drew a random sample of 1,710 panel members representing a general population sample of the United States. Seventy percent (1,205 panel members) completed the survey.

Survey respondents were 18 years of age or over, with a median age of 46. The typical person reported an income between $35,000 and $50,000. Seventy-three percent of respondents were white; 57 percent were married; 52 percent were female. In addition, Figure 3.1 shows the educational levels of respondents.

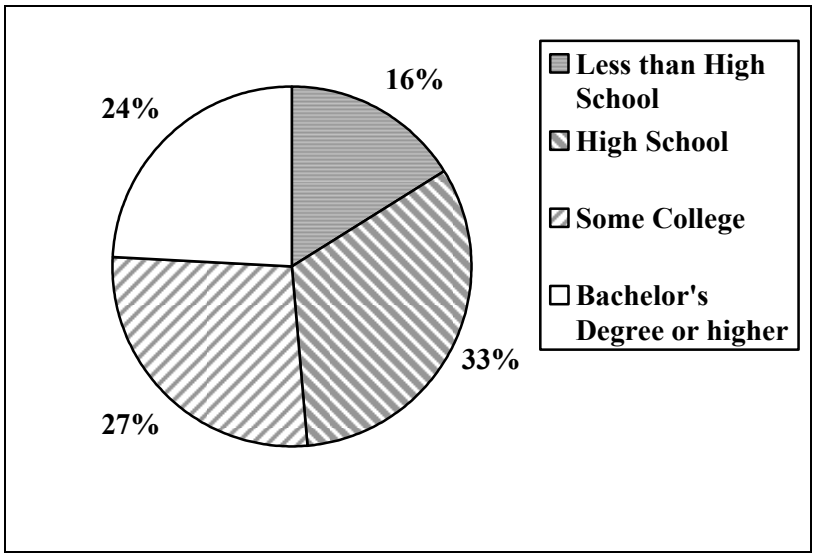


Figure 3.1
Education Levels of Respondents

4. SURVEY RESULTS

This chapter uses the MIT CCSTP Survey as a structure for a broader discussion of public understanding of and attitudes toward climate change and climate change-mitigation technologies. The results of some survey questions permit a focus on public knowledge of CCS while other questions help to describe broader public attitudes toward and understanding of global climate change and the environment.

The tables in this chapter that refer to a question include a code for the number of the question as it appeared on the survey and as it appears in Appendix A. For example, the text refers to Question 7 as Q7. For ease of reference, the questions included in the survey also appear as a footnote under each table.

There are a number of worldwide research efforts attempting to understand public attitudes and understanding of CCS. Chapter 5 includes a review of these efforts. The first survey reviewed in Chapter 5 is particularly relevant because it contains the results of a survey conducted by colleagues at the Fuji Research Institute in Japan that included questions from the MIT CCSTP survey.

4.1. Public Understanding

The survey included one question about carbon dioxide sources and sinks and two questions exploring recognition and understanding of CCS. The responses suggest that the public generally knows where carbon dioxide originates but they have not heard of CCS nor do they know what it is. The small portion of the public who has heard of or read about CCS in the past year is no better at answering a question about what environmental concern the technology addresses than the much larger portion of the public who has never heard of the technology.

4.1.1. Understanding of Global Warming

A number of public surveys have included questions about global warming. In recent years, these surveys have returned results that show that a very high percentage of the American public has heard of global warming. An October 2002 Harris Poll found that

85 percent of people say that they have "seen, heard or read about the theory of global warming" and 74 percent of those people "believe in the theory that increased carbon dioxide and other gases will lead to global warming and an increase in average temperatures" (Harris Interactive, 2002). A survey conducted between November 2002 and February 2003 by researchers at the University of Oregon reported that 92 percent of respondents answered "Yes" when asked "Have you ever heard of global warming?" and 74 percent responded that they were somewhat or very concerned when asked "How concerned are you about global warming?" (Leiserowitz, 2003).

The University of Oregon study included questions attempting to draw out public support for specific government actions. In the study, 54 percent of respondents said that they supported a "gas guzzler tax" that would "add approximately $1,000 to the price of a $20,000 car." Only 17 percent supported a "60-cent per gallon gasoline tax…to encourage people to drive less and thus reduce carbon dioxide emissions" (Leiserowitz, 2003).

Kempton, Boster, and Hartley have written on the cultural models used to understand climate change. Their work shows that 83 percent of U.S. voters support higher fuel efficiency standards but only 23 percent support taxes on energy (Kempton et al., 1995). Meanwhile, 66 percent of voters say, "reducing pollution is a more effective way to prevent global climate change than energy conservation" (Kempton, 1997, p.13).

Kempton's research has shown that the public is largely unaware that energy consumption (or, more specifically, fossil fuel consumption) is the primary source of the gases that contribute to climate change (Kempton, 2004).

Researchers at Carnegie Mellon University and Georgia Institute of Technology have conducted extensive research on a mental models approach to characterize public understanding of climate change. Their research shows that "mitigation and control strategies proposed by interviewees typically focused on general pollution control, with few specific links to carbon dioxide and energy use" (Bostrom et al., 1994, p. 969). The

researchers report that 14 percent of 177 respondents listed CO_2 and 18 percent listed fossil fuel burning as "things" that "could cause global warming" in an open ended question (Morgan et al., 2002). In the same study, 41 percent listed automobiles, 32 percent listed industry, and 15 percent listed nuclear power/weapons as things that could cause global warming. The researchers concluded that "laypeople (a) do not understand the central role played by carbon dioxide produced by burning fossil fuels and (b) confuse global warming with the stratospheric and tropospheric ozone problems" (Morgan et a., 2002, p. 135).

This difficulty in establishing a clear causal relationship between energy use and climate change led the MIT survey designers to construct a question asking respondents to identify sources of CO_2. The question asked if specific technologies or systems increased CO_2, decreased CO_2, or had no impact on CO_2. Respondents could answer that they were not sure. Table 4.1 shows responses for selected technologies and systems.

Table 4.1
Public Opinions About Technology and System Contributions to CO2 Levels (Q7)*

Technology or System	Increases CO_2 (%)	Decreases CO_2 (%)	No Impact (%)	Not Sure (%)
Automobiles	78	3	2	18
Factories	73	3	2	23
Coal burning power plants	70	2	3	25
Home heating	53	3	9	36
Nuclear power plants	30	8	20	43
Trees	7	66	8	19
Oceans	4	29	26	41
Windmills	3	21	49	27

*Question 7: There is a growing concern about increasing levels of carbon dioxide in the atmosphere. How do you think the following contribute to these levels?

The public is generally correct about automobiles, coal burning power plants, and factories being sources of CO_2. They are less certain about home heating being a source

of CO_2. Notably, the public is uncertain about nuclear power plants being CO_2 sources and oceans being CO_2 sinks. It is interesting to note that the public appears to be aware that trees are CO_2 sinks while showing weak awareness of carbon sequestration (3 percent are familiar with carbon sequestration as shown in Table 4.3).

Compiling these data, and cross referencing them with a separate question about home heating methods (Q17), Table 4.2 shows the number of people who provided a correct answer for each technology or system.

Table 4.2
How Respondents Answered Q7

Technology or System	Answered Correctly (%)	Answered Incorrectly (%)	Not Sure (%)
Automobiles	78	5	18
Trees	74	7	19
Factories	73	5	23
Coal burning power plants	70	5	25
Windmills	70	3	27
Home heating*	53	11	36
Oceans	29	30	41
Nuclear power plants	28	30	43

* Correct answers included any person who answered "increases carbon dioxide" and any person who answered "decreases carbon dioxide" AND answered no heating, don't know, and other in response to Q17: How do you heat your home? Note that someone heating their home with electricity that was predominately hydro or nuclear would could be correct if they answered "decreases carbon dioxide" but it was impossible to separate these individuals.

One of the potential biases of this question is that respondents may associate CO_2 with a general notion of pollution. As in the surveys referenced above, the respondents may not know what CO_2 is (and that it is different from other forms of pollution) or may not make the connection between CO_2 and global climate change. It is possible that the public was responding to a general idea of air pollution when saying that automobiles, factories, and coal burning power plants increase the amount of carbon dioxide.

The number of correct answers to Q7 provides a crude marker of knowledge about CO_2 (or pollution) sources. The regressions of willingness to pay in Section 4.3 use the number of correct responses to test the effect of knowledge about CO_2 on willingness to pay. Figure 4.1 shows the distribution of the number of correct answers. Note that the "zero" column includes those who answered they were not sure for all technologies.

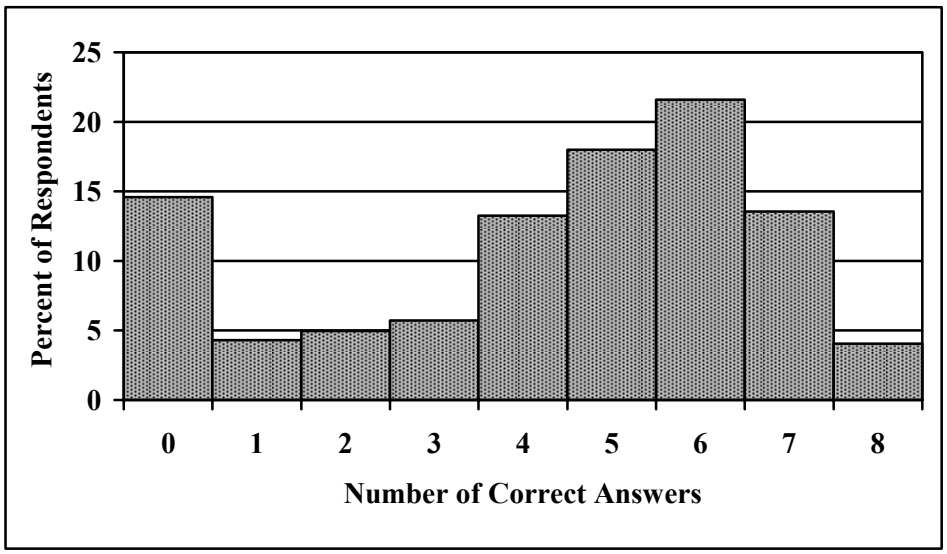


Figure 4.1
Correct Responses to Q7

The low number of people who have heard of carbon capture and storage or carbon sequestration, and the even lower number of people who know what environmental concern the technologies address, give a clear indication that the public is unaware of CCS and that it is a potential climate change-mitigation technology.

4.1.2. Public Understanding of CCS

The survey included a question about climate mitigation technologies in general and a question about CCS specifically. These responses provide some insight into the limits of public understanding of CCS.

Table 4.3 shows the results of a question focused on whether respondents heard of or read about 10 different technologies or energy sources in the past year. The question included

the list of technologies shown in Table 4.3. Respondents could select as many technologies as they wished or could answer "none of these."

Table 4.3
Public Familiarity with Specific Technologies and Energy Sources (Q4)*

Technology or Energy Source	Heard of or read about (%)
More efficient cars	70
Solar energy	64
Nuclear energy	54
Wind energy	50
More efficient appliances	49
Hydrogen cars	48
Bioenergy/biomass	10
Carbon capture and storage	4
Carbon sequestration	3
Iron fertilization	2
None of these	17

*Question 4: Have you heard of or read about any of the following in the past year?

The recognition of carbon capture and storage and carbon sequestration is minimal. The only demographic indicator that distinguishes those who have heard of carbon sequestration and carbon capture and storage from those who have not heard of either is education. At a 90 percent confidence interval, those who have heard of either of the technologies are slightly more educated.

