

A Prediction Market for Climate Outcomes

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Introduction.....	2
I. Why is Climate Science So Hard?	6
A. Disparateness	10
B. Complexity and Uncertainty	13
C. The Benefits of Denial	16
D. Reform Proposals.....	19
II. Prediction Markets	21
III. The Tax-and-Cap-and-Trade Proposal	28
IV. Implementation Issues and the Realpolitik of Carbon Taxes	35
A. Establishing the Carbon Tax.....	35
1. <i>Who is Subject to the Tax?</i>	36
2. <i>The Carbon Tax Level</i>	38
3. <i>Which Climate Outcomes?</i>	40
B. The Cap-and-Trade Program	49
1. <i>Initial Allocation of Permits</i>	49
2. <i>How Far in Advance Should Permits Be Available?</i>	51
3. <i>How Many Permits Should be Available for a Vintage Year?</i> 52	
C. Competitiveness and Trade Concerns.....	54
D. How Well Will the Market Work?	57
E. What Kinds of Information Will Be Reflected in Trading Activity?	62
F. The Politics of Carbon Taxes and Cap-and-Trade	67
V. Conclusion	69
Appendix A.....	70
Appendix B	77

Thanks to Michael Abramowicz, John Abraham, Ross McKittrick, Andrew Dessler, Xuebin Zhang, Judith Curry, Yoram Margalioth, and commenters at the First Colloquium on Environmental Scholarship at Vermont Law School, and the attendees at the Environmental Law and Policy Workshop at the Buchman Faculty of Law at Tel Aviv University for their help and comments.

Introduction

Few challenges in the history of humankind have received as much attention or been the target of as much funding as global climate change. This unprecedented deployment of resources seems warranted, given the potential for vast, sweeping, environmental changes that could destabilize not only vital ecosystems, but also lead to civil unrest that could politically destabilize entire regions. Climate change is also alone among environmental problems in its extraordinary complexity and inherent uncertainty, and therefore requiring a massive research effort. But a spastic outpouring of money has only produced a huge and intractable body of science trying very hard but falling well short of predicting future climate conditions. Layered on top of this literature is another set of educated guesses, the variety of possible human response scenarios to climate conditions, which in turn could affect the future climate.¹ These disparate and complicated bodies of knowledge, products of research efforts at hundreds of universities and research institutes throughout the world, have been foisted upon a hapless global public in desperate need of a "Climate Change for Dummies" manual.²

Into this comprehension vacuum has rushed a variety of interest groups which have helped produce a public discourse that has been at times emotional and vitriolic, and at other times puzzlingly apathetic, but rarely constructive and rarely leading to rational policy discussion. Climate scientists, not generally accustomed to the glare of public policy debate, have found themselves the target of accusations and

1 Integrated assessment models link climate change effects and economic activity and effects in a joint climate and economic model to project climate changes and economic costs and benefits together. For a review of the two dozen or so integrated assessment models, see, NICHOLAS STERN, THE STERN REVIEW ON THE ECONOMICS OF CLIMATE CHANGE 145-152 (2007), available online at http://www.hm-treasury.gov.uk/stern_review_report.htm (hereinafter the "Stern Review"), and Hans-Martin Füssler and Michael D. Mastrandrea, *Integrated Assessment Modeling*, Ch. 14 150-161 in CLIMATE CHANGE SCIENCE AND POLICY (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009).

2 A book *Global Warming for Dummies* is available, but by most indicators, does not seem to be as popular as one would expect it to be. One of the two authors is the leader of the Green Party in Canada, and a former president of Sierra Club Canada. The Amazon.com rank for the book is 1,186,902 (as of December 7, 2010), as opposed to THE ROUGH GUIDE TO CLIMATE CHANGE (2d ed., 2008) by IPCC climate scientist Robert Henson, which ranked 177,658, or THE CLIMATE CRISIS: AN INTRODUCTORY GUIDE TO CLIMATE CHANGE by David Archer and Stefan Rahmstorf (2010) which ranked 72,471.

A Prediction Market for Climate Outcomes

investigations, and sometimes the recipients of death threats.³ In this science policy discussion of supreme importance, it is painfully obvious that more heat than light is emerging from the vast amount of climate information available, and that the lay public has understandably thrown up its hands and tried to not think about climate change. Climate policy has suffered as a result.

This article proposes a way of introducing some organization and tractability in climate science, generating more widely credible evaluations of climate science, and imposing some discipline on the processing and interpretation of climate information. I propose a two-part policy instrument—a tax-and-cap-and-trade program consisting of (1) a carbon tax that is indexed to a "basket" of climate *outcomes* (including, but not limited to temperatures), and (2) nested inside this carbon tax, a cap-and-trade system of emissions permits that can be redeemed in lieu of paying the carbon tax. The amount of the carbon tax in this proposal (per ton of CO₂) would be set each year on the basis of some objective, non-manipulable climate indices, such as temperature and mean sea level, and also on the measured severity of certain climate events, such as hurricanes or droughts, that occurred in the preceding year or some *moving average* of previous years. In addition to setting a carbon tax rate each year, an auction would be held each year for tradable permits to emit a ton of carbon dioxide in separate, specific, future years. That is, in the year 2012, a number of permits to emit in 2013 would be auctioned, as well as a number of permits to emit in 2014, in 2015, and so forth. In 2013, some more permits to emit in 2014 would be auctioned, as well as more permits to emit in 2015, and so forth.

The permits to emit in the future would essentially be unitary exemptions from a future carbon tax: an emitter can either pay the carbon tax or surrender an emissions permit to emit in the specific vintage year. Because of this link between the carbon tax and the permit market, the trading price of the permits should reflect market expectations of what the carbon tax will be in the future, and concomitantly, expectations of future climate outcomes. The idea is to link the price of tradable permits

³ *Climate scientists barraged with death threats*, CLIMATEWIRE, July 7, 2010; Stephen Leahy, *Violent Backlash Against Climate Scientists*, IPS News, March 9, 2010, online: <http://ipsnews.net/news.asp?idnews=50607>; ABCNews.com, *Climate Scientists Receive Death Threats*, May 24, 2010, online: <http://abcnews.go.com/WNT/video/climate-scientists-receive-death-threats-10729457> (accessed February 25, 2011).

A Prediction Market for Climate Outcomes

to future climate outcomes, so that a market is created in which accurate and credible information about future climate conditions are inputs into the price of permits. The market for tradable permits to emit in the future is essentially a *prediction market* for climate outcomes.

In prediction markets, as in futures markets, contracts are bought and sold in which payoffs are contingent upon specified future outcomes.⁴ The trading prices of contracts thus rise and fall with the perceived probabilities of their occurrence. Prediction markets have a fairly long but inconspicuous history of successfully predicting a variety of outcomes, such as electoral outcomes.⁵ The Iowa Electronic Markets project,⁶ one of the pioneers of prediction markets, has long successfully operated a presidential election market in which "shares" of candidates are bought and sold, their trading price proving to be an accurate predictor of their vote share or the probability of their victory. But this proposal goes well beyond what most prediction markets have thus far tried to accomplish: this proposal creates a prediction market against the backdrop of an actual regulatory instrument with very substantial financial implications. The indexed carbon tax proposed here, even though quite modest, will give rise to a prediction market of unprecedented size, and will create unprecedented incentives for information compilation and revelation.

At the same time, the advantages of prediction markets are uniquely useful in processing climate science. First, the ability of prediction markets to aggregate and organize vast, disparate pieces of information is nowhere employed as productively as in the case of climate change. With climate science coming from so many quarters and drawing on information that is local in many ways, prediction markets are a singularly effective way to process the otherwise intractably numerous bodies of climate science. Secondly, prediction markets tap into pecuniary self-interest to process information in a way that is presumptively free of bias or preference for certain outcomes. This advantage is of crucial importance in the climate debate, as climate

4 Prediction markets are really an extension of futures markets, with outcomes taking on a broader range of possibilities. While futures markets usually contemplate the delivery of some agricultural commodity or other resource (such as natural gas), shares in a prediction market can be predicated on any outcome.

5 Discussed *infra*, section II.

6 University of Iowa College of Business, Iowa Electronic Markets, <http://tippie.uiowa.edu/iem/index.cfm> (accessed February 11, 2011).

A Prediction Market for Climate Outcomes

science is not only in need of aggregation and filtering, but also an institution that can scrub out some of the taint of ideology or political manipulation. In the current environment, beliefs about climate change are too intertwined with a variety of economic and professional interests, such that virtually no one can make an assertion about climate change without being accused of having *some* interest—economic, professional, or psychic—in convincing others. In prediction markets, it is simply too costly to sustain a disingenuous position. It is harder to put your money where your mouth is when you do not *truly* believe what you are saying, particularly when market prices are providing constant feedback.

This marriage between the idea of prediction markets and the problem of climate science draws out, as marriages should, the best of each partner. There is no better mechanism for processing climate science than prediction markets, and there is no better way to showcase the power of prediction markets than to apply one to climate science. In climate science, prediction markets have found their heretofore highest and best calling, and in prediction markets, climate science has found its redeemer. While this proposal *could* reduce greenhouse gas emissions, the primary purpose of this proposal is not to regulate or price emissions, but to create a market that harnesses, processes and even creates information about climate science in a way that is presumptively free of ideology and bias.

This tax-and-cap-and-trade mechanism also enjoys a political advantage, which is critical whenever the "tax" word is used. The carbon tax is proposed to be a low one, and increases only if climate change turns out, after all, to be a real problem. By indexing the carbon tax to climate outcomes, it creates a pay-as-you-go policy, requiring payments from carbon emitters as the consequences of their emissions become more tangible and costly. And because the climatic anomalies of climate change will impose costs and in some cases necessitate disaster assistance, the proceeds from the carbon tax and the auction proceeds from the cap-and-trade program can be used to provide this assistance. In this sense, this tax-and-cap-trade program is a pay-as-is-needed policy of assistance. Couched this way as a *funding* mechanism rather than a revenue-grab, it may be easier to sell to a tax-averse public.

Part I of this article provides a background of the information problems that have plagued climate science, and hampered the development of climate policy. Part II of this article provides some background theory

A Prediction Market for Climate Outcomes

and practice of prediction markets. Part III of this article sets forth the proposed policy, setting out the details of the policy proposal, along with some rationales for the many micro-decisions that need to be made to make this proposal work. Part IV addresses some implementation issues created by this proposal, as well as some of the political realities that would be confronted by this proposal. Part V concludes with some summary remarks.

I. Why is Climate Science So Hard?

While public opinion on the seriousness of climate change has fluctuated,⁷ the general public has consistently harbored fundamental misunderstandings about the causes and risks of climate change,⁸ and has maintained an inflated perception of the extent of disagreement among climate scientists.⁹ Why is it that global climate change seems to pose such an insurmountable problem in terms of knowledge dissemination? Hasn't humankind grappled with new and complicated sciences before, like nuclear energy and weaponry, space exploration, and information technology, and eventually wrestled them down to some satisfactory understanding? Why can't people get their heads wrapped around climate change?

Clearly, part of the problem is due to an active campaign waged by a legion of "climate skeptics"¹⁰ of varying credibility, who have

⁷ Lydia Saad, *Did Hollywood's Glare Heat Up Public Concern About Global Warming?* Gallup News Service, March 21, 2007, online: <http://www.gallup.com/poll/26932/Did-Hollywoods-Glare-Heat-Public-Concern-About-Global-Warming.aspx> (accessed December 6, 2010).

⁸ For example, a recent study found that 67 percent of Americans believe that "reducing toxic waste" would reduce global warming, while 43 percent believe that "punching holes in the ozone layer with rockets" contributes to global warming. Yale Project on Climate Change Communication 11-12 (2010), online at <http://environment.yale.edu/climate/files/ClimateChangeKnowledge2010.pdf>.

⁹ See, e.g., Matthew C. Nisbet and Teresa Myers, *Twenty Years of Public Opinion About Global Warming*, 71 *Publ. Opinion Quarterly* 444, 450-454 (2007); Gallup, *Americans' Global Warming Concerns Continue to Drop* (March 11, 2010) online at <http://www.gallup.com/poll/126560/americans-global-warming-concerns-continue-drop.aspx>.

¹⁰ **Is this the author's own term of art? If not, CITE NEEDED.** Climate skeptics is a common term describing people that have doubts about the validity of the science supporting action on climate change. "Skeptic" and "skepticism" are terms that are commonly used by advocates for policy action on climate change (see, e.g. Grist.org, *How to Talk to a Climate Skeptic: Responses to the Most Common Skeptical Arguments on Global Warming*, 2011, online: <http://www.grist.org/article/series/skeptics>, accessed

A Prediction Market for Climate Outcomes

challenged conventional climate wisdom, and scrutinized a broad range of assertions by climate scientists. Some climate skeptics are more serious and thoughtful than others and some raise more legitimate issues than others. The labels "climate skeptics," and "climate scientists" are not intended to suggest that climate skeptics do not include scientists in their ranks. They include M.I.T. climate science Professor Richard Lindzen, an outspoken climate skeptic.¹¹ On occasion, Lindzen has been accused of overselling his climate skepticism,¹² but for the most part, Lindzen's disagreements with climate scientists have mostly been on scientific grounds, much of it having to do with the effect of clouds on climate change.¹³ They also include Roy Spencer, a respected

April 22, 2011; and John Cook, *How climate skeptics mislead*, Skeptical Science, June 13, 2010, online: <http://www.skepticalscience.com/How-climate-skeptics-mislead.html>, accessed April 22, 2011), and by the skeptics themselves (*see, e.g.*, Climate Skeptic, www.climate-skeptic.com, accessed April 22, 2011, and The Climate Sceptics, <http://climatesceptics.net/>, subtitled "The world's first political party representing scepticism and objectivity in climate policy," accessed April 22, 2011).

11 *See, e.g.*, Richard S. Lindzen, *The Climate Science Isn't Settled*, WSJ.com, November 30, 2009, at: <http://online.wsj.com/article/SB10001424052748703939404574567423917025400.html>.

12 Lindzen and several other physics professors once wrote an open letter to Congress titled: "To the United States Congress: You are being deceived about global warming," and claiming, among many other things, that "there is no such evidence, it doesn't exist." July 1, 2009, reprinted on Climate Depot, *Scientists Write Open Letter to Congress*, <http://www.climatedepot.com/a/1745/Scientists-Write-Open-Letter-to-Congress-You-Are-Being-Deceived-About-Global-Warming--Earth-has-been-cooling-for-ten-years> (accessed February 24, 2011). This was sharply criticized by his M.I.T. colleague and fellow Republican, Kerry Emanuel subsequently blogged on a website for the National Association of Scholars that he "confronted the sole climate scientist among the authors with this statement, and he confessed that he did not hold that to be the case. Last I checked, lying to Congress was a federal crime." Kerry Emanuel, *Climategate: a Different Perspective*, National Association of Scholars, July 19, 2010, url: http://www.nas.org/polArticles.cfm?doc_id=1444 (accessed February 24, 2011). On Kerry Emanuel's political affiliation, *see, MIT Professor a 'Rare Example of a Republican Scientist*, GREENWIRE, January 5, 2011. One can reasonably surmise that Lindzen is a Republican, given his connections to the Republican party. *See, e.g.*, History Commons, Profile: Richard Lindzen, February 4, 2004: GOP Memo Offers Advice to Republicans About How to Respond to Questions About the Environment, url: http://www.historycommons.org/entity.jsp?entity=richard_lindzen_1 (accessed February 25, 2011).

13 Lindzen has hypothesized that rising temperatures increase the formation of cirrus clouds which would reflect solar radiation. Richard S. Lindzen, Ming-Dah Chou, Arthur Y. Hous, *Does the Earth Have an Adaptive Infrared Iris?* 82 Bull. Am. Meteorological Soc. 417 (2001). A subsequent study found that the effect of cirrus clouds actually lead to greater warming, not less Bing Lin, Bruce A. Wielicki, Lin H.

A Prediction Market for Climate Outcomes

climatologist at the University of Alabama at Huntsville, who developed a global temperature database based on satellite data.¹⁴ Scientific progress depends on skepticism, and it would be unprincipled to dismiss the challenges posed by Lindzen and Spencer, at least when they are grounded in science.

Skepticism *not* grounded in science, however, has also been a part of the climate debate. This less credible skepticism has either been very selective in attacking climate science, or taken the form of specious allegations of conspiracy or scientific misconduct. The recent "Climategate" affair, in which a number of emails to and from climate scientists were mysteriously stolen and leaked, has raised the suggestion that climate scientists have engaged in data manipulation.¹⁵ Although the scientists implicated in Climategate have been exonerated,¹⁶ doubt seems

Chambers, Yongxiang Hu, and Kuan-Man Xu, *The Iris Hypothesis: a Negative or Positive Cloud Feedback?*¹⁵ *J. of Climate* 7 (2002). Lindzen has also hypothesized that increased sea surface temperatures correspond with higher rates of radiation leaving the Earth's atmosphere. Richard S. Lindzen, Yong-Sang Choi, *On the determination of climate feedback from ERBE data*, 36 *Geophys. Res. Lett.* L16705 (2009). This has been criticized for assuming away energy flows in and out of the tropics. Kevin. E. Trenberth, John T. Fasullo, Chris O'Dell, and Takmeng Wong, *Relationships between tropical sea surface temperature and top-of-atmosphere radiation*, 37 *Geophys. Res. Lett.* L03702 (2010).

¹⁴ Roy W. Spencer & John R. Christy, *Precise Monitoring of Global Temperature Trends from Satellites*, 247 *Science* 1558 (1990).