Researchers often use the term "carbon sequestration" to refer to the uptake of CO_2 by plants as trees. Tables 4.1 and 4.2 show that the public is largely aware of the familiar with the idea that trees uptake CO_2 but Table 4.3 shows that the public is unfamiliar with the term carbon sequestration. This shows that it is not the idea of CO_2 uptake by trees that is misunderstood by the public but the term frequently used in the literature to describe it.

This question is sensitive to the bias that respondents might say that they have heard of a particular item to give the expected answer or to appear knowledgeable. The possible presence of this bias makes low response rates for carbon capture and storage and carbon sequestration particularly striking. Very few people have heard of these technologies.

The survey included a question specifically about carbon capture and storage and carbon sequestration. The question asked respondents to choose the environmental concern that carbon sequestration or carbon capture and storage is able to address. Respondents could choose more than one concern. Table 4.4 shows the responses.

Table 4.4
Public Opinion About Environmental Concerns Addressed by Carbon Sequestration or Carbon Capture and Storage (Q6)*

Environmental Concern	Can Reduce (%)	Does Not Reduce (%)	Not Sure (%)
Smog	29	3	68
Water pollution	23	5	72
Global warming	23	5	73
Ozone depletion	21	5	74
Acid rain	21	6	73
Toxic waste	16	8	76

*Question 6: Please select if "carbon sequestration" or "carbon capture and storage" can reduce each of the following environmental concerns.

A large number of respondents were unsure about what environmental concern the technology addresses. In the entire sample, the number who answered the question correctly is within the margin of error. Less than 0.5 percent (5 respondents out of 1,205) answered the question correctly (marking "can reduce" for global warming and "not sure" or "does not reduce" for the remaining answers). Interestingly, about the same number of respondents (7) answered the question completely incorrectly (marking "not sure" or "does not reduce" for global warming and "can reduce" for all the other concerns). Over half the respondents (58 percent) answered "not sure" for all the concerns.

Table 4.5 shows the responses to the same question for the 4 percent of respondents who said that they had heard or read about carbon capture and storage in the past year.

Table 4.5
Public Opinion About Environmental Concerns Addressed by CCS
For Those Who Had Heard of Carbon Capture and Storage (n=46)

Environmental Concern	Can Reduce (%)	Does Not Reduce (%)	Not Sure (%)
Water pollution	57	6	37
Smog	56	5	40
Global warming	52	6	43
Ozone depletion	49	12	38
Acid rain	48	7	45
Toxic waste	31	27	42

The respondents who said they had heard of carbon capture and storage were no more likely to answer the question correctly. However, they were more likely to attempt to answer the question. Fourteen percent of those who had heard of carbon capture and storage answered "not sure" for all of the concerns (n=46). The results for the 3 percent who said that they had heard of or read about carbon sequestration in the past year are similar to the results for carbon capture and storage shown in Table 4.5.

4.2. Public Attitudes

Additional survey questions considered public attitudes toward the environment, global warming, and climate change-mitigation technologies. The emphasis of the questions in this section is on attitudes toward climate change-mitigation technologies for electricity generation.

4.2.1. Attitudes Toward the Environment

Four of the survey questions addressed general attitudes towards the environment and asked questions about spending on the environment. Later sections of this thesis use the answers to these questions to complement the demographic data and determine if there

are any general environmental attitudes that predict willingness to pay to solve global warming.

Table 4.6 shows public opinions on the issues facing the United States at the time of the survey. The survey included the 22 issues listed in Table 4.6 and asked the respondents to choose the three most important issues.

Table 4.6
Public Opinion About the Most Important Issues Facing the U.S. (Q1)*

Issue	Percent Listing in the Top Three	Issue	Percent Listing in the Top Three
Terrorism	42	Taxes	11
Health care	35	Environment	9
Economy	35	Poverty	8
Unemployment	30	Aging population	5
Family values	20	Income inequality	4
Education	19	AIDS	4
Federal budget deficit	15	Abortion	4
Foreign policy	14	Racism	4
Crime	14	Welfare	3
Social Security	13	Inflation	3
Drugs	12	Stock market	2

*Question 1: Consider the following issues. What are the three most important issues facing the U.S. today?

The environment ranks thirteenth on the list. The results are consistent with those Gallup reported for a similar timeframe (The Polling Report, 2004). Respondents who chose the environment in response to this question are considered concerned about the environment. Concern about the environment was not a strictly partisan issue. Of Republicans surveyed, 7.3 percent listed the environment compared to 7.8 percent of Democrats. A higher number of independents, 17.5 percent, said they were concerned about the environment.

Table 4.7 shows public opinion about specific environmental problems. The survey included the 10 environmental problems shown in this table. Respondents picked one problem from the list and were then asked to choose a second problem from the same list (excluding their first choice).

Table 4.7
Public Opinion About the Most Important Environmental Problems (Q2)*

Environmental Problem	First Choice (%)	Second Choice (%)	Total (%)
Water pollution	17	22	39
Destruction of ecosystems	16	15	31
Toxic waste	14	17	30
Overpopulation	15	8	24
Ozone depletion	11	11	22
Global warming	11	10	21
Urban sprawl	8	8	16
Smog	5	6	11
Endangered species	2	2	4
Acid rain	1	1	1

Question 2: Consider the following environmental problems. Which is the most important problem facing the U.S. today?

As the table shows, global warming ranked sixth out of the issues in the survey. Among those who listed the environment as one of their top three concerns, global warming was the third highest ranked concern (27 percent ranked it as first or second) preceded by destruction of ecosystems (60 percent) and water pollution (29 percent). In a recent Gallup Poll[5], global warming ranked ninth on a list of 10 comparable environmental problems that respondents were worried about when asked "if you personally worry about this problem a great deal, a fair amount, only a little, or not at all. How much do

[5] March 8-11, 2004. N=1,005 adults nationwide. Margin of error ± 3. The Polling Report (2004) Environment The Polling Report, Inc. Accessed April, 2004. http://www.pollingreport.com/enviro.htm. (Accessed April 2004)

you personally worry about [specific environmental problem]?" (The Polling Report, 2004).

Table 4.8 shows the results of a question about trade-offs between the economy and the environment.

Table 4.8
Public Preference Between the Economy and the Environment (Q3)*

Statement	Percent Responding
The highest priority should be given to protecting the environment, even if it hurts the economy.	9
Both the environment and the economy are important, but the environment should come first.	45
Both the environment and the economy are important, but the economy should come first.	39
The highest priority should be given to economic considerations such as jobs even if it hurts the environment.	8

* Question 3: Many environmental issues involve difficult trade-offs with the economy. Which of the following statements best describes your view?

Public polling results show that public opinion about the trade-offs between the economy and the environment has fluctuated over the past three decades. The survey results in Table 4.8 are consistent with the split found in recent poll results.

Table 4.9 shows the results of a question about U.S. Department of Energy (USDOE) priorities. Respondents were asked to select a priority from the entire list and a second priority from a list that did not contain the first choice. The two options that have the closest relationship to CCS are "ways to remove carbon from atmosphere" and "cleaner burning coal." Respondents did not give much support to either of these options when choosing priorities for the USDOE.

Table 4.9
Public Opinion About USDOE Priorities (Q5)*

Priority	First Choice (%)	Second Choice (%)
New energy sources: solar, wind, or bioenergy/biomass	30	17
Anti-terrorism and security	19	13
New oil and gas reserves	12	10
More energy efficient cars and trucks	9	12
Clean drinking water	7	12
Energy conservation	7	11
Ways to better manage toxic waste	4	7
Mass transportation	4	4
Nuclear waste disposal	2	5
Nuclear power	3	3
Ways to remove carbon from atmosphere	1	3
More energy efficient buildings	1	2
Hydropower	1	1
Cleaner burning coal	1	1

* Question 5: If the U.S. Department of Energy has $10 billion to spend, which do you think should be the top priority?

In a separate study by MIT in 2001, researchers asked about the allocation of $30 billion for research in the United States. The results of that survey also found strong support for solar power and wind power (Deutch et al., 2003).

4.2.2. Public Attitudes Toward Global Warming

Concern over global climate change and the need to limit CO_2 emissions drives the need for CCS. Before asking about technological options, the survey asked for opinions about global warming. Table 4.10 shows the responses to a general question about global warming. The survey included the five choices listed in the table.

Table 4.10
Public Opinion About the Need for Action in Response to Global Warming (Q10)*

Opinion	Percent
Global warming has been established as a serious problem and immediate action is necessary.	17
There is enough evidence that global warming is taking place and some action should be taken.	36
We don't know enough about global warming and more research is necessary before we take any actions.	24
Concern about global warming is unwarranted.	7
No opinion	16

*Question 10: From what you know about global warming, which of the following statements comes closest to your opinion?[6]

In the MIT CCSTP survey, 50 percent of those who ranked the environment in the top three issues facing the U.S. chose the first answer in Table 4.10. Twenty-eight (28) percent of those who said they were concerned about global warming chose the first answer; 42 percent chose the second answer.

To consider public preferences regarding technological change versus lifestyle change, the survey included the question shown in Table 4.11.

[6] A July 1999 NBC News/Wall Street Journal Poll asked a similar question to 500 adults in the United States. The results of that survey were: immediate action is necessary, 23 percent; some action should be taken, 28 percent; more research is necessary, 32 percent; concern is unwarranted, 11 percent; not sure, 6 percent. Ibid. Accessed April, 2004.

Table 4.11
Public Opinion about the Likely Response to Global Warming (Q11)*

Likely Action	Percent
I believe that firms and government researchers will develop new technologies to solve the problem.	21
I believe we will have to change our lifestyles to reduce energy consumption.	32
I believe we will learn to live with and adapt to a warmer climate.	17
I believe global warming is a problem but the U.S. won't do anything about it.	24
I believe we will do nothing since global warming is not a problem.	7

* Question 11: Assuming that global warming is a problem, what do you think the U.S. is likely to do about it?

Of those who ranked the environment in the top three issues facing the U.S., 45 percent chose the cynical answer that they believe in global warming but do not believe that the U.S. is going to do anything about it. Thirty-six percent of those saying that they are concerned about global warming said that we will have to change our lifestyles, and 33 percent chose the option that the U.S. will not do anything about global warming.

Those who chose the cynical view (n=277) were primarily Democrats (42 percent compared to 15 percent Republicans and 18 percent independents). The cynicism may measure frustration with the policies of the current administration.

4.2.3. Public Attitudes Toward Climate Change-Mitigation Technologies

As shown in Section 4.1.2, very little of the public claims to have heard of CCS in the past year and even less of the public is able to say what environmental concern the technology addresses. There is essentially no knowledge of CCS. Table 4.12 shows public opinion about nine climate change-mitigation technologies. On the survey, a one-sentence definition accompanied each technology; none of the technologies was defined earlier in the survey. Table 4.12 includes the definitions with each technology. Respondents chose from five answers for each technology: definitely use, probably use,

probably not use, definitely not use, and not sure. Table 4.12 groups "definitely use" and "probably use" in one column and "definitely not use" and "probably not use" in another column. Appendix A includes the numbers broken out.

Table 4.12
Public Technology Preferences (Q13)*

Technology	Definitely / Probably Use (%)	Probably/ Definitely Not Use (%)	Not Sure (%)
Solar energy: Using the energy from the sun for heating or electricity production.	82	3	15
Energy efficient appliances: Producing appliances that use less energy to accomplish the same tasks.	81	4	15
Energy efficient cars: Producing cars that use less energy to drive the same distance.	81	4	16
Wind energy: Producing electricity from the wind, traditionally in a windmill.	76	6	18
Carbon sequestration: Using trees to absorb carbon dioxide from the atmosphere.	67	9	24
Bioenergy/biomass: Producing energy from trees or agricultural wastes.	59	10	30
Nuclear energy: Producing energy from a nuclear reaction.	38	34	28
Carbon capture and storage: Capturing carbon dioxide from power plant exhaust and storing in underground reservoirs.	29	33	38
Iron fertilization of oceans: Adding iron to the ocean to increase its uptake of carbon dioxide from the atmosphere.	20	36	44

*Question 13: The following technologies have been proposed to address global warming. If you were responsible for designing a plan to address global warming, which of the following technologies would you use?