¹⁵ Reasonably objective accounts of the controversy are the exception, but one credible account was published by the Guardian (UK), not ordinarily known for its restraint, but in a series compiled by the Guardian but incorporating public comments, seems to have most accurately picked out the most salient details: Fred Pearce, *Climate Wars: Guardian Special Investigation*, [Guardian.co.uk](http://www.guardian.co.uk), February 9, 2010, url: <http://www.guardian.co.uk/environment/series/climate-wars-hacked-emails> (accessed February 21, 2011). Some fundamental facts seem to account for much of the controversy: the data that was sought by climate skeptics has been presented in a fashion that would appear opaque, but that the raw data was provided to researchers at the Climatic Research Unit at the University of East Anglia, one of the centers of the controversy, on the condition that they not be publicly disseminated. *Editorial: Closing the Climategate*, 468 *Nature* 345 (2010), doi:10.1038/468345a ("It remains the case that many of the data used by CRU scientists are covered by agreements that prevent their wider distribution... there are often good reasons for such sequestering of data, and some studies might not be done without it. But where the full information needed to reproduce a study is not publicly available, scientists have a duty to report that, and say why."); online: <http://www.nature.com/nature/journal/v468/n7322/full/468345a.html> (accessed February 21, 2011).

¹⁶ See, e.g., The Independent Climate Change Emails Review, July 2010, online: http://www.eenews.net/assets/2010/07/08/document_cw_01.pdf (accessed December 6, 2010); Lauren Morello, *'Climategate' Investigators Find No 'Deliberate' Misconduct by*

A Prediction Market for Climate Outcomes

to persist about the credibility of climate science.¹⁷ Other forms of skeptical nonsense are more substantive. Some skeptics have asserted that global warming is due to increased sunspot activity, or that Arctic sea ice is actually increasing,¹⁸ and mis-cited sources as support for these

Scientists, ClimateWire, April 15, 2010 (citing Report of the Findings of the International Panel set up by the University of East Anglia to examine the research of the Climatic Research Unit, April 14, 2010, online at <http://www.uea.ac.uk/mac/comm/media/press/CRUstatements/SAP>).

17 See, e.g., Anthony Leiserowitz, Edward Maibach, Connie Roser-Renouf & Nicholas Smith, *Global Warming's Six Americas* 9 (fig. 1) (June 2010) online at <http://environment.yale.edu/climate/files/SixAmericasJune2010.pdf> (showing that from November 2008 to January 2010 (spanning the "Climategate" incident) those "alarmed" about global warming decreased from 18% to 10%, and those "dismissive" (not at all concerned about global warming) rose from 7% to 16%. Those figures have rebounded somewhat but remained below 2008 levels, with those alarmed rising back up to 14% in June 2010, and those dismissive dropping back down to 12% (accessed August 7, 2010). See also, Patrick Jonsson, *Climate Scientists Exonerated in 'Climategate' but Public Trust Damaged*, Christian Science Monitor, July 7, 2010, online: <http://www.csmonitor.com/Environment/2010/0707/Climate-scientists-exonerated-in-climategate-but-public-trust-damaged>; David R. Baker, *'Climategate' Fallout May Impact Legislation*, San Francisco Chronicle, July 19, 2010, online: <http://www.sfgate.com/cgi-bin/article.cgi?file=/c/a/2010/07/19/MNNS1EFLDU.DTL>.

18 Many people make these arguments, but as a prominent example, they have been made by Lord Christopher Monckton, a former advisor to British Prime Minister Margaret Thatcher, and policy advisor to a think tank called the Science and Public Policy Institute (<http://scienceandpublicpolicy.org/>). Monckton has asserted, among many other things, that sunspot activity was responsible for global warming, and that we would begin to get global cooling (YouTube, Lord Christopher Monckton Speaking in St. Paul, October 15, 2009, <http://www.youtube.com/watch?v=stij8sUybx0>, at 1:07), and that arctic sea ice has actually been increasing over the last thirty years (U.S. House of Representatives, Committee on Ways and Means, Testimony of Lord Christopher Monckton, Hearing on Protecting Lower-income Families While Fighting Global Warming, March 5, 2009, transcript at <http://waysandmeans.house.gov/Hearings/transcript.aspx?NewsID=10376>). Sunspot activity has been thoroughly debunked as an explanation of global temperature changes (see, e.g., Mike Lockwood, *Solar Change and Climate: an Update in the Light of the Current Exceptional Solar Minimum*, 466 Proc. Royal Soc. A 303 (2010); Anatoliy D. Erlykin, Terry Sloan, Arnold W. Wolfendale, *Solar Activity and the Mean Global Temperature*, 4 *Envtl. Res. Lett.* 014006 (2009); Terry Sloan and Arnold W. Wolfendale, *Testing the Proposed Causal Link Between Cosmic Rays and Cloud Cover*, 3 *Envtl. Res. Lett.* 024001 (2008)), and Monckton's statement that sea ice was declining was based on an inaccurate comparison of two carefully selected years, 1980 and 2009 (for two of several rebuttals to this absurdity, see, Alden Griffith, *Is Arctic Sea Ice 'Just Fine'?* SkepicalScience.com, August 18, 2010, http://www.skepticalscience.com/Is_Arctic_Sea_Ice_Just_Fine.html, and John Abraham, *Abraham Shows Monckton Wrong on Sea Ice*, SkepicalScience.com, June 2, 2010, <http://www.skepticalscience.com/print.php?n=214>).

A Prediction Market for Climate Outcomes

assertions.¹⁹ While spurious claims are relatively easy for scientists to debunk, they are difficult for most others to process. Even spurious claims, some climate skeptics seem to have astutely calculated, muddy otherwise robust conclusions for a lay public with a limited attention span and competing demands for time. An unwitting media industry, conditioned to provide balanced reporting, has given equal time to climate skeptics, credible or not, and has helped to create an exaggerated impression of controversy among reputable climate scientists and experts.²⁰

But it is ultimately self-defeating to focus on the role of climate skeptics in trying to explain why people have trouble understanding climate change. Even without an opposition campaign, the task of communicating and addressing climate change is bound to run into trouble. If there was ever a scientific problem that was tailor-made to create public doubt and confusion, it would be global climate change. This part outlines some of the reasons that climate change is such a difficult problem to study and communicate. They stem from the disparate sources of climate science, the complexity of the science, and the overwhelming temptation for people to resist engagement with the complicated and depressing realities of climate science.

A. Disparateness

One obstacle to broad comprehension lies in the disparate, far-flung sources of climate science, which make it more difficult for the lay public to collate the information. Climate science probably *should* have many origins because climate science draws on so many different sources of information, every ecosystem in every corner of the world having something to teach us about the effects of climate change and potential feedback effects. Studying climate change thus requires an extremely broad research effort; no single institution could undertake even a fraction of the research required to understand the broad impacts and sources of climate change. Moreover, some systems are so complex

¹⁹ Lord Monckton, for example, stated that the International Astronomical Union "held a symposium" on solar activity and "concluded" that solar activity was largely responsible for increases in temperature, a conclusion that was denied by the President of the International Astronomical Union's Division of Sun and Heliosphere. John Abraham, Monckton Chronicles Part II – Here Comes the Sun?, SkepticalScience.com, June 4, 2010, <http://www.skepticalscience.com/print.php?n=216>.

²⁰ Maxwell T. Boykoff & Jules T. Boykoff, *Balance as Bias: Global Warming and the U.S.* Prestige Press, 14 Global Envtl. Change 125 (2004).

A Prediction Market for Climate Outcomes

that multiple research efforts are required just to study one system or one aspect of climate change.

To take just one example, there are no fewer than five U.S. government-funded institutes that have made it their part of their core mission to study or fund the study of climate changes in the polar regions.²¹ And these five entities do not actually perform the bulk of the work; that is mostly left to the hundreds of groups and institutes based in academic institutions worldwide (many of which are funded by these five), such as the National Snow and Ice Data Center based at the University of Colorado;²² the Byrd Polar Research Center at Ohio State University,²³ the International Arctic Research Center at the University of Alaska at Fairbanks,²⁴ the Nordic Network on Sea-Ice Research, based at the University of Helsinki,²⁵ and the Sea-Ice Group at the University of Otago in New Zealand.²⁶ Even collectively, all of these groups are, for lack of a better phrase, just the tip of the iceberg.

There is probably considerable overlap in all of this research. But a time-consuming consolidation would clearly be unhelpful. Some of these entities already cooperate.²⁷ Each group, institute, or department has a unique perspective on the arctic environment, and each probably has something important to contribute as a stand-alone entity conducting arctic research. For example, the National Ice Center in Suitland, Maryland has historically served as a navigational resource, collecting

21 The National Ice Center in Suitland, Maryland, <http://www.natice.noaa.gov/>; the Arctic Climate Research branch of the National Science Foundation, http://www.nsf.gov/news/special_reports/arctic/overview.jsp; the Arctic Research Program of the National Oceanic and Atmospheric Administration, <http://www.arctic.noaa.gov/arp/>; the Arctic Research of the Composition of Troposphere from Aircraft and Satellites program of the National Aeronautics and Space Administration (NASA), http://www.nasa.gov/mission_pages/arctas/; and NASA's Goddard Institute for Space Studies, <http://www.giss.nasa.gov/>.

22 National Snow and Ice Data Center, <http://nsidc.org/>.

23 Byrd Polar Research Center at the Ohio State University, http://bprc.osu.edu/polar_pointers/index.php?category=Sea+Ice.