This question appeared late in the survey (the thirteenth question out of 17 non-demographic questions), and this was the first information respondents received defining the various technologies. Note the differences in definition between carbon sequestration

and carbon capture and storage. Carbon sequestration, as defined in this question, refers to "using trees to absorb carbon dioxide from the atmosphere" while carbon capture and storage refers to "capturing carbon dioxide from power plant exhaust and storing in underground reservoirs." Part of the reason for the different definitions was to avoid confusion between terrestrial sequestration and geologic capture and storage and show distinct answers for each alternative.

Table 4.12 shows that significantly fewer people are unsure about using solar energy, wind energy, and energy efficiency technologies to address global warming compared to other listed technologies. There are very few people who said they would "definitely not use" or "probably not use" renewable or energy efficiency technologies. Solar energy, wind energy, and energy efficiency technologies were also at the top of Table 4.3, which listed the percent of respondents saying they had heard of different technologies or energy sources.

Nuclear energy was in the top five technologies listed on Table 4.3 with 54 percent of respondents replying that they had heard of or read about nuclear energy in the past year. As shown in Table 4.12, support for the use of nuclear energy is much lower than that of the other technologies most respondents said they had heard of or read about in the past year. Table 4.13 shows a breakout of responses for those who had heard of nuclear energy and the corresponding responses to Q13. Those who had heard of nuclear energy were more likely to say that they would use nuclear energy to address global warming. Those who had not heard of nuclear energy were much more likely to choose "not sure".

Table 4.13
Effect of Familiarity on Responses to
"Would you use nuclear energy?" (Q13)

Heard of Nuclear Energy (Q4)	Definitely Use (%)	Probably Use (%)	Probably Not Use (%)	Definitely Not Use (%)	Not Sure (%)	N
No	8	17	22	12	42	540
Yes	21	28	21	14	17	633
Total	15	23	21	13	28	1173

Table 4.14 shows a similar breakdown for solar energy. A large percentage of those who had not heard of solar energy supported its use.

Table 4.14
Effect of Familiarity on Responses to
"Would you use solar energy?" (Q13)

Heard of Solar Energy (Q4)	Definitely Use (%)	Probably Use (%)	Probably Not Use (%)	Definitely Not Use (%)	Not Sure (%)	N
No	35	34	4	1	27	425
Yes	64	26	1	1	9	763
Total	54	29	2	1	15	1188

The wind energy, efficient appliances, and efficient cars all had results similar to solar energy.

The definitions in this section influenced an individual's response. For example, there is a significant difference between those saying they would "definitely use" or "probably use" carbon sequestration and those saying that they would "definitely use" or "probably use" carbon capture and storage. There are significantly more people opposed to carbon capture and storage than carbon sequestration as the question defines them. The similarities in the acceptance of biomass and carbon sequestration suggest that the public was responding the more natural idea of trees or agriculture.

Carbon capture and storage did not fair well - nine percent more people were willing to "definitely use" or "probably use" nuclear power compared to CCS. However, 10 percent more people said they were unsure about carbon capture and storage compared to nuclear power. It is not possible to draw strong conclusions about what effect increased familiarity might have on carbon sequestration but a large portion of the public is both unfamiliar and undecided.

4.2.4. Summary

There are a significant number of issues the public consider to be more important that the environment. Out of twenty-two issues, concern over the environment ranked thirteenth. Concern over the environment is not a strongly partisan issue; which is interesting given the heated partisan rhetoric on the issue.

Global warming is not considered the most important environmental problem by the public or by those who are concerned about the environment. Those concerned about the environment rank global warming behind destruction of ecosystems and water pollution. Public opinion is split over the relative importance of the environment versus the economy.

In choosing priorities for USDOE, the public has limited interest in funding technologies related to clean coal and removing carbon from the atmosphere. There is strong support for renewable energy sources. Energy technology preferences are strongly slanted towards renewable energy and energy efficiency. Almost 40 percent of respondents were unsure if they would use carbon capture and storage, and 12 percent said they definitely would not use carbon capture and storage.

4.3. Willingness to Pay to Solve Global Warming

The survey included a question asking about willingness of the respondent to pay more on his or her monthly electricity bill to "solve global warming." Before asking about willingness to pay, a question asked respondents to estimate the previous month's electric bill. This response gave respondents and researchers an anchor for the willingness to pay question. Table 4.15 shows the breakout of responses to the electric bill question.

Table 4.15
Responses to Previous Month's Electric Bill (Q8)*

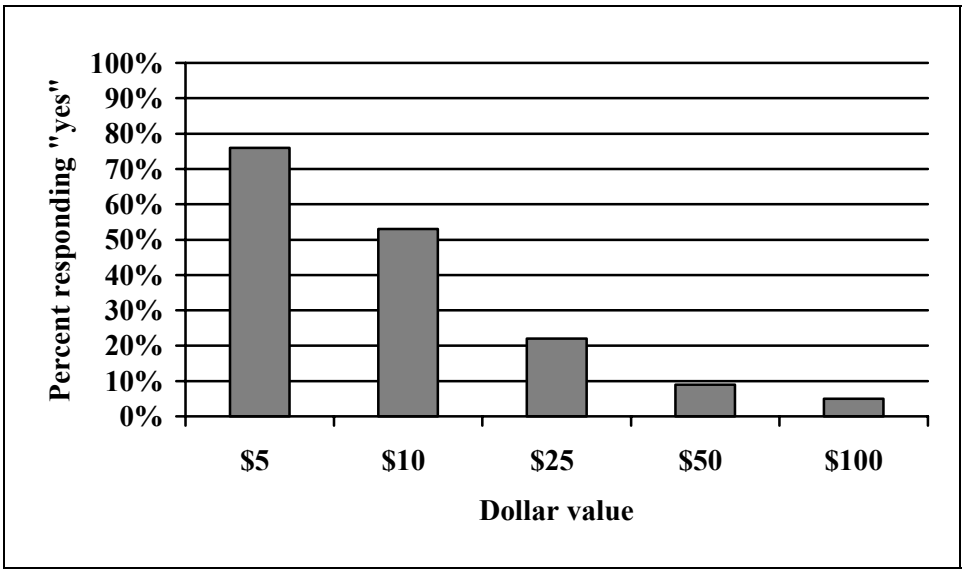
Amount	Percent of Respondents?
Under $10	1
$10-25	3
$26-50	14
$51-75	16
$76-100	19
$101-150	21
$151-200	12
More than $200	8
Don't know	6

*Question 8: How much was your electric bill last month?

Forty percent of respondents reported an electric bill between $76 and $150 for the month before the survey (Knowledge Networks administered the survey in October 2003). According to the Energy Information Administration, in 2002 the average monthly residential bill in the United States was $76.74 (EIA, 2003a).

Respondents were then asked "If it solved global warming, would you be willing to pay [dollar value] more per month on your electricity bill?" The first dollar value offered as a response was $5. If the respondent answered yes, the dollar value increased to $10. A second yes response increased the dollar value to $25, followed by $50, and $100.

Figure 4.2 shows the responses to the willingness to pay question. Each bar represents the number of respondents who agreed to that price.



*Question 9: If it solved global warming, would you be willing to pay ___ more per month on your electricity bill?

Figure 4.2
Expressed Monthly Willingness to Pay to Solve Global Warming (Q9)*

Twenty-four percent of respondents answered "no" when asked if they were willing to pay $5. One of the remarkable things about the responses to this question is how quickly the willingness to pay drops off. When the dollar value jumped from $10 to $25, 60 percent of the remaining respondents answered that they would not pay $25.

As shown in Figure 4.2, the dollar value options did not increase linearly. As a result, a straight calculation of the average willingness to pay would result in a value biased upward by those who answered "yes" to $100. Taking the natural log of the willingness to pay creates a linear scale for comparison (Appendix B details the calculations). Using the natural log transformation, the mean expressed willingness to pay is estimated to be $6.61. This is likely a conservative estimate of the willingness to pay as those who rejected a dollar value were set at the previously offered dollar value. For example, a respondent who said "no" to $5 was assigned a $0 willingness to pay and a respondent who said "no" to $100 was assigned a $50 willingness to pay. In reality, some of these respondents have a willingness to pay between $0 and $5 or $50 and $100.

There are important caveats to the willingness to pay estimate. The question in the MIT CCSTP survey is abstract and does not define global warming or provide information about the potential impacts of global warming. It measures the respondent's willingness to pay to solve his or her personal definition of global warming. As discussed earlier, it is not clear if the public has a correct definition of global warming. A number of studies have found that that the public is confused about what causes global warming and what actions are possible to address global warming (Bostrom et al., 1994; Read et al., 1994; Kempton, 1997). As such, it is impossible to say what an individual might mean when responding that he or she wants to solve global warming. Kempton, Boster, and Hartley suggest that well established cultural models shade an individual's idea of global climate change (Kempton et al., 1995). Morgan, Fischhoff, Bostrom, and Atman advocate risk communication through and understanding of "mental models" of complex and uncertain risks (Morgan et al., 2002).

The regression analysis attempts to uncover some of these models using demographic variables and responses to questions about the immediacy of the global climate change problem as independent variables. However, it is impossible to draw clear conclusions about what particular aspects of global warming concern those who are willing to pay.

There have been other, more specific, attempts to draw out a willingness to pay for global warming. Berk and Fovell report on one such attempt where they define particular regional impacts of global climate for the region they studied (Southern California). Using this methodology, they varied the regional impacts between cooling and warming, and between more rain and less rain. They found that the framing of the question had definite impacts on the willingness to pay. They arrived at willingness to pay numbers that ranged from $4.40 to prevent summer cooling in the California Valley to $19.92 to prevent summer warming in the California Valley. They found that people were less willing to pay to address the problem of more rain than they were to address the problem of less rain (Berk and Fovell, 1999).

The question asked in the MIT CCSTP survey elicits an expressed willingness to pay as opposed to a revealed willingness to pay. It is well established in the literature that people reveal a different price level when confronted with an actual cost than they do when they are describing how much they would pay for something. Expressed willingness to pay gives a general idea of how much an individual is willing to pay but it does not give a precise value. In this case, despite the limitations, expressed willingness to pay is a useful metric for comparing the relative attitudes of different groups of individuals toward bearing a cost for this environmental problem.

To measure the effects of changes in variables on willingness to pay, a regression analysis was performed. The dependent variable in the analysis was the natural log of the willingness to pay and the independent variables were based on responses to questions discussed earlier in this chapter and demographic characteristics. Calculations based on the regression resulted in an average expressed willingness to pay of $6.49, slightly lower than the expected value estimate but within the 95 percent confidence interval. Appendix B includes the details of the regression analysis.

Figures 4.3 and 4.4 present the results of the regression analysis. The first four variables in both figures are variables for answers to Q10. The other variables are ordered by the absolute value of their effect on willingness to pay. Where applicable, the variable name includes the question number. Variables in bold are significant at the 95 percent confidence interval ($t > 1.96$).