24 University of Alaska at Fairbanks, International Arctic Research Center, <http://www.iarc.uaf.edu/>.

25 University of Helsinki, Nordic Network on Sea-Ice Research, <http://www.helsinki.fi/netice/#>.

26 Sea-Ice Group, University of Otago <http://www.physics.otago.ac.nz/research/ice/research.html>.

27 The Byrd Polar Research Center at Ohio State University and the National Snow and Ice Data Center are both supported by the Arctic Climate Research branch of the National Science Foundation. <http://nsidc.org/arcss/>

A Prediction Market for Climate Outcomes

data on Arctic and Antarctic ice conditions, and jointly operated by the U.S. Navy, the Coast Guard, and NOAA.²⁸ The day-by-day ice monitoring is a vital information resource that complements, for example, the analytical modeling and forecasting expertise in other agencies. And the diversity of institutions also serve to monitor ice throughout the world, tracking, for example, the recession of glaciers in far-flung corners such as the Himalayas, the Rocky Mountains, and Southern Chile.²⁹ A large, diverse crowd of researchers is a good thing.

But how does anyone make sense of the barrage of information from these hundreds of entities? One institution, the United Nations-created Intergovernmental Panel on Climate Change³⁰ (IPCC), has become a repository of climate research and a leading interpreter of climate science. Because of this leadership role, it has also served as a lightning rod. A relatively small number of errors in the IPCC's two thousand-plus-page 2007 report on the science and policy of climate change³¹ has spurred calls for the dissolution of the IPCC, and not just by climate skeptics.³² But even if the IPCC were not (rightly or wrongly) under assault, it only serves as a rough compiler of climate science, only issuing assessment reports every six or seven years.³³

In the meantime, it is a huge a challenge to keep track of the daily news about climate science developments, even for a dedicated layperson. Even if one is sophisticated and committed enough to subscribe to a

28 National Ice Center, Mission Statement, <http://www.natice.noaa.gov/mission.html?bandwidth=low>.

²⁹ CITE NEEDED there is no specific source for this assertion. The assertion is mine, and I chose these locations because they are from all over.

³⁰ The Intergovernmental Panel on Climate Change ("IPCC") is a United Nations-appointed body of over four hundred scientists engaged in the science of climate change. See, www.ipcc.ch. The IPCC was developed and staffed as part of an attempt to develop some science that was as broadly representative as possible of the divergent viewpoints on climate science. Often criticized, the IPCC was awarded the Nobel Peace Prize, along with former U.S. Vice President Al Gore, in 2007. CITE NEEDED for Nobel Prize assertion. Nobelprize.org, *All Nobel Peace Prizes*, http://nobelprize.org/nobel_prizes/peace/laureates/, accessed April 22, 2011.

³¹ INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS (2007) ("IPCC Fourth Assessment"), available online at http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm#1.

³² John M. Broder, *Scientists Taking Steps to Defend Work on Climate*, N.Y. TIMES, March 2, 2010, at A11.

³³ Assessment reports have been issued in 1990, 1995, 2001, and 2007 (http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml) and the next one is due in 2014 (<http://www.ipcc.ch/activities/activities.shtml>).

A Prediction Market for Climate Outcomes

news intermediary such as Greenwire,³⁴ the daily bombardment of climate research findings is overwhelming. Under these circumstances, it begins to appear rational to delegate some of the information processing to intermediaries, an interpretive vacuum into which interest groups of all types have been happy to fill in a self-serving manner.

B. Complexity and Uncertainty

A second major cause of the climate comprehension problem is the complexity of climate science, and the attendant uncertainties of modeling complex systems. Given the complexities and uncertainties of climate science, we should probably feel fortunate to have a reasonably definitive projection of global mean temperature increase. The best estimate thus far, generated by the IPCC, is that a doubling of CO₂ concentration in the Earth's atmosphere will most likely lead to an increase in global mean temperature of 2° C to 4.5° C.³⁵ But this is a wide range, and within it, a variety of things can happen. At a 2.5° C increase, the Prairie Pothole Region of the Central United States and Canada, home to the most productive waterfowl habitat in the world, will lose almost 40% of its seasonal wetlands; at a 4° C increase, the loss would be more like 85%.³⁶ Given the extraordinary predictions that climate researchers are being asked to make, this example of uncertainty is not unreasonable. But it does not make for easy communications to a mass audience.

Studying climate change is no less than studying how almost every system on Earth reacts to changing concentrations of greenhouse gases, and incorporating them into one gigantic model. Climate models, developed for decades now, essentially try to do this. The most sophisticated climate models, "general circulation models," (GCMs) are so data-intensive that they can only be run on the world's most powerful

34 Greenwire, www.greenwire.com.

35 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS, SUMMARY FOR POLICYMAKERS 38 (2007) ("IPCC Fourth Assessment Summary"), available online at http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Pub_SPM-v2.pdf.

36 This is assuming, as climate models predict, that an increase in temperature is accompanied by an increase in precipitation for the Northern Great Plains. Lisa G. Sorenson, Richard Goldberg, Terry Root, & Michael G. Anderson, *Potential Effects of Global Warming on Waterfowl Populations Breeding in the Northern Great Plains*, 40 *Climatic Change* 343, 359 (fig. 4a, assuming a 7% increase in precipitation).

A Prediction Market for Climate Outcomes

supercomputers.³⁷ GCMs depict the Earth's atmosphere as a three-dimensional grid consisting of cells that are, at present, roughly 100 kilometers square by one kilometer high.³⁸ Each of the resulting billions of cells is governed by a menu of physical, chemical, and biological equations which describe what happens in each cell, as well as a number of equations which describe energy transfers between cells.³⁹ GCMs are validated and calibrated by seeing how well they reproduce *past* temperatures. Climate scientists have reconstructed historical records of temperatures using tree rings, mountain glaciers, coral reefs, and pollen from lake beds,⁴⁰ and reconstructed historical carbon dioxide concentrations from frozen air bubbles in ice core samples.⁴¹ Models are then run as if they were operating in the distant past and trying to predict a future (a more recent past) that climate scientists have already reconstructed. Despite the painstaking validation process, climate scientists have only slightly alleviated concerns about underlying model quality, especially as the historical reconstructions themselves have come under attack.⁴²

Climate modelers readily concede that even the most sophisticated GCMs can only do so much. While the resolution of GCMs is vastly improved from just a decade ago, much can happen within a space 100 kilometers square by a kilometer high. Clouds, for example, are often smaller than a cell, so GCMs have only crudely modeled the behavior of clouds.⁴³ Climate modelers have also struggled to model the impact of aerosols, airborne particles (often pollution) that may reflect sunlight, reducing the amount of solar radiation trapped in the Earth's

³⁷ **CITE NEEDED? Or is this covered in the subsequent citation?** It is covered in the subsequent citation, and on page 23

³⁸ Michael D. Mastrandrea and Stephen H. Schneider, *Climate Science Overview*, Ch. 1 in CLIMATE CHANGE SCIENCE AND POLICY 23 (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009).

³⁹ *Id.*

⁴⁰ Michael D. Mastrandrea and Stephen H. Schneider, *Climate Science Overview*, Ch. 1 in CLIMATE CHANGE SCIENCE AND POLICY 12 (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009).

⁴¹ *Supra*, note 40, at 19, at 16-18.

⁴² Most notably, the "hockey stick" controversy has been a particularly bloody battleground, with some climate skeptics claiming that it is created by academic fraud, and climate scientists rallying around temperature modelers such as the embattled Michael Mann, one of the central figures in the "Climategate" affair. *See*, e.g., notes and text accompanying notes 16-17.

⁴³ *Supra*, note 40, at 24-25.

A Prediction Market for Climate Outcomes

atmosphere.⁴⁴ Alternatively, they may also absorb sunlight and *increase* trapped heat.⁴⁵ Climate modelers have also had to improvise in modeling certain non-anthropogenic events that affect climate, like the 1991 eruption of Mount Pinatubo, which spewed enough volcanic ash into the air to slightly cool global mean temperatures for years.⁴⁶ Every time something happens that affects climate, climate modelers have to scramble to figure out if their models can accurately reproduce the temperature changes resulting from the event. Uncertainties remain large.

Perhaps more importantly, climate modelers concede that GCMs are generally not very good in modeling many *feedbacks* that, as a result of temperature increases, could either amplify or attenuate a temperature increase.⁴⁷ Cloud formation due to higher temperatures, for example, could potentially reflect sunlight and reduce temperatures,⁴⁸ or could trap more heat within the atmosphere, and further increase temperatures.⁴⁹ Models are currently inconclusive in predicting which direction clouds will push temperatures.⁵⁰ Models also struggle with projecting the formation of water vapor, which could increase with higher temperatures,⁵¹ and the emissions of methane, a greenhouse gas twenty-five times more powerful than carbon dioxide,⁵² which could increase catastrophically as higher temperatures melt the Arctic permafrost that has trapped huge quantities of methane.⁵³ That experts *still* have little

⁴⁴ **CITE NEEDED** Michael D. Mastrandrea and Stephen H. Schneider, *Climate Science Overview*, Ch. 1 in CLIMATE CHANGE SCIENCE AND POLICY 19 (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009) (“Unfortunately the uncertainty in aerosol radiative forcing complicates the assessment of ‘climate sensitivity’: the amount the Earth’s surface warms for a given increase in forcing...”).