Figure 4.3 presents the raw results from the regression as the coefficients for each independent variable and the confidence interval associated with that variable. These results show the effect of the variables on the natural log of willingness to pay. The coefficient values for each variable are marked "X" and the confidence intervals are shown. The closer a variable is to the vertical black line that cuts through the plot (set at zero), the less of an impact that variable has on willingness to pay. Variables with confidence intervals that include zero are not significant at the 95 percent confidence interval.

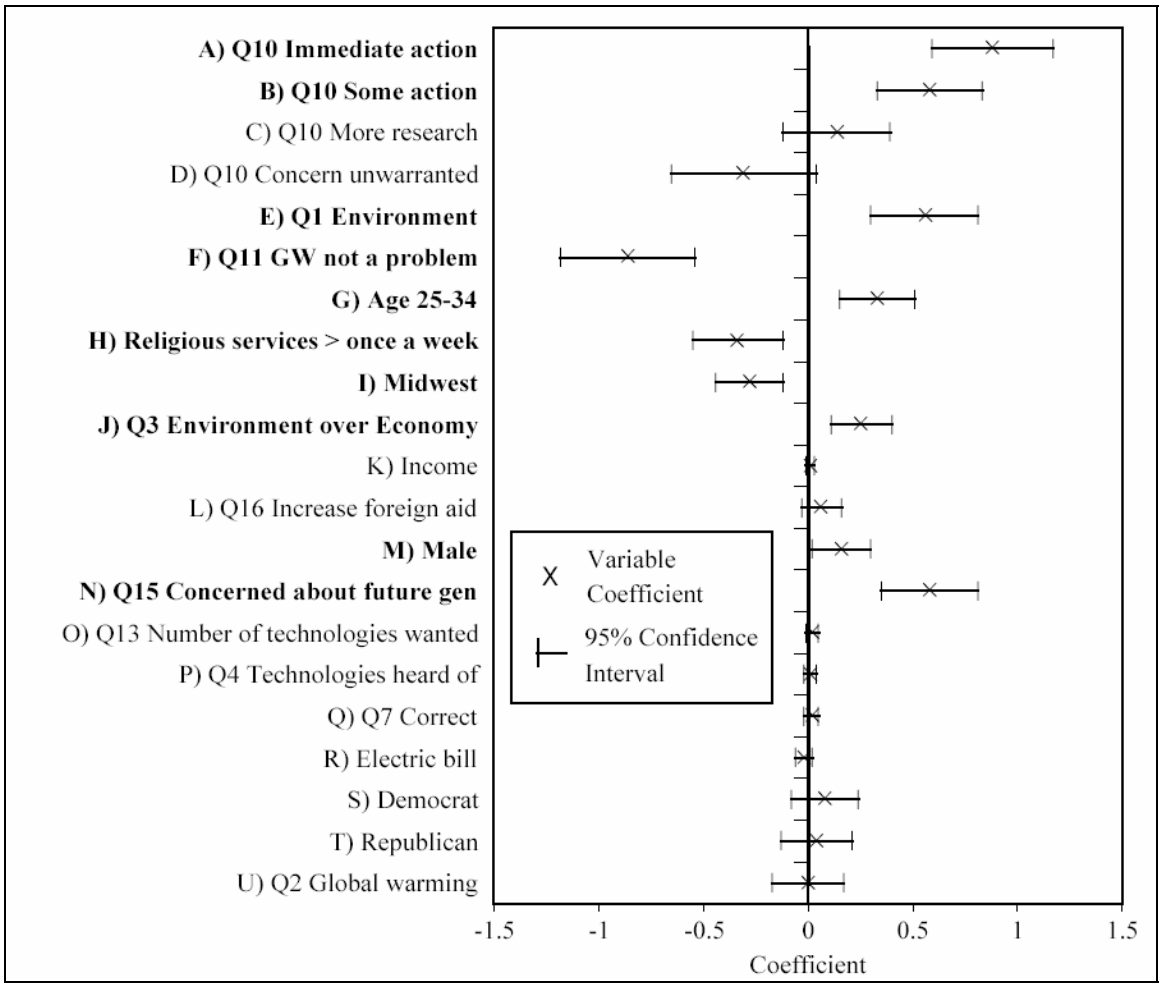


Figure 4.3
Effects of Variables on Natural Log of Willingness to Pay

The data in Figure 4.3 are more meaningful when the effect on willingness to pay is shown in real dollars (instead of a change in the natural log of willingness to pay). Figure 4.4 shows a transformation of the results of the regression analysis. The data in Figure 4.4 are shown as the effect of a change in the variable on willingness to pay. The vertical black line marks the mean willingness to pay ($6.49). The "X" next to each variable marks the willingness to pay of an individual with the characteristics of that variable while all other variables are held constant at their average value. For example, "Q1 Environment" shows the effect of an individual ranking the environment in the top three concerns while the other characteristics are held at the average. An average respondent

who ranked the environment in the top three concerns is willing to pay $10.81, $4.32 more than the average survey respondent.

The confidence intervals shown in Figure 4.4 are approximate. They are based on a transformation of the standard errors of the regression and do not accurately represent the significance of the variables. The confidence intervals in Figure 4.3 present a clearer picture of the significance of the variables.

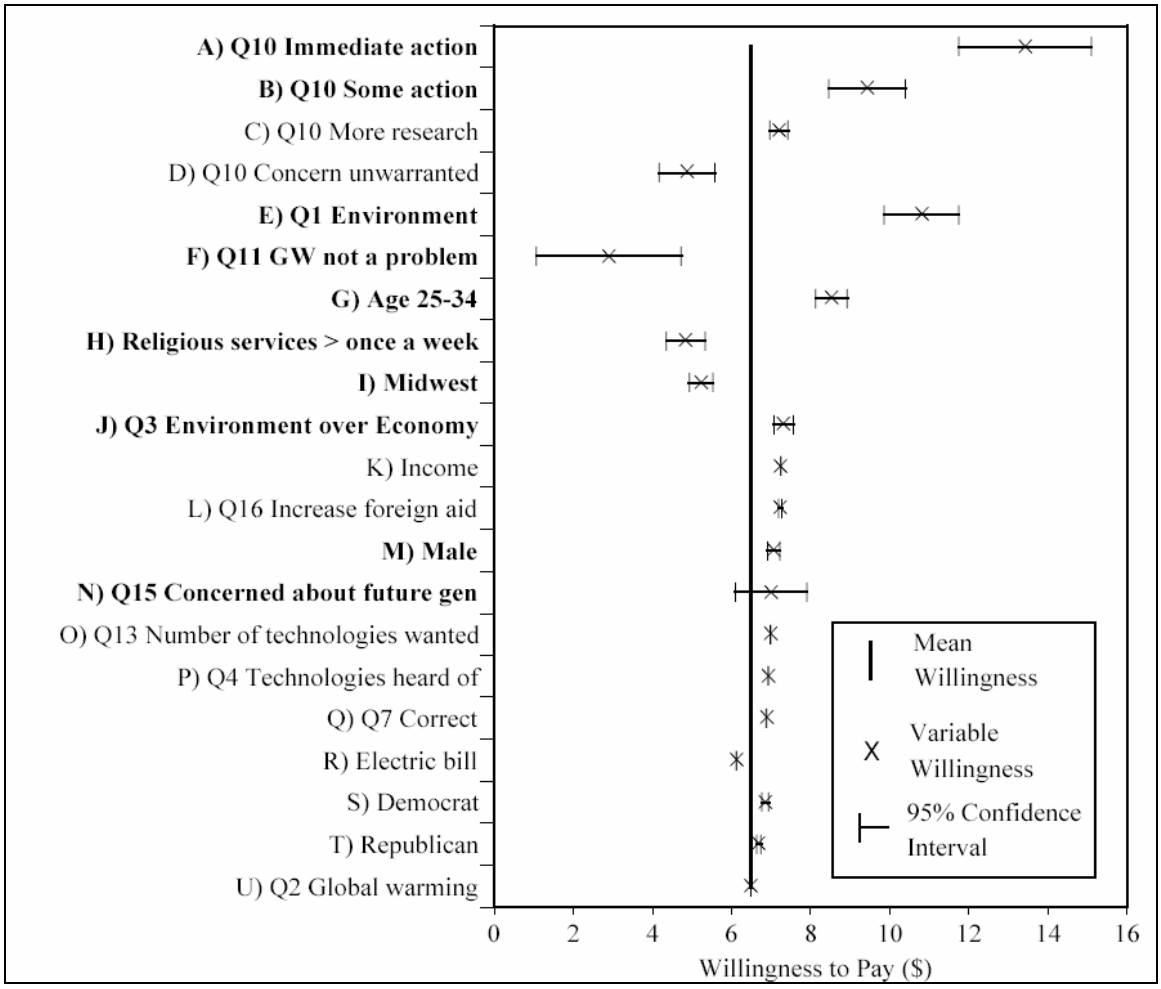


Figure 4.4
Effects of Variables on Willingness to Pay

As shown in Figure 4.4, Q10 (which asked what action should be taken to address global warming) had an almost linear effect on the willingness to pay. Moving from Variable A

(Q10 Immediate action) to Variable D (Q10 Concern unwarranted), the willingness to pay decreases about $2 to $3 between each response. Unsurprisingly, those who said that they believed that "immediate action is necessary" were willing to pay the most followed by those who said "some action should be taken" and so on down to concern is unwarranted. "No opinion" was the excluded from the regression and, if plotted, would fall between Variable C and Variable D, close to the overall mean willingness to pay.

Respondents who chose the environment as one of the three most important issues facing the United States today (Variable E) had a significantly higher expressed willingness to pay. One of the surprising results was that the selection of global warming as one of the top two environmental concerns from the list in Q2 (Variable U) did not have an effect on willingness to pay. Using Q11 (Variable F) as a measure of concern over global warming, those who answered that global warming is not a problem were less willing to pay than those who chose an answer that described a specific course of action. These data suggest that while global warming is not a top concern among the population, those who believe the United States should take action against global warming express a higher willingness to pay.

The other question responses with statistically significant effects on willingness to pay were responses to Q3 (Variable J) and Q15 (Variable N). In Q3, which asked about respondent preference between the environment and the economy, those who chose one of the two answers that favored the environment over the economy (see the first and second answer in Table 4.8) were willing to pay more. Q15 asked about concern for future generations. Those who said "we have a responsibility to look out for the interests of future generations, even if it means making ourselves worse off" were $0.50 more willing to pay compared to the mean. They were about $3.00 more willing to pay than those who answered no to the same question.

Q13 and Q4 (Variables O and P respectively) asked about the number of technologies respondents were willing to use and had heard of in the past year. Neither variable had a significant impact on mean willingness to pay. Q7 asked about specific technology and

system effects on CO_2. As suggested earlier, the number of correct answers to Q7 (Variable Q) can be used as a measure of knowledge about climate change. The results of the regression suggest that knowledge about CO_2 (at least knowledge about CO_2 measured in this way) has little impact on willingness to pay.

In total, the effects of responses to Q4, Q7, and Q13 suggest that information about climate change-mitigation technologies and the knowledge of CO_2 have little impact on the expressed willingness to pay.

Of the demographic variables, age, sex, region, and frequency of attendance at religious services had statistically significant effects on willingness to pay. The only age group that expressed a significantly different willingness to pay was the group between 25 and 34 years of age, which showed a willingness to pay of $2.03 above the mean and $2.41 above the other age groups. Males were willing to pay about $1.00 more than females ($0.50 more than the mean). Respondents from the Midwest were less willing to pay than counterparts in other regions of the country. Interestingly, respondents who attended church more than once a week had a lower willingness to pay than the mean; other demographic variables collected for this survey do not explain this effect.

Unexpectedly, the amount of income and the monthly electric bill did not have a statistically significant effect on willingness to pay. Controlling for income and other variables, it was expected that an increase in the electric bill would decrease the willingness to pay. The experiment conducted in Q14 and discussed in the next section provides insight into the actual effect of increasing the electric bill on willingness to pay.

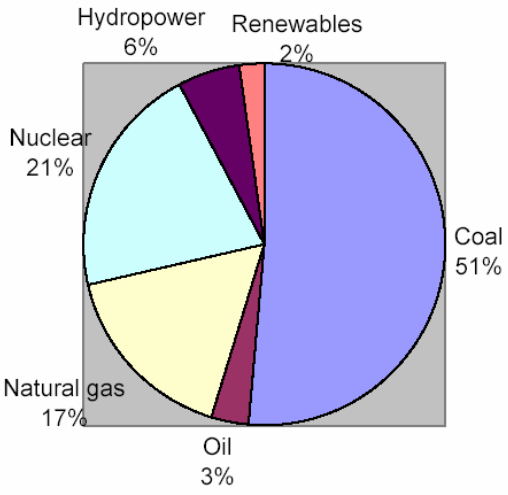
4.4. Public Response to Price Information

The survey included an experiment to test the effect of price and production information on public preference for methods to address the issue of global warming as it relates to electricity production. Q14 gave respondents seven choices for addressing global warming and asked them to choose the one that they preferred. About half of the survey respondents (n=691) received no information and about half of the survey respondents (n=614) received the information shown in Figure 4.5.

The electricity production data shown in Figure 4.5 was derived from electricity net generation data compiled by the Energy Information Agency (EIA) data for 2002.[7] The price information was not meant to be exact, but was meant to clearly portray relative costs between the technologies. Round numbers were used to gather information on whether the public maintained their support for renewable energy in the face of higher prices. It should be noted that on a regional or local level, there are economically competitive sources of renewable energy (wind turbines, hydropower, etc.) that could be cheaper than the costs shown in Figure 4.5.

Now we would like to present some facts on electricity production and prices.

The following chart shows our reliance on fossil fuels (coal, oil and natural gas) for producing electricity.



Based on published studies, we can summarize electricity production costs as follows:

- Using coal and natural gas, the typical family pays $1,200 per year for electricity.
- Using all nuclear power would emit no carbon dioxide and would increase electricity costs for families to $2,400 per year.
- Using carbon sequestration along with coal and natural gas would reduce carbon dioxide emissions by 90% and would also increase electricity costs to $2,400 per year.
- Using renewables (solar and wind power) would increase annual electricity costs to $4,000.

Figure 4.5
Information Provided to Half of the Respondents Before Answering Q14

[7] For the raw data, visit EIA at http://www.eia.doe.gov/emeu/aer/txt/ptb0802a.html.

Table 4.16 shows the responses for the group who received no information and the group who received the information in Figure 4.5.

Table 4.16
Public Opinion About Ways to Address Global Warming as it Relates to Electricity Production (Q14)

Method to address global warming	Respondents who received no information (%)*	Respondents who received information (%)**
Do nothing. We can live with global warming.	4	5
Invest in research and development. A new technology will solve global warming.	24	28
Continue using fossil fuels but with capture and storage of carbon dioxide.	6	16
Expand nuclear power.	7	11
Expand renewables (solar and wind power).	49	25
Reduce electricity consumption, even if it means lower economic growth.	4	10
Do nothing. There is no threat of global warming.	7	6

* Question 14 (without information): How do you feel we can best address the issue of global warming as it relates to electricity production? (n=691)
** Question 14 (with information): Considering these facts, how can we best address the issue of global warming as it relates to electricity production? (n=614)

This experiment takes advantage of the fact that the public is generally supportive of renewable sources of electricity but largely unaware of the costs associated with these sources. If the public were more aware of the cost difference between renewable electricity and current electricity sources, the difference between the two cases would not be as striking.

The shift in responses in Table 4.16 from those who did not receive information to those who received information reflects the price sensitivity of the public when considering electricity alternatives. Contrary to the willingness to pay analysis (where an increasing

electric bill had no effect on willingness to pay), respondents moved away from the most expensive option when presented with cost data. This suggests there is a limit to willingness to pay as the electric bill increases.

The results of this experiment suggest that the public is sensitive to the price of options directed at solving global warming. In the no information case, 49 percent of respondents choose renewable energy sources. When provided price information showing that the annual cost of switching to an all-renewable electricity portfolio is over three times the current fossil fuel portfolio cost, the number of respondents choosing renewable electricity drops in half to 25 percent. However, even in the case with information, renewable electricity enjoys a considerable amount of support relative to the other options.

There is no clear winner when respondents shift away from renewable electricity. When respondents receive cost information, they do not move to a particular technology. Reduction in consumption fares slightly better in the information case but may not have been embraced because it was put in terms of the tradeoff between a reduction in consumption and lower economic growth.

The largest increase in support from the no information case to the information case is for fossil fuel-based electricity with carbon capture and storage. There is a 10 percent increase in the number of respondents choosing fossil fuels with carbon capture and storage when price and current production information are given. It is not clear if this shift is in response to the technology or to the cost. Respondents may be reacting to the idea of using fossil fuels as opposed to the idea of using carbon capture and storage.

5. OTHER SURVEYS OF PUBLIC OPINION FOCUSED ON CCS

As work on the technological and economic feasibility of CCS continues, researchers have begun to collect data on public attitudes and perceptions toward CCS. Four recent public surveys in the United States, Japan, Great Britain, and the Netherlands have focused on CCS (Huijts, 2003; Itaoka, 2004; Palmgren et al., 2004; Shackley et al., 2004). All of the surveys, except the Japanese survey, contained an educational component and judged the effect of education on the acceptance of CCS. The Dutch survey is particularly interesting because it measured the attitudes of people who lived directly above natural gas formations that could later be the site of carbon dioxide storage. It is important for business and government to understand the concerns of people directly affected by carbon dioxide storage. Local attitudes can have a significant impact on project siting.

Before discussing the surveys in general, Section 5.1 presents some results from the Japanese survey.

5.1. Fuji Research Institute Survey of Japanese Public Opinion

The results of the Japanese survey are particularly relevant to the results discussed in the previous chapter because the researchers designed some of the questions to match the phrasing of MIT CCSTP survey questions. For the Japanese survey, researchers at the Fuji Research Institute in Japan conducted a written survey of a representative sample of the Japanese public in the Tokyo metropolitan area and Sapporo. The researchers obtained 1,006 responses.

Mr. Kenshi Itaoka of the Fuji Research Institute provided preliminary results of the Japanese survey (Itaoka, 2004). The Japanese responses paired with the MIT CCSTP survey responses to similar questions are shown in the Tables 5.1 through 5.4. Tables 5.1 and 5.2 show the results of questions about awareness of technologies and knowledge of CCS.

Table 5.1
Japanese and American Familiarity with Technologies and Energy Sources (MIT Survey Q4)*

Technology or Energy Source	Fuji Research Institute Survey: Heard of or read about (%)	Fuji Research Institute Survey: I know it to some extent (%)	MIT Survey: Heard of or read about (%)
More efficient cars	44	52	70
Solar energy	37	60	64
Nuclear energy	41	54	54
Wind energy	44	52	50
More efficient appliances	45	38	49
Hydrogen cars	45	33	48
Bioenergy/biomass	34	18	10
Carbon capture and storage	22	9	4
Carbon sequestration	38	52	3
Iron fertilization	13	5	2
None of these	NA	NA	17

NA – Not applicable.
*Question 4: Have you heard of or read about any of the following in the past year?

Table 5.2
Japanese and American Opinions About Environmental Concerns Addressed by Carbon Sequestration or Carbon Capture and Storage (MIT Survey Q6)*

Environmental Concern	Fuji Research Institute Survey: Can reduce (%)	Fuji Research Institute Survey: Not sure (%)	MIT Survey: Can reduce (%)	MIT Survey: Not Sure (%)
Smog	45	41	29	68
Water pollution	42	41	23	72
Global warming	82	16	23	73
Ozone depletion	67	24	21	74
Acid rain	55	35	21	73
Toxic waste	24	54	16	76

*Question 6: Please select if "carbon sequestration" or "carbon capture and storage" can reduce each of the following environmental concerns.

As shown in Table 5.1, the Fuji Research Institute's survey included the answer "I know it to some extent" in the responses for MIT CCSTP survey Question 4. It is difficult to compare the survey results for this question directly because it is impossible to tell how many people would have chosen "some extent" on the MIT CCSTP survey. However,

Table 5.1 shows that the Japanese recognition of carbon sequestration much larger than the American recognition of carbon sequestration. It is difficult to draw strong conclusions about why there is such a stark difference in recognition. It may be the result of more discussion within the Japanese government of ocean sequestration as a possible climate-change mitigation activity or it may be the result of confusion in the translation of the question or the answers. It is possible that CCS or CO_2 refers to global warming in Japanese more clearly than it does in English. Additionally, there may be cultural differences between the U.S. and Japan in the willingness of respondents to answer "not sure" or that they have not heard of a technology. This is an area of further research between the Fuji Research Institute and MIT.

Table 5.2 shows that there appears to be a greater understanding of what environmental concern CCS is meant to address. Global warming clearly rises above the other options, although almost 70 percent also chose ozone depletion. The same caveat about language differences exists.

Tables 5.3 and 5.4 show the results of two other questions that were on the MIT and Fuji Research Institute surveys. These results reflect the different attitudes between Japanese citizens and American citizens concerning ways that that the countries should address global warming and ways that the countries likely will address global warming.

Table 5.3
Japanese and American Opinion About the Need for Action in Response to Global Warming (MIT Survey Q10)*

Opinion	Fuji Response (%)	MIT Response (%)
Global warming has been established as a serious problem and immediate action is necessary.	54	17
There is enough evidence that global warming is taking place and some action should be taken.	34	36
We don't know enough about global warming and more research is necessary before we take any actions.	8	24
Concern about global warming in unwarranted.	0	7
No opinion	3	16

*Question 10: From what you know about global warming, which of the following statements comes closest to your opinion?

Table 5.4
Japanese and American Opinion About the Likely National Response to Global Warming (MIT Survey Q11)*

Likely Action	Fuji Response (%)	MIT Response (%)
I believe that firms and government researchers will develop new technologies to solve the problems.	22	21
I believe we will have to change our lifestyles to reduce energy consumption.	66	32
I believe we will learn to live with and adapt to a warmer climate.	4	17
I believe global warming is a problem but Japan [U.S.] won't do anything about it.	6	24
I believe we will do nothing since global warming is not a problem.	NA	7
No opinion	2	NA

* Question 11: Assuming that global warming is a problem, what do you think [Japan or the U.S.] is likely to do about it?

The results in Tables 5.3 and 5.4 show a clear difference in the opinions of the Japanese public compared to the American public. While there are no clear winners in the MIT

CCSTP responses, the Fuji Research Institute responses indicate that the majority of the Japanese public believes that global warming is a serious problem and that individuals will have to reduce energy consumption to address global warming.

5.2. Other Surveys of Public Opinion Towards CCS

Researchers at Carnegie Mellon University conducted a public survey in the Pittsburgh, PA area on both geologic and ocean CCS. The Carnegie Mellon survey used a modified version of their mental models approach. In a working paper, they describe a two-step process where they elicit responses from a small sample (n=18) through semi-structured interviews. They then use the responses to develop a closed-form survey given to a larger sample (n=125). The closed-form survey is used to measure the prevalence of responses identified during the interview process. Early in the interview process, the researchers concluded that very few people in the public understood CCS and they added background information on geologic and oceanic CCS to both surveys. They used carbon capture and disposal instead of CCS or carbon sequestration in the closed-form survey after discovering that interviewees rarely used "sequestration" after hearing the term. They found an "initial dislike for geological and oceanic carbon sequestration relative to other carbon management options" that seemed to increase with more detailed information (Palmgren et al., 2004).