⁴⁵ *Supra*, note 40, at 19.

⁴⁶ *Supra*, note 40, at 25.

⁴⁷ **CITE NEEDED** Michael D. Mastrandrea and Stephen H. Schneider, *Climate Science Overview*, Ch. 1 in CLIMATE CHANGE SCIENCE AND POLICY 21-23 (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009).

⁴⁸ Lindzen, et al, *supra*, note 13.

⁴⁹ IPCC Fourth Assessment, *supra*, note 31, at 635.

⁵⁰ IPCC Fourth Assessment, *supra*, note 31, at 635.

⁵¹ IPCC Fourth Assessment, *supra*, note 31, at 593.

⁵² Michael D. Mastrandrea and Stephen H. Schneider, *Climate Science Overview*, Ch. 1, 11-28, 23 in CLIMATE CHANGE SCIENCE AND POLICY (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009).

⁵³ Robert Henson, *A Rough Guide to Climate Change* 86 (2d ed., 2008).

A Prediction Market for Climate Outcomes

idea of how much methane is being emitted⁵⁴ is indicative of the huge uncertainties that confront climate scientists.

Climate science has advanced by leaps and bounds in the last several decades. But the world's climate scientists, as a group, are tasked with a continuing research assignment that is so vastly unlike anything ever attempted in the history of humankind. Uncertainty and complexity are naturally going to be parts of this process, which makes for problematic communications to a lay public that may not relish the complexity or have the patience for uncertainty, and might just be looking for a reason to not think about such a depressing subject.

C. The Benefits of Denial

The Bible contains passages which, if taken literally, suggest that Earth is stationary and whatever objects that can be observed from the Earth are the moving objects.⁵⁵ One popular storytelling of Galileo's advocacy of Copernican astronomy would be that Ptolemaic, Earth-centered astronomy was a fundamental part of the teachings of the Catholic Church, which found Galileo's advocacy threatening and convicted him for heresy for contradicting the Church.⁵⁶ However, other versions that are more contextual and sympathetic to the Church emphasize how conventional a wisdom Ptolemaic astronomy was, and how the Copernican, sun-centered astronomy was really a challenge to a very

54 Edward A.G. Schuur, Jason G. Vogel, Kathryn G. Crummer, Hanna Lee, James O. Sickman, and T.E. Osterkamp, *The Effect of Permafrost Thaw on Old Carbon Release and Net Carbon Exchange from Tundra*, 459 *Nature* 556 (29 May 2009); Katey M. Walter, Sergey A. Zimov, Jeff P. Chanton, Dave Verbyla and F. Stuart Chapin III, *Methane Bubbling from Siberian Thaw Lakes as a Positive Feedback to Climate Warming*, 443 *Nature* 71 (2006).

55 See, e.g. Glenn Elert, *The Scriptural Basis for a Geocentric Cosmology*, <http://hypertextbook.com/eworld/geocentric.shtml> (accessed December 3, 2010). The Earth could be understood to stand still from the following passages: "tremble before him, all the earth; yea, the world stands firm, never to be moved." *citing* 1 Chronicles 16: 354) and "Yea, the world is established; it shall never be moved." (*citing* Psalms 93: 571) The sun could be understood to be moving from the following: "Then spoke Joshua to the Lord in the day when the Lord gave the Amorites over to the men of Israel; and he said in the sight of Israel, 'Sun, stand thou still at Gibeon, and thou Moon in the valley of Aijalon.' *And the sun stood still, and the moon stayed*, until the nation took vengeance on their enemies. Is this not written in the Book of Jashar? The sun stayed in the midst of heaven, and did not hasten to go down for about a whole day." (*citing* Joshua 10: 197, emphasis added) (citations obtained from Bible.com).

56 The Galileo Project, *Galileo and the Inquisition* (2003), http://galileo.rice.edu/bio/narrative_7.html (accessed November 10, 2010).

A Prediction Market for Climate Outcomes

broad social and economic order.⁵⁷ Under this version, the Church, with its variety of Papal leaders and its own internal divisions, was more susceptible to outside advocacy than one would think. Galileo's trial could thus be seen as more of a failed campaign than an anti-science persecution.⁵⁸ Climate scientists, like Galileo, face similar challenges as they seek to upend the value judgments implicit in a world economy that has equated fossil fuel combustion with economic growth.

Climate scientists have not had to face an Inquisition as Galileo did, but they have had to face modern versions that are in some ways more disturbing. U.S. Senator James Inhofe, a long-time and vociferous climate skeptic, recently used his office in the Senate Committee on Environment and Public Works, to publish its own specious analysis of climate science, culminating with a list of seventeen climate scientists who, in Inhofe's view, have perpetrated a "fraud" on the public.⁵⁹ The charges have not stuck substantively, but have succeeded in clouding the

⁵⁷ **CITE NEEDED** Douglas O. Linder, *The Trial of Galileo (1633)*, Famous Trials, University of Missouri-Kansas City (2002), <http://www.law.umkc.edu/faculty/projects/ftrials/galileo/galileoaccount.html> (accessed April 22, 2011) ("Copernicus' theory was a challenge to the accepted notion contained in the natural philosophy of Aristotle, the astronomy of Ptolemy and the teachings of the Church that the sun and all the stars revolved around a stationary Earth. In the half-century since its publication, however, Copernicus' theory met mostly with skepticism.").

⁵⁸ Douglas O. Linder, *The Trial of Galileo (1633)*, Famous Trials, University of Missouri-Kansas City (2002), <http://www.law.umkc.edu/faculty/projects/ftrials/galileo/galileoaccount.html> (accessed December 3, 2010); RICHARD G. OLSON, *SCIENCE AND RELIGION, 1450-1900: FROM COPERNICUS TO DARWIN* 16 (2006) (arguing that there is little evidence of Church suppression of astronomical inquiry). One economist has even made the argument that it was the league of astronomy professors that persuaded the Church to quash dissent from the Ptolemaic theory, at that time the dominant theory taught in universities. E. RAY CANTERBURY, *THE MAKING OF ECONOMICS: THE FOUNDATION* 64 (2009).

⁵⁹ U.S. Senate Committee on Environment and Public Works, *Minority Staff Report, 'Consensus' Exposed: the CRU Controversy*, February 2010. The report states that "[i]n our view, the CRU documents and emails reveal, among other things, unethical and potentially illegal behavior by some of the world's preeminent climate scientists," (at 1 and at 29), lists the federal laws that the scientists may be violating (at 30-31), and then lists seventeen climate scientists as "key players" (at 35-37) that it says it is "investigating" for misconduct (at 32). Inhofe has infamously and persistently called global warming a "hoax." *See, e.g.*, Interview with Amanda Little, *James Inhofe, Senate's Top Skeptic, Explains His Climate-Hoax Theory*, Grist.org, February 25, 2010, online at: <http://www.grist.org/article/2010-02-25-james-ihofe-senate-top-skeptic-explains-climate-hoax-theory> (accessed December 6, 2010).

A Prediction Market for Climate Outcomes

reports and its authors.⁶⁰ Even the even-keeled *Economist* called for the resignation of the head of the IPCC, Rajendra Pachauri,⁶¹ the man that American energy lobbyists and the George W. Bush Administration fought hard to install as IPCC president.⁶² Most ominously, some climate scientists have received death threats relating to their climate work,⁶³ including the late Stanford climatologist Stephen Schneider, one of the early pioneers of climate science.⁶⁴

Perhaps even more troubling than the fanaticism behind death threats is the indifference with which much of the global public receives climate science. Even as the IPCC issues more definitive and more worrisome findings, the appetite for legislative action on climate change, particularly in the United States, does not seem to reflect climate scientists' alarm.⁶⁵ Climate scientists believe that the credible and peer-reviewed and climate science yields the inescapable conclusion that climate change presents some very substantial *risks* to human and non-human life, in the present and in the future.⁶⁶ But even with so much at stake, the public reaction among those that even do consider climate change a problem amounts to little more than a shrug.⁶⁷ A popular climate skeptic blog, Climate Audit, posted by retired Canadian mining executive, Steve McIntyre, boasts an incredible audience, claiming

60 Lauren Morello, *Panel Criticizes IPCC Leadership but Upholds Science*, CLIMATEWIRE, September 7, 2010).

61 *Rajendra Pachauri and the IPCC*, ECONOMIST, February 4, 2010.

62 Andrew Revkin, *Dispute Arises Over Push to Change Climate Panel*, N.Y. TIMES, April 2, 2002.

63 *Climate scientists barraged with death threats*, CLIMATEWIRE, July 7, 2010; Stephen Leahy, *Violent Backlash Against Climate Scientists*, IPS News, March 9, 2010, online: <http://ipsnews.net/news.asp?idnews=50607>; ABCNews.com, *Climate Scientists Receive Death Threats*, May 24, 2010, online: <http://abcnews.go.com/WNT/video/climate-scientists-receive-death-threats-10729457>.