One of the researchers' hypotheses is that public hesitance to adopt CCS could develop around concerns that it is a temporary solution to global warming and that it could cause unforeseen problems in the future. They caution against an "arrogant approach" to using CCS and recommend an open regulatory process that emphasizes public communication (Palmgren et al., 2004).

Huijts conducted a survey of local attitudes toward geologic CCS in the Netherlands (Huijts, 2003). She conducted a field study where she gave questionnaires to individuals living in three residential areas situated above gas fields (the most likely site for CO_2 injection in the Netherlands). Residents returned 112 questionnaires. Huijts provided the residents with background information about CCS. She found that people were "neutral to a bit positive" about the usefulness of CCS but they were "neutral to negative" when it

came to using the natural gas reservoirs under their homes. Huijts called this the not-under-my-backyard (NUMBY) effect. Huijts found that residents generally felt the risks of CCS were larger than the benefits and held stronger negative than positive emotions toward CCS. She also concludes that an open regulatory and decision-making process might help to create a feeling of trust among the public and the various governmental, NGO, and industry actors (Huijts, 2003).

The Tyndall Centre in Great Britain conducted a study of public opinion based on focus group responses and face-to-face surveys of 212 individuals in August 2003. The study was funded by the Tyndall Centre and UK Department of Trade and Industry (Shackley et al., 2004). In the study, Shackley, McLachlan, and Gough found that people were generally unaware of CCS when first approached. Upon learning about CCS, they found that the public was concerned that, as a stand-alone option, "CCS might delay more far-reaching and necessary long-term changes in society's use of energy" (Shackley et al., 2004, p. 2). However, they found that CCS was viewed more favorably when projects currently using it (in the North Sea, EOR, etc.) were described. They also found that people were concerned about the uncertain risks of leakage and accidents along with uncertain impacts on the environment, ecosystem, and human health. Shackley, McLachlan, and Gough conclude that CCS should be put in "the context of climate change and the need for large long-term reductions in CO_2 emissions to the atmosphere" (Shackley et al., 2004, p. 2).

6. IMPLICATIONS FOR PUBLIC OUTREACH

The MIT CCSTP survey shows that a very small portion of the public has heard of CCS and a negligible number know what environmental problem it addresses. When asked if they would consider using this technology to address global warming, 38 percent said they were not sure if they would or would not use the technology. This unawareness and uncertainty suggests that the public will make opinions about CCS over the coming years and decades (assuming the number of experimental, demonstration, and commercial operations continues to increase).

The results of the MIT CCSTP survey do not suggest specific actions to increase awareness of CCS; the number of respondents that had heard of CCS was so small that it was impossible to draw clear conclusions about public perception towards the technology. However, taking a step away from CCS, the survey does provide some ideas about attitudes toward climate change and climate change mitigation.

While the MIT CCSTP survey shows that public generally responds correctly to the idea that automobiles, factories, and coal burning power plants emit CO_2, the survey also shows the public is confused about whether some nuclear power plants, home heating, and oceans increase or decrease CO_2. This result suggests that there are gaps in public understanding of the sources that release CO_2 to the atmosphere and that these gaps affect not only a new technology such as CCS but also such longstanding, visible technologies as nuclear power plants. A program to increase awareness of CCS should not assume that the public is aware of the effect of older, better-established technologies on climate change.

The results found in the MIT CCSTP survey suggest that raising the level of awareness and concern about the environment and global climate change could increase the willingness to people to accept higher costs of climate change mitigation. People who are concerned about the environment are willing to pay more to solve global warming than the average respondent. Additionally, people who believe that immediate action on global warming is necessary are willing to pay more. From these results, it appears as

though those who have been convinced that global climate change is a serious threat are willing to pay to solve the problem. The difficulty for policy makers is that a small portion of the public ranks the environment as a top priority and only a quarter of that segment believes global warming is one of the top two environmental concerns.

The survey did not consider ways to increase public concern over the environment or over global warming through public outreach but it did consider the effects of some types of knowledge on willingness to pay. The results suggest that increased knowledge about sources and sinks of CO_2 has little effect on willingness to pay. Those individuals who knew more about sources and sinks of CO_2 had the same willingness to pay as the average respondent. A separate metric, familiarity with climate change-mitigation technologies, also had no impact on willingness to pay. Further, the number of technologies an individual said they were willing to use had no impact on willingness to pay. Each of these metrics suggest that increasing specific knowledge about CO_2 or awareness of technologies aimed at reducing CO_2 will have a limited impact on public willingness to accept mitigation costs.

It is important to note, however, that the technologies that received the largest recognition and popular support in the absence of information were renewable energy technologies. The experiment of providing electricity cost and production data to half of the sample population showed that the public is largely uninformed about the cost of renewable electricity. This experiment suggests that accurate price information is essential to the public making a decision about climate change. Awareness and understanding of technological options might not be as essential as awareness of the cost of technological options.

As Kempton argues, scientists and policy analysts would like to believe that complex decisions, such as what to do about global climate change "are based on the best science available and that the costs and benefits are balanced impartially." However, he says, "elected leaders also have to consider how voters feel about these issues" (Kempton, 1997, p. 13).

Over the next years and decades, the public will likely begin to form opinions about CCS. It is probable that the influence of popular public opinion on CCS policy will be limited in the early stages of development. Commercial CCS projects are already underway in parts of the world and there are a number of experimental and demonstration projects underway in the U.S. Historically, policy makers in the government and the energy industry make the decisions about research allocation and facility placement without much public input. Public perceptions usually only enter the debate when there is local opposition to project siting (Conn, 1983).

The not-in-my-backyard (NIMBY) effect (or not-under-my-backyard (NUMBY) effect as Huuijts calls it) will probably have a stronger impact on the development of CCS than the general public sentiment. In the early stages of development, local residents will be asked to take a cost for the global good. There will be diffuse benefits and concentrated costs, a situation where opposition is traditionally very effective.

Communicating the risks of CCS to local residents will be a difficult task. Researchers from Carnegie Mellon University and the Georgia Institute of Technology recently published a book with their philosophies on how to communicate risk (Morgan et al., 2002). One danger is that the risk communicator operates from a biased position. While developing methodologies for communicating the risks of CCS, one has to be aware of internal biases and the fact that local communities might be asked to bear a risk for the global society to benefit.

The recent surveys of public attitudes toward CCS suggest that an open decision-making process with clear avenues for public comments and concerns will aid in the acceptance of the technology (Huijts, 2003; Palmgren et al., 2004; Shackley et al., 2004). Keeping the process open will help address some of the concerns that the government and industry working alone might miss.

CCS is a complicated technology to explain and it is an unnecessary technology in the absence of global climate change. Any explanation of CCS must be motivated with an

explanation of global climate change. If the public does not connect energy use to fossil fuel use to CO_2 emissions to climate change, CCS does not make sense. Building a CCS infrastructure will require costs to the consumer. Understanding what motivates willingness to pay will help ease the process.

7. CONCLUSIONS

A number of public surveys conducted over the past 10 years show belief in global climate change and support for action to address it. However, the public is uncertain about what actions are available to address climate change. In fact, the public is uncertain about what exactly is causing climate change and often links climate change to increased pollution as opposed to increased concentrations of greenhouse gases. The results reviewed here suggest that it will be difficult to motivate the public about global warming as long as it is perceived as part of a far off, uncertain future. Those who are convinced that immediate action is necessary are currently willing to pay twice as much per month as the average member of the public.

The important conclusions from the MIT CCSTP survey are:

- The environment is not a pressing concern for the majority of the public.
- Global warming is not the top environmental concern (even among those who are concerned about the environment).
- Very few people in the United States have heard of CCS.
- Those who have heard of CCS are no more likely to know what environmental concern it addresses than those who have not heard of CCS.
- The public has an expressed willingness to pay to solve global warming of about $6.50 per month.
- The largest influences on willingness to pay are concern about the environment and the opinion that global warming requires immediate action.
- A large portion of the public supports investment in renewable energy technologies but that support decreases when cost information for all climate mitigation technologies is provided.

Future Work

Future work on attitudes and understanding of CCS should include a review of actors within government, industry, and NGOs. Since global climate change is a global issue with global impacts, research on the opinions of people throughout the world should continue. MIT CCSTP intends to continue collaboration with researchers at the Fuji

Research Institute and the University of Cambridge. In addition to a follow-up survey in the United States, there are plans for a European survey and continued analysis of the opinions of the Japanese public. It is hoped that the survey detailed in this thesis can serve as a baseline for future public surveys on CCS.

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APPENDIX A: MIT CARBON CAPTURE AND SEQUESTRATION TECHNOLOGIES PROGRAM SURVEY QUESTIONS AND ANSWERS

Question 1: *Consider the following issues. What are the three most important issues facing the US today?*

Issue	Percent Listing in the Top Three	Issue	Percent Listing in the Top Three
Terrorism	42	Taxes	11
Health care	35	Environment	9
Economy	35	Poverty	8
Unemployment	30	Aging population	5
Family values	20	Income inequality	4
Education	19	AIDS	4
Federal budget deficit	15	Abortion	4
Foreign policy	14	Racism	4
Crime	14	Welfare	3
Social Security	13	Inflation	3
Drugs	12	Stock market	2

Question 2A and 2B: *Consider the following environmental problems. Which is the most important problem facing the US today?*

Environmental Problem	First Choice (%)	Second Choice (%)	Total (First + Second)
Water pollution	17	22	39
Destruction of ecosystems	16	15	31
Toxic Waste	14	17	30
Overpopulation	15	8	24
Ozone depletion	11	11	22
Global warming	11	10	21
Urban sprawl	8	8	16
Smog	5	6	11
Endangered species	2	2	4
Acid rain	1	1	1

Question 3: *Many environmental issues involve difficult trade-offs with the economy. Which of the following statements best describes your view?*

Statement	Percent
The highest priority should be given to protecting the environment, even if it hurts the economy.	9
Both the environment and the economy are important, but the environment should come first.	45
Both the environment and the economy are important, but the economy should come first.	39
The highest priority should be given to economic considerations such as jobs even if it hurts the environment.	8

Question 4: *Have you heard of or read about any of the following in the past year? Check all that apply.*

Technology or Energy Source	Percent
More efficient cars	70
Solar energy	64
Nuclear energy	54
Wind energy	50
More efficient appliances	49
Hydrogen cars	48
Bioenergy/biomass	10
Carbon capture and storage	4
Carbon sequestration	3
Iron fertilization	2
None of these	17

Question 5A and 5B: *If the US Department of Energy has $10 billion to spend, which do you think should be the top priority?*

Priority	First Choice (Percent)	Second Choice (Percent)	Total (First + Second)
New energy sources: solar, wind, or bioenergy/biomass	30	17	47
Anti-terrorism and security	19	13	32
New oil and gas reserves	12	10	21
More energy efficient cars and trucks	9	12	20
Clean drinking water	7	12	19
Energy conservation	7	11	18
Ways to better manage toxic waste	4	7	12
Mass transportation	4	4	8
Nuclear waste disposal	2	5	7
Nuclear power	3	3	6
Ways to remove carbon from atmosphere	1	3	4
More energy efficient buildings	1	2	3
Hydropower	1	1	2
Cleaner burning coal	1	1	2

Question 6: *Please select if "carbon sequestration" or "carbon capture and storage" can reduce each of the following environmental concerns.*

Environmental Concern	Percent Can Reduce	Percent Does Not Reduce	Percent Not Sure
Toxic waste	16	8	76
Ozone depletion	21	5	74
Global warming	23	5	73
Acid rain	21	6	73
Smog	29	3	68
Water pollution	23	5	72

Question 7: *There is a growing concern about increasing levels of carbon dioxide in the atmosphere. How do you think the following contribute to these levels?*

Technology or Practice	Increases Carbon Dioxide (%)	Decreases Carbon Dioxide (%)	No Impact (%)	Not Sure (%)
Automobiles	78	3	2	18
Factories	73	3	2	23
Coal burning power plants	70	2	3	25
Home heating	53	3	9	36
Breathing	41	5	28	26
Nuclear power plants	30	8	20	43
Farming	13	28	19	40
Trees	7	66	8	19
Oceans	4	29	26	41
Windmills	3	21	49	27

Question 8: *How much was your electric bill last month?*

Amount	Percent
Under $10	1
$10-25	3
$26-50	14
$51-75	16
$76-100	19
$101-150	21
$151-200	12
More than $200	8
Don't know	6

Question 9: *If it solved global warming, would you be willing to pay [dollar value] more per month on your electricity bill?* (Dollar value started at $5, if a respondent chose "yes" it increased to $10 then $25, $50, and $100.)

Expressed Willingness to Pay	Percent
Less than $5	24
$5 to $9.99	23
$10 to $24.99	31
$25 to $49.99	13
$50 to $99.99	4
$100 or greater	5

Question 10: *From what you know about global warming, which of following statements comes closest to your opinion?*

Opinion	Percent
Global warming has been established as a serious problem and immediate action is necessary.	17
There is enough evidence that global warming is taking place and some action should be taken.	36
We don't know enough about global warming and more research is necessary before we take any actions.	24
Concern about global warming is unwarranted.	7
No opinion	16

Question 11: *Assuming that global warming is a problem, what do you think the US is likely to do about it?*

Likely Action	Percent
I believe that firms and government researchers will develop new technologies to solve the problem.	21
I believe we will have to change our lifestyles to reduce energy consumption.	32
I believe we will learn to live with and adapt to a warmer climate.	17
I believe global warming is a problem but the US won't do anything about it.	24
I believe we will do nothing since global warming is not a problem.	7

In the survey, half of the sample were asked Question 12a and half Question 12b.

Question 12a: *An international treaty calls on the US and other industrialized nations to cut back on their emissions from power plants and cars in order to reduce global warming. Some people say this would hurt the US economy and is based on uncertain science. Others say that this is needed to protect the environment and could create new business opportunities. What's your view—do you think the US should or should not join this treaty requiring less emissions from US power plants and cars?*

View	Percent
Should join/ Wrong	55
Should not join/ Right	15
No opinion	30

Question 12b: *The US government says that it won't join the Kyoto Protocol (an international treaty to limit emissions of greenhouse gases) because it would hurt the US economy and is based on uncertain science. Do you think the US position is right or wrong?*

View	Percent
Right	20
Wrong	30
No opinion	50

Question 13: *The following technologies have been proposed to address global warming. If you were responsible for designing a plan to address global warming, which of the following technologies would you use?*

Technology	Definitely Use (%)	Probably Use (%)	Probably Not Use (%)	Definitely Not Use (%)	Not Sure (%)
Solar energy: Using the energy from the sun for heating or electricity production.	54	29	2	1	15
Energy efficient appliances: Producing appliances that use less energy to accomplish the same tasks.	57	25	3	1	15
Energy efficient cars: Producing cars that use less energy to drive the same distance.	54	27	2	2	16
Wind energy: Producing electricity from the wind, traditionally in a windmill.	48	28	5	1	18
Carbon sequestration: Using trees to absorb carbon dioxide from the atmosphere.	39	29	6	3	24
Bioenergy/biomass: Producing energy from trees or agricultural wastes.	26	33	8	2	30
Nuclear energy: Producing energy from a nuclear reaction.	15	23	21	13	28
Carbon capture and storage: Capturing carbon dioxide from power plant exhaust and storing in underground reservoirs.	10	20	21	12	38
Iron fertilization of oceans: Adding iron to the ocean to increase its uptake of carbon dioxide from the atmosphere.	5	15	24	13	44

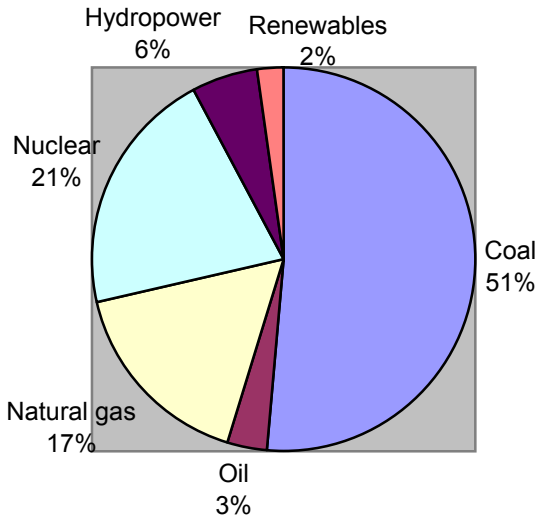
Question 14: *How can we best address the issue of global warming?* In the survey, we provided half of the sample with information on cost and current use and provided half of the sample with no additional information. The next page includes the information.

Options	Percent without information	Percent with information
Do nothing. We can live with global warming.	4	5
Invest in research and development. A new technology will solve global warming.	24	28
Continue using fossil fuels but with capture and storage of carbon dioxide.	6	16
Expand nuclear power.	7	11
Expand renewables (solar and wind power).	49	25
Reduce electricity consumption, even if it means lower economic growth.	4	10
Do nothing. There is no threat of global warming.	7	6

Information for Question 14:

Now we would like to present some facts on electricity production and prices.

The following chart shows our reliance on fossil fuels (coal, oil and natural gas) for producing electricity.



Based on published studies, we can summarize electricity production costs as follows:

- Using coal and natural gas, the typical family pays $1,200 per year for electricity.
- Using all nuclear power would emit no carbon dioxide and would increase electricity costs for families to $2,400 per year.
- Using carbon sequestration along with coal and natural gas would reduce carbon dioxide emissions by 90% and would also increase electricity costs to $2,400 per year.
- Using renewables (solar and wind power) would increase annual electricity costs to $4,000.

Question 15: *Do you believe that we have a responsibility to look out for the interests of future generations, even if it means making ourselves worse off?*

Response	Percent
Yes	87
No	13

Question 16: *We currently assist other nations through foreign aid and charitable donations, do you think we should increase that assistance, let it stay the same, decrease our assistance or remove it entirely?*

Response	Percent
Increase	6
Stay the same	35
Decrease	48
Remove it entirely	12

Question 17: *How do you heat your home?*

Heat Source	Percent
Oil	9
Electricity	31
Natural Gas	50
Wood	3
No Heating	2
Don't know	2
Other	4

Questions 18-20 provided demographic information and are not included here.

APPENDIX B: DETAILS OF THE WILLINGNESS TO PAY CALCULATIONS

As described in Section 3 of Chapter 4, calculation of the mean willingness to pay required a transformation of the data to create a linear relationship. Table B.1 shows the responses to the willingness to pay question as originally shown in Table 4.16 with two additional columns in the middle. One of the additional columns has the dollar value associated with each response and the other has the natural log of the dollar value.

Table B.1
Expressed Monthly Willingness to Pay to Solve Global Warming (Q9)*

Expressed Willingness to Pay	Dollar Value	Natural Log of Dollar Value	Percent
Less than $5	0	0**	24
$5 to $9.99	5	1.61	23
$10 to $24.99	10	2.30	31
$25 to $49.99	25	3.22	13
$50 to $99.99	50	3.91	4
$100 or greater	100	4.61	5

*Question 9: If it solved global warming, would you be willing to pay ___ more per month on your electricity bill?
**Set at zero.

Figure B.1 shows a plot of the dollar value and the natural log of the dollar value. The natural log of the dollar value is linear and more useful for the multivariate regression. Figure B.2 shows better detail of the natural log plot.

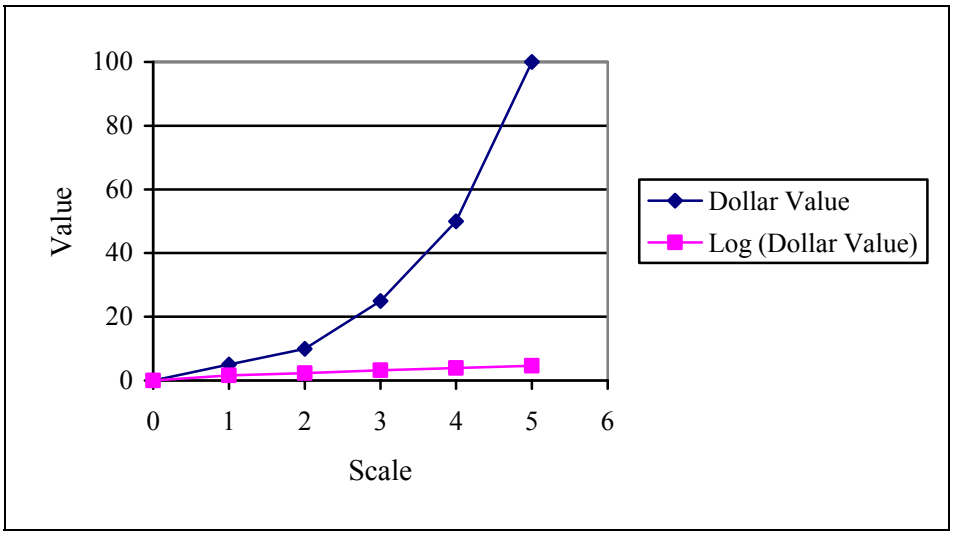


Figure B.1
Comparison of the plots of willingness to pay and the transformation of willingness to pay

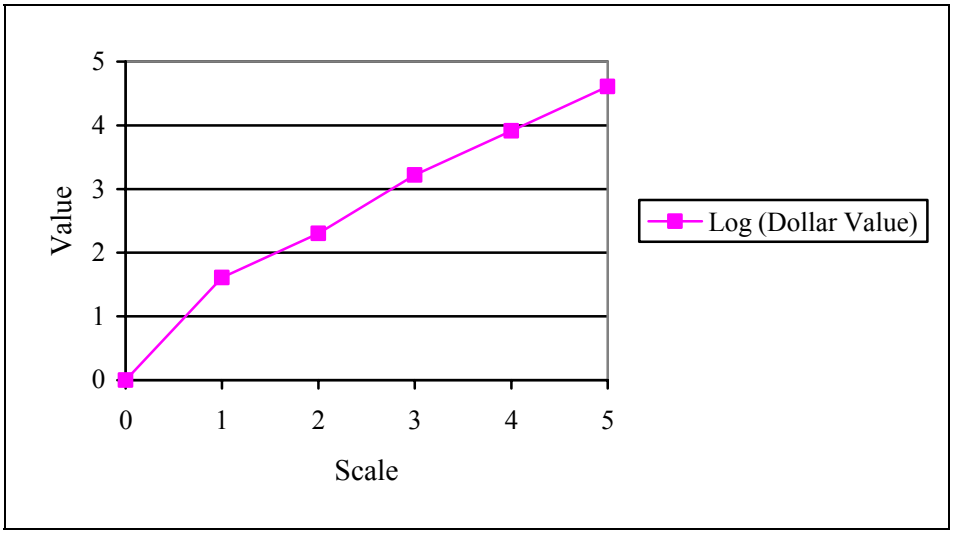


Figure B.2
Plot of the transformation of willingness to pay

Figures B.3 and B.4 show added-variable, or partial regression, plots of willingness to pay and the natural log of willingness to pay, respectively. Both plots compare the dependent variables to the first answer to Q10. The plots are based on the multivariate regressions used in Chapter 4.