64 Stephen Schneider, *The Genesis Strategy: Climate and Global Survival* (1976) and GLOBAL WARMING (1989).

65 Anthony Leiserowitz, *supra*, note 17, at 9 (Fig. 1) (showing that from November 2008 to January 2010, those "alarmed" about global warming decreased from 18% to 10%, and those "dismissive" (not at all concerned about global warming) rose from 7% to 16% (accessed August 7, 2010).

66 **CITE NEEDED** I am sorry, I disagree – this is too general of a statement to support with just one or even a group of cites. I'll find if you insist.

67 For example, the Leiserowitz et al study, *supra*, note 17, reported that among those that were "concerned" about global warming, 15% of respondents reported that they paid "a lot" of attention to global warming, while 53% said they paid "some" and 31% said they pay "a little." Leiserowitz et al at 13. Of the same "concerned" group, 29% said they were "very" interested, while 64% said they were "moderately" interested. Leiserowitz et al at 15.

A Prediction Market for Climate Outcomes

nearly two million hits from September 12 to February 25, 2011.⁶⁸ The large following of McIntyre's blog itself is evidence itself that there are large numbers of the general public that seem to at least be ready to be talked out of the dangers of climate change. Rational or not (McIntyre has never been discredited), it is a current reality that many people distrust the sources of the scientific predictions about future climate conditions.

Climate scientists should not be any more surprised by the apathy than they are by the violence. If climate scientists are right, then the world faces a stark choice: either undertake fundamental changes in the way that almost every economy operates, imposing substantial costs on almost every country and society in the world, or roll the dice and see what happens with the Earth's climate. Avoiding this question by finding fault with the underlying science provides enormous psychic benefits.

D. Reform Proposals

The disparate, complex, and uncertain nature of climate information thus makes it *convenient* for people to find fault with climate science. Who wants to do the work required to keep pace with climate scientists and climate skeptics, only to reinforce the reality of having to choose between two bad options? In fact, in a very selfish sense, it is arguably rational to avoid the pain of reducing greenhouse gases now, on the grounds that centuries of economic history suggest that the future generations that will have to deal with climate change will be much wealthier than the current one.⁶⁹ This is a risky approach, because there is a small (as far as we currently know) but significant chance that climate change could have such catastrophic consequences, and that future generations might not be wealthier after all.⁷⁰ But given the high costs of trying to avoid climate change, this economic uncertainty, coupled with the scientific complexities and uncertainties, make a compelling case for rational denial.

68 Climate Audit, <http://climateaudit.org/> (accessed February 25, 2011).

69 An argument suggested by Thomas Schelling, in *Intergenerational Discounting*, 23 ENERGY POLICY 395 (1995). Schelling would favor, however, foreign aid to help less developed societies begin to build a capacity to adapt to climate change.

70 This is the controversial conclusion reached by the Stern Review. NICHOLAS STERN, THE STERN REVIEW ON THE ECONOMICS OF CLIMATE CHANGE 162-163 (2007); see also, Thomas Sterner and U. Martin Persson, *An Even Sterner Review: Introducing Relative Prices into the Discounting Debate*, 2 REV. ENVTL. ECON. & POL'Y. 61 (2008).

A Prediction Market for Climate Outcomes

Some believe that better communications of climate science can help change minds, by better explaining, the complexities of climate science, and perhaps and placing the uncertainties in a more familiar context. For example, the notion of insurance has sometimes been invoked as a metaphor for reducing greenhouse gas emissions now, and reducing the *risk* of climate change in the future.⁷¹ A collection of prominent climate and social scientists have called for a nonpartisan climate communications initiative to take on some of the intermediary role of interpretation.⁷² Too much discussion of Climategate and other putative scandals has taken on the air of self-defense, which has detracted from discussion of the underlying issues. The thinking would be that a separate communications body that is less personally involved with the science itself may have more success focusing the discussion on the science, rather than the processes that have been impugned by Climategate and other climate skeptics.

Other reforms and oversights have been proposed to bolster the credibility of climate science. In the wake of the few but embarrassing errors in the IPCC Fourth Assessment report, the United Nations created an independent panel to review IPCC procedures for transparency and credibility.⁷³ The panel concurred with the IPCC's scientific conclusions, but was critical of its procedures.⁷⁴ Universities, as well, have investigated claims made against their faculty members accused of manipulating data.⁷⁵

71 European Commission, EU Action Against Climate Change: Leading Global Action to 2020 and Beyond 7 (2008) ("This is a small price to pay to insure ourselves against dangerous levels of climate change"); Martin L. Weitzman, *GHG Targets as Insurance Against Catastrophic Climate Damages*, NBER Working Paper Series, Vol. w16136 (September 2010) available at SSRN: <http://ssrn.com/abstract=1630141>; Stephanie Doster, *Leading UA Scholars Say Early Action is Best 'Insurance Policy' Against Climate Change*, University of Arizona Institute of the Environment, January 12, 2006, online: <http://www.environment.arizona.edu/news/early-action> (accessed December 7, 2010);

72 Thomas E. Bowman, Edward Maibach, Michael E. Mann, Richard C. J. Somerville, Barry J. Seltser, Baruch Fischhoff, Stephen M. Gardiner, Robert J. Gould, Anthony Leiserowitz, Gary Yohe, *Letters: Time to Take Action on Climate Communication*, 130 SCIENCE 1044 (November 19, 2010).

73 United Nations, Non-governmental Liaison Service, Members of UN Climate Oversight Panel Announced, May 5, 2010 (accessed December 7, 2010), online: <http://www.un-ngls.org/spip.php?article2419>.

74 Morello, *supra*, note 60.

75 Pennsylvania State University, RA-10 Final Investigation Report Involving Dr. Michael E. Mann June 4, 2010, online: http://live.psu.edu/fullimg/userpics/10026/Final_Investigation_Report.pdf; The

A Prediction Market for Climate Outcomes

Unsurprisingly, none of these measures have mollified critics or climate skeptics.⁷⁶ It would be fanciful to think that this kind of fiat would change anybody's mind. It has been simple for climate skeptics to attack the review panels in much the same way that they have attacked climate science: that the outcomes were pre-ordained, and that the climate conspiracy includes those that are asked to provide oversight.⁷⁷ It is hard to escape the conclusion that climate skeptics will simply never be convinced by institutional adjustments aimed at making climate science more credible, and would find fodder in efforts to increase transparency. This article thus advocates an entirely different path for evaluating climate science, and proposes to draw on an institution that is truly independent: markets.

II. Prediction Markets

Talk is cheap. Predictions are very cheap. In the public world of climate science, talk and predictions are not only cheap, they are frequently valueless, issued as they are by individuals and organizations with self-serving agendas, and on the basis of questionable information. Quality climate science (and reasonable climate skepticism) is mixed with too much ideology to create an ill broth containing very little informational nutrition.

There is an institution that, while currently suffering through a period of disapproval, is still at least thought to be apolitical, and may still be more confidence-inspiring than climate scientists: markets. The recent global financial downturn has called into question the accuracy of market prices

Independent Climate Change Emails Review, July 2010, and Report of the Findings of the International Panel set up by the University of East Anglia to examine the research of the Climatic Research Unit, April 14, 2010, *supra*, note 16.

⁷⁶ For example, Senator Inhofe and others continue their plans to investigate the IPCC, *supra*, note 59. Lauren Morello, '*Climategate*' Inquiry Vindicates Scientists, ClimateWire, July 8, 2010.

⁷⁷ Climate skeptic Steve McIntyre has lambasted a review of the Climategate emails, chaired by Sir Muir Russell, for report with numerous entries critical of report chair Sir Muir Russell, in a number of entries in his Climate Audit blog (*see, e.g.*, Climate Audit blog entries October 26, 2010, September 11, 2010, July 22, 2010, or July 6, 2010 ("I don't expect the Muir Russell report to be as much of an insult to the public as the Penn State report or the Oxburgh report – both of which set the bar pretty low.")).

A Prediction Market for Climate Outcomes

as an indicator of value. The rational expectations hypothesis⁷⁸ and the efficient markets hypothesis⁷⁹ that have served as ideological and intellectual bases for those that believe in the efficiency of markets as a means of signaling value, are obviously under attack.⁸⁰⁸¹ Robert Schiller's 2000 book *Irrational Exuberance*,⁸² prescient in its understanding of the delirious overvaluations of the dot.com bubble, was published in a second edition in 2005,⁸³ just in time to drop hints of the real estate asset bubble that sunk world markets in 2009. Combined with the Enron scandal earlier this century, in which accounting tricks were parlayed into artificially inflated share prices⁸⁴, traumatic market plunges have cast doubt about whether markets are to be trusted at all. Behavioral economists have long studied systemic divergences from rationality, but it seems that the accumulation of market travails has made it fashionable to find not just exceptions to the rational expectations hypothesis and the efficient markets hypothesis, but to declare that they are "dead," and utterly useless as descriptive theories.⁸⁵

This is hyperbole. Nobody reasonable doubts that markets still largely work. It would be callous to ignore the individual retirement portfolios that have been wrecked by stock market swings, but by and large, investors still entrust the stock market with large chunks of their individual wealth. Every time stock markets have plunged on the heels of a bursting bubble, investors have eventually returned.⁸⁶ And bursting

⁷⁸ John F. Muth, *Rational Expectations and the Theory of Price Movements*, 29 *ECONOMETRICA* 315 (1961); Robert E. Lucas, *Expectations and the Neutrality of Money*, 4 *J. ECON. THEORY* 103 (1972).

⁷⁹ Eugene Fama, *Efficient Capital Markets: A Review of Theory and Empirical Work*, *J. Finance*, 383 (1970).

⁸⁰ John Quiggin, *Rational Manias*, *Out of the Crooked Timber*, July 19, 2004, url: <http://crookedtimber.org/2004/07/19/rational-manias/> (accessed December 7, 2010); David Wighton, *Efficient Market Hypothesis is Dead – for Now*, *The Times*, January 29, 2009, online: <http://business.timesonline.co.uk/tol/business/columnists/article5607960.ece> (accessed December 7, 2010).

⁸¹ **CITE NEEDED.** Perhaps cite to some foundational articles on these two hypothesis, or articles that attack them. See moved footnotes

⁸² Robert J. Schiller, *Irrational Exuberance* (Princeton University Press, 2000).

⁸³ Robert J. Schiller, *Irrational Exuberance* (2d ed., Princeton University Press, 2005).

⁸⁴ **CITE NEEDED** See, e.g., FRANK PARTNOY, *INFECTIOUS GREED: HOW DECEIT AND RISK CORRUPTED THE FINANCIAL MARKETS* 302-304 (2003).

⁸⁵ *Supra* note 80.

⁸⁶ **CITE NEEDED** I think this, too, is a little too general to support with a few cites. How would you want this supported – showing the dips and recoveries of stock

A Prediction Market for Climate Outcomes

bubbles have only spurred calls for regulation; nobody believes that markets inherently do a poor job of allocating capital, at least as compared with the alternatives.

Most importantly for climate science, markets have always been very effective in knitting together disparate pieces of information and transmitting them in the pithy singularity of a price. If well-designed, markets are capable of collecting, filtering, and processing a huge amount of information of varying quality. An illustrative essay by libertarian icon Leonard Read,⁸⁷ *I, Pencil*,⁸⁸ concerns the geneology of a pencil. The reason that Read devotes an essay to the lowly pencil is that there are such a huge number of economic factors that determine how many pencils are made. At one time, one and a half billion pencils were made every year in factories in San Leandro, California, and the markets that determined their production levels were (and remain) enormously complex.⁸⁹ Even a simple pencil has a huge number of inputs, including the wood from cedar trees, the graphite (then mined in then-Ceylon) and clay (then brought into California from Mississippi) used to make the pencil "lead."⁹⁰ As well, there are the labor inputs: the labor at the mills, at the power plants that power the California pencil factories, and at the coffeeshops frequented by truckers hauling cedar logs from Oregon to California sawmills.⁹¹ All of these labor and material inputs have competing uses. The point of the essay is that all of the countless allocative decisions made during the course of the manufacturing of a pencil are implicitly made by *prices*, which signify the scarcity of a commodity or worker, and the importance of competing uses. Market prices, in communicating scarcity, collect, filter, and process the countless pieces of information that go into an implicit, decentralized allocation of resources.

The ability to buy and sell in different quantities also allows markets to *weight* information in accordance to its significance and credibility. If a

indices? One would have to describe the dips as bubbles, and the subsequent recoveries as investor confidence returning. Does not seem worth it to me.

⁸⁷ Read was also the founder of the Foundation for Economic Education, www.fee.org.

⁸⁸ Leonard Read, *I, Pencil: My family tree as told to Leonard Read*, Library of Economics and Liberty, online at <http://www.econlib.org/library/Essays/rdPnc11.html> (accessed August 28, 2010).

⁸⁹ CITE NEEDED. (presumably just "*Id.*") *Id.*

⁹⁰ CITE NEEDED. (presumably just "*Id.*") *Id.*

⁹¹ CITE NEEDED. (presumably just "*Id.*") *Id.*

A Prediction Market for Climate Outcomes

large retailer such as Staples or Office Depot that sells school supplies were to negotiate a contract for pencils, its negotiated prices are likely to reflect a great deal of information and research about the competitive price of pencils. Such a contract would thus likely to be both an important (due to the market size of the retailer) and a credible (due to the likelihood that it negotiated a realistic price) source of information, as opposed to an offer to buy from a previously unknown, potentially fly-by-night stationary store owner.

As Michael Abramowicz explains in his book *Predictocracy*,⁹² markets can also be harnessed to provide non-financial information to improve public decision-making. A *prediction* market is a constructed market in which trades are made on contracts that specify payouts based on specific outcomes. Participating in a prediction market is *betting* on outcomes. Depending on the type of prediction market, "shares" of an outcome are bought and sold, so that the trading prices reflect expectations about the likelihood of that specific outcome ultimately taking place. As briefly noted above, perhaps the best known of the examples of prediction markets are housed at the Iowa Electronic Markets project,⁹³ which for decades has accurately predicted, among other things, political election outcomes. In the Iowa Electronic Markets project, trading in presidential prediction markets can take place on a "winner-take-all" basis, which involve only binary outcomes (Republican winning or Democrat winning the Presidency), in which the contracts traded that pay out a full amount if the outcome occurs and nothing if it doesn't, so that an "Obama share" after the 2008 presidential election would be worth the full payout amount, and a "McCain share" worth nothing. Alternatively, trading can take place on a "share" basis, in which the specified payout is indexed to a continuous number, such as the popular vote share, so that an Obama share was worth 53 cents on the dollar after the election, while a McCain share was worth 47 cents on the dollar.⁹⁴ Either way, trade prices leading up to elections reflect broad expectations about the outcome. As Abramowicz has argued, prediction

92 Michael Abramowicz, *Predictocracy* (2008). For another review of prediction markets, see, Justin Wolfers and Eric Zitzewitz, *Prediction Markets*, 18 J. Econ. Perspectives 107 (2004).

93 Iowa State University, Tippie College of Business, Iowa Electronic Markets, <http://tippie.uiowa.edu/iem/index.cfm>.

94 HistoryCentral.com, 2008 U.S. Presidential Election, 2008 Presidential Elections Popular Vote <http://www.historycentral.com/elections/12008/popularvote2008.html> (accessed December 7, 2010).

A Prediction Market for Climate Outcomes

markets are best justified by the fact that in a prediction market, "traders can profit from information suggesting that the market price is wrong."⁹⁵ In this way, prediction markets harness disparate pieces of information and aggregate them into the price.

The Iowa Electronic Markets project, which has operated to predict a wide variety of outcomes, including many political elections (not just Presidential), has generally been more accurate than polls, and considerably less volatile.⁹⁶ The reason for this is that a prediction market like the Iowa Electronic Markets project seems to do a better job of evaluating the value of new information.⁹⁷ For example, while a poll errantly captures the emotional "bump" after say, a party's nominating convention, a prediction market is likely to have factored into its price the ultimate value of such an anticipated event.⁹⁸ Prediction markets generally do not get excited and overreact.

But Abramowicz argues that much, much more information could be mined for a variety of other purposes. Hewlett-Packard and Eli Lilly, huge companies with critical decisions to make about product lines, have set up internal (i.e., employee) prediction markets to predict future printer sales (in the case of HP) and future pharmaceutical sales (in the case of Eli Lilly).⁹⁹ They were remarkably effective in identifying which products were likely to succeed in the marketplace.¹⁰⁰ Most relevant for purposes of this article, prediction markets can be used to help formulate public policy. Among the public policy applications for prediction markets that Abramowicz calls for are prediction markets for defense and anti-terrorism policy,¹⁰¹ fiscal policy,¹⁰² banking regulation,¹⁰³ and

95 Abramowicz, *supra*, note 92, at 15.

96 JAMES SUROWIECKI, *THE WISDOM OF CROWDS* 18-19 (2004); Joyce E. Berg, Forrest D. Nelson & Thomas A. Rietz, *Prediction Market Accuracy in the Long Run*, 24 *Int'l. J. Forecasting* 283 (2008); Joyce E. Berg, Robert Forsythe, Forrest D. Nelson & Thomas A. Rietz, Ch. 80, pp 742-751 in *Results from a Dozen Years of Election Futures Markets Research*, in *Handbook of Experimental Economics Results* (C.R. Plott and V.L. Smith, eds., Elsevier, 2008).

97 Oleg Bondarenko & Peter Bossaerts, *Expectations and Learning in Iowa*, 24 *J. Banking & Fin.* 1535, 1547-48 (2000).

98 Berg et al, *Prediction Accuracy*, *supra*, note 97, at 293.

⁹⁹ CITE SUROWIECKI, *supra*, note 96, at 221.