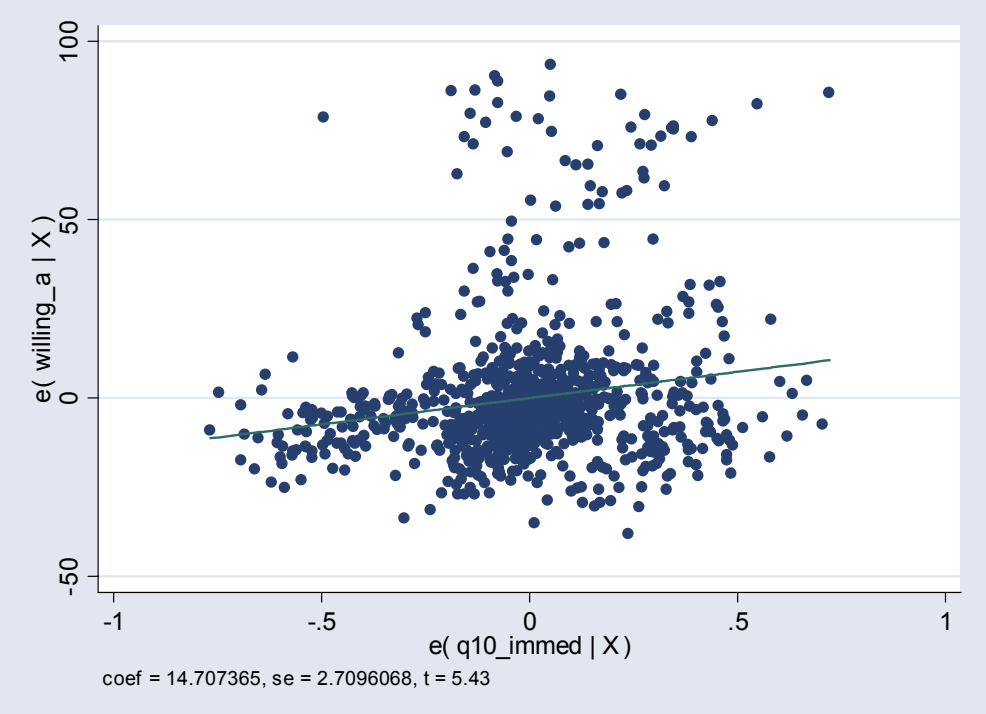


Figure B.3
Added-variable plot of willingness to pay vs. Answer 1 to Q10

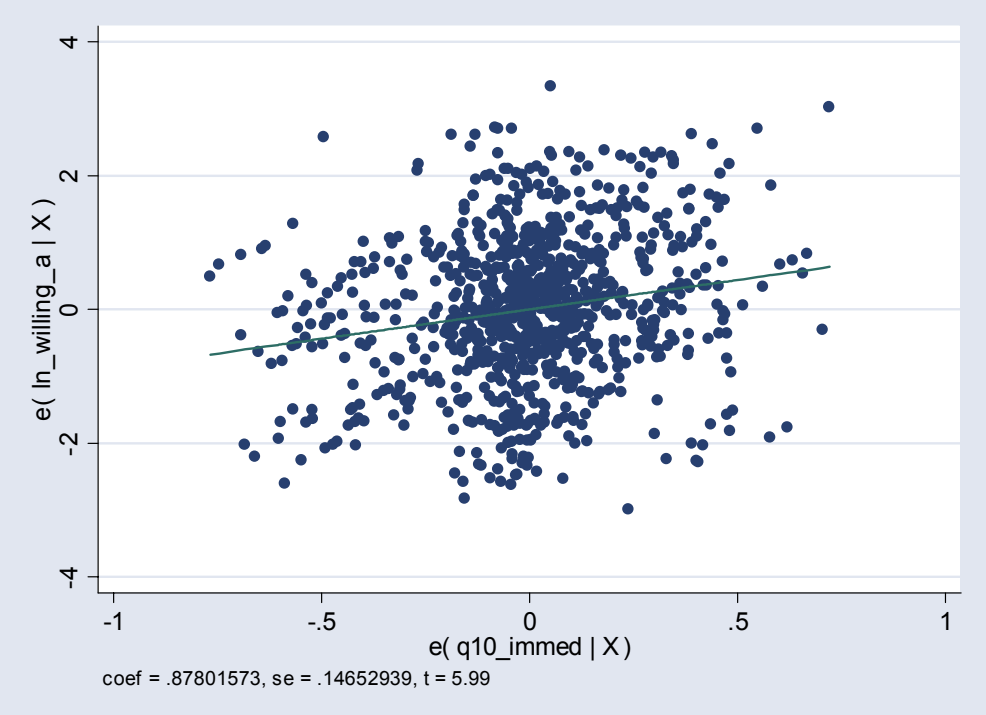


Figure B.4
Added-variable plot of log of willingness to pay vs. Answer 1 to Q10

Figures B.3 and B.4 show that the natural log of willingness to pay recalibrates the higher willingness responses and gives a better distribution of the results.

The regression of willingness to pay in Chapter 4 focuses on a subset of the variables. For reference, Table B.2 shows the results of a regression with more independent variables.

Table B.2
Regression of the Natural Log of Willingness to Pay with Extra Independent Variables

Source	SS	Df	MS	Number of obs	=	953
Model	490.4	38	12.9	Prob > F	=	0
Residual	1021.5	914	1.1	R-squared	=	0.3
Total	1511.9	952	1.6	Root MSE	=	1.1

Independent Variable	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Q1 Environment*	0.58	0.13	4.34	0.00	0.32	0.84
Q2 Global warming	0.00	0.09	-0.01	0.99	-0.18	0.18
Q3 Environment over Economy*	0.25	0.08	3.34	0.00	0.10	0.40
Q4 Technologies heard of	0.01	0.02	0.48	0.63	-0.03	0.04
Q7 Correct	0.02	0.02	1.17	0.24	-0.01	0.05
Electric bill $10-25	-0.42	0.49	-0.87	0.38	-1.38	0.53
Electric bill $26-50	-0.54	0.46	-1.19	0.23	-1.44	0.35
Electric bill $51-75	-0.67	0.45	-1.48	0.14	-1.55	0.22
Electric bill $76-100	-0.62	0.45	-1.37	0.17	-1.51	0.27
Electric bill $101-150	-0.53	0.45	-1.18	0.24	-1.42	0.35
Electric bill $151-200	-0.63	0.46	-1.38	0.17	-1.52	0.26
Electric bill More than $200	-0.75	0.46	-1.62	0.11	-1.66	0.16

Q10 Immediate action*	0.85	0.15	5.69	0.00	0.56	1.14
Q10 Some action*	0.56	0.13	4.30	0.00	0.30	0.82
Q10 More research	0.12	0.13	0.95	0.34	-0.13	0.38
Q10 Concern unwarranted	-0.37	0.18	-2.01	0.05	-0.73	-0.01
Q11 GW not a problem*	-0.84	0.17	-5.04	0.00	-1.16	-0.51
Q13 Number of technologies wanted	0.02	0.02	1.32	0.19	-0.01	0.06
Age 25-34*	0.28	0.14	2.00	0.05	0.01	0.56
Age 35-44	-0.02	0.13	-0.16	0.87	-0.28	0.24
Age 45-54	0.02	0.14	0.12	0.90	-0.25	0.28
Age 55-64	0.00	0.14	0.02	0.98	-0.28	0.28
Age 65-74	-0.09	0.16	-0.57	0.57	-0.39	0.22
Age 75+	-0.21	0.21	-1.00	0.32	-0.61	0.20
Midwest	-0.29	0.11	-2.72	0.01	-0.49	-0.08
Northeast	-0.09	0.11	-0.79	0.43	-0.31	0.13
South	0.02	0.10	0.21	0.83	-0.17	0.22
Q16 Increase foreign aid	0.08	0.05	1.67	0.10	-0.01	0.18
Q15 Concerned about future gen*	0.57	0.12	4.69	0.00	0.33	0.81
Income	0.01	0.01	1.19	0.24	-0.01	0.03
Democrat	0.08	0.08	0.96	0.34	-0.08	0.25
Republican	0.06	0.09	0.65	0.52	-0.12	0.24
Religious services > once a week*	-0.33	0.14	-2.27	0.02	-0.61	-0.04
Religious services once a week	-0.07	0.12	-0.58	0.56	-0.31	0.17
Religious services once a month	0.00	0.15	-0.01	0.99	-0.29	0.29
Religious services a few times a year	0.00	0.12	0.02	0.99	-0.23	0.24
Religious services once a year	0.15	0.13	1.16	0.25	-0.10	0.40
Male	0.16	0.07	2.19	0.03	0.02	0.30
Constant	0.91	0.49	1.85	0.06	-0.05	1.88

Table B.2 is included to justify the use of the second age category (ppagecat_2) as an independent variable and leave out the other age groups. The table shows that the other age groups were not significant at the 95 percent confidence interval ($t > 1.96$). Similarly, Table B.2 justifies using the Midwest as the only region and using those who attended religious services more than once a week variable as the only church attendance variable in Chapter 4. The religious service attendance statistics in Table B.2 are referenced to those who answered that they never attended religious services.

Tables B.3 and B.4 show the summary statistics and regression output for the independent variables discussed in Chapter 4.

Table B.3
Regression Summary Statistics

Observations	F(21, 931)	Adjusted R^2	Constant	Constant Std. Err.	Constant t-statistic
953	20.4	0.30	0.42	0.23	1.85

Table B.4
Expressed Willingness to Pay and Confidence Intervals for Selected Independent Variables

Independent variable*	Coefficient	Standard Error	t-statistic	Willingness to Pay
A) Q10 Immediate action	0.88	0.15	5.99	$13.43
B) Q10 Some action	0.58	0.13	4.54	$9.43
C) Q10 More research	0.14	0.13	1.05	$7.20
D) Q10 Concern unwarranted	-0.31	0.18	-1.73	$4.88
E) Q1 Environment	0.56	0.13	4.28	$10.81
F) Q11 GW not a problem	-0.86	0.16	-5.31	$2.90
G) Age 25-34	0.33	0.09	3.60	$8.53
H) Religious services > once a week	-0.34	0.11	-3.04	$4.84
I) Midwest	-0.28	0.08	-3.40	$5.23
J) Q3 Environment over Economy	0.25	0.07	3.41	$7.31
K) Income	0.01	0.01	1.30	$7.24
L) Q16 Increase foreign aid	0.06	0.05	1.36	$7.23
M) Male	0.16	0.07	2.27	$7.07
N) Q15 Concerned about future gen	0.58	0.12	4.86	$7.00
O) Q13 Number of technologies wanted	0.02	0.02	1.21	$6.99
P) Q4 Technologies heard of	0.01	0.02	0.59	$6.93
Q) Q7 Correct	0.02	0.02	1.02	$6.89
R) Electric bill	-0.02	0.02	-0.93	$6.13
S) Democrat	0.08	0.08	0.97	$6.85
T) Republican	0.04	0.09	0.45	$6.69
U) Q2 Global warming	0.00	0.09	-0.01	$6.49

* Bold independent variables are significant at the 95 percent confidence level.