100 SUROWIECKI, *supra*, note 96, at 221.

101 Abramowicz, *supra*, note 92, at 46-49.

102 Abramowicz, *supra*, note 92, at 62-63.

103 Abramowicz, *supra*, note 92, at 148-49.

A Prediction Market for Climate Outcomes

mine safety regulation.¹⁰⁴ In all of these cases, Abramowicz argues, prediction markets have advantages over more traditional policymaking processes, because of the potential for the markets to harness information from disaggregated and informed market participants.¹⁰⁵

Abramowicz's suggestion of using prediction markets to predict the number of injuries and deaths at particular mines seems especially prescient in light of the 2010 explosion of a Massey Energy-operated Upper Big Branch mine in West Virginia that killed 29 miners, the worst mine explosion in the U.S. since 1970.¹⁰⁶ During the ensuing investigation, Massey Energy disputed accounts of the Mining Safety and Health Administration officials that cited past violations and illegally high levels of coal dust in the mine at the time of the explosion as causes of the explosion.¹⁰⁷ While prediction markets in these kinds of tragic events have been condemned as "people profiting from terrible things happening,"¹⁰⁸ it is worth wondering about the following proposition: might a prediction market in safety violations (or even injuries) at specific mines – that could have drawn in mining experts with important local knowledge about the Upper Big Branch mine – have *saved* the lives of the 29 miners killed in the Massey explosion?

In appreciating the vast information network embodied in market prices, it becomes apparent how markets can play a role in aggregating and weighting the disparate pieces of climate science. This article proposes to set up a prediction market for future climate outcomes by linking a carbon tax to climate outcomes, and then establishing a market for tradable permits to emit CO₂ that are unitary exemptions from the carbon tax. If greenhouse gas emitters *needed* information about future climate conditions – as they would under this proposal, to evaluate their potential

¹⁰⁴ Abramowicz, *supra*, note 92, at 151.

¹⁰⁵ CITE – probably a *supra* to Abramowicz Yes – at 282

¹⁰⁶ Greg Bluestein & Vicki Smith, *Mine Rescue Effort Turns to Recovery*, MSNBC.com, April 10, 2010, online: http://www.msnbc.msn.com/id/36183425/ns/us_news-life/ (accessed December 8, 2010).

¹⁰⁷ Kimberly Kindy, *Probe into Fatal W.V. Mine Explosion Finds Large Amounts of Volatile Coal Dust*, WashingtonPost.com, September 17, 2010, online: <http://www.washingtonpost.com/wp-dyn/content/article/2010/09/17/AR2010091704242.html> (accessed December 8, 2010).

¹⁰⁸ JAMES SUROWIECKI, *supra*, note 96, at 80 (2004); *see also*, Abramowicz, *supra*, note 92, at 47 (both discussing political criticism of prediction markets that would have allowed trading in events in the Middle East including (but not limited to) terrorist attacks).

A Prediction Market for Climate Outcomes

future carbon tax liabilities – they would become effective collectors of climate information. Together with other emitters that face a potential carbon tax liability, they would likely form a network of information gatherers of climate information. While many amateur climate wonks would continue to pore through reams of daily climate reports, the evaluations of emitting firms would likely take on central importance.

In addition, prediction markets, like markets generally, *weight* the value of information by allowing market participants to vary the amount of money invested. This allows prediction market participants to place a premium on information that they believe to be especially important or credible, and likely to change the expectation of an outcome. This kind of weighting is difficult with an opinion poll. Even surveys that provide a rating scale are vulnerable to variations in how different people express their opinions.

Perhaps most importantly, a prediction market in future climate conditions would force market participants – in the first instance, emitters of greenhouse gases that face a future carbon tax liability – to be extremely discerning consumers of climate science, critically evaluating climate science and the critiques offered by climate skeptics. While some emitters may have an ideological axe to grind in terms of climate policy, it would probably turn out to be very expensive to allow an ideological filter to affect its evaluation of the value of different pieces of climate science. For example, one study showed that while the majority of participants in a prediction market for the 1988 Presidential election were Republican, the predicted outcome was not ideologically skewed toward a Republican result, but accurately predicted the margin of victory by President George H.W. Bush over Michael Dukakis in 1988.¹⁰⁹ Talk is cheap; but prediction markets force participants to back their stated beliefs with money, forcing people to, as Abramowicz puts it, "put their money where their mouth is."¹¹⁰ In the world of climate change, climate scientists and climate skeptics alike, can, instead of lobbing rhetorical grenades at the other, profit by trading on what they believe is superior information. It would not be Pollyannaish to imagine that some of the vitriol characterizing climate debate could be displaced by a discussion of whether the market price for future emissions permits

¹⁰⁹ Robert Forsythe, Forrest Nelson, George R. Neumann, and Jack Wright, *Anatomy of an Experimental Political Stock Market*, 82 Am. Econ. Rev. 1142, 1155-56 (1992).

¹¹⁰ Abramowicz, *supra*, note 92, at 8.

is too high or too low. Complaints that the market price reflects too much optimism or too much pessimism about future climate outcomes could be met with the advice to go and buy or sell some emissions permits.

III. The Tax-and-Cap-and-Trade Proposal

The proposal in this article builds upon two other works. First, Professor Abramowicz's *Predictocracy* features prominently and obviously in this proposal and its policy justifications.¹¹¹ Second, economist Ross McKittrick has proposed an important precursor to this proposal: the idea of a temperature-indexed carbon tax.¹¹²

McKittrick proposed the idea of a temperature-indexed carbon tax in part as a way of introducing a different "referee" for climate science.¹¹³ If temperatures increase, the level of the carbon tax goes up.¹¹⁴ As McKittrick, a climate skeptic, told New York Times columnist John Tierney

"[t]he only people who lose will be those whose positions were disingenuous, such as opponents of greenhouse policy who claim to be skeptical while privately believing greenhouse warming is a crisis, or proponents of greenhouse gas emission cuts who neither understand nor believe the I.P.C.C. projections, but invoke them as a convenient argument on behalf of policies they want on other grounds even if global warming turns out to be untrue."¹¹⁵

McKittrick's clever (and admirably constructive) proposal should be received with several caveats. First, a temperature-indexed carbon tax should not be viewed as a way of neatly internalizing the cost of carbon dioxide emissions. I have argued in my other work¹¹⁶ that a carbon tax is an imperfect, though a first and necessary step towards creating an effective carbon price. Given the current vast and profound

¹¹¹ CITE NEEDED I don't understand the need for a cite to this.

¹¹² Ross McKittrick, *A Simple State-contingent Pricing Rule for Complex Intertemporal Externalities*, 33 ENERGY ECON. 111 (2010)

¹¹³ CITE Id.

¹¹⁴ CITE Id.

¹¹⁵ John Tierney, *Trusting Nature as the Ultimate Referee*, N.Y. TIMES, December 15, 2009, at D1.

¹¹⁶ SHI-LING HSU, THE CASE FOR A CARBON TAX: GETTING PAST OUR HANG-UPS TO EFFECTIVE CLIMATE POLICY (Island Press, forthcoming, 2011)

A Prediction Market for Climate Outcomes

disagreements over the appropriate price of carbon,¹¹⁷ however, it seems unrealistic to believe that any one-to-one correspondence between damages and contemporaneous temperature measurements could be agreed upon. This caveat is not specific, of course, to McKitrick's proposal.

Second, McKitrick's model limits the degree to which temperature could be a nonlinear function of emissions.¹¹⁸ This is problematic, since it is widely believed among climate scientists that nonlinearities may exist in a relationship between emissions and temperature because of a number of potential "tipping points," or "thresholds" may exist beyond which some runaway positive feedbacks could suddenly change the state of the Earth's climate.¹¹⁹ It seems problematic to assume that even in short periods of time, the relationship between temperature and emissions cannot change quickly.

The final caveat to McKitrick's proposal pertains to his temperature index, which he proposes should be a mean annual temperature for the tropical troposphere – the upper atmospheric layers above the band of Earth between 20 degrees north and south of the Equator.¹²⁰ McKitrick offers a reasonable argument that instead of the more intuitive global mean temperature, tropical tropospheric temperature offers better data and a more stable signal.¹²¹ But while this might serve as a reasonable climate "referee," it would not necessarily be a good barometer of the state of the Earth's climate, statically or over a long period of time. As discussed below, a single tropical temperature reading would obscure,

117 This is discussed Section IV, *infra*.

118 McKitrick, *supra*, note 112, at 113 ("[Assumption 2] will not be true if s is nonlinear in the es , in which case it will be true only approximately, where the approximation will depend on how much "curl" s has over time."). McKitrick's model also imposes an assumption of "symmetry," which requires that a lagged marginal effect of emissions on temperature be the same no matter what year. In other words, while a temperature may be more influenced by some years than others, the influence of emissions on temperature ten years (for example) hence will always be the same, no matter the year. McKitrick, *supra*, note 112, at 113.

119 See, e.g., Martin L. Weitzman, *On Modeling and Interpreting the Economics of Catastrophic Climate Change*, 91 *Rev. Econ. & Stat* 1 (2009) (citing and analyzing Margaret S. Torn and John Harte, *Missing Feedbacks, Asymmetric Uncertainties, and the Underestimation of Future Warming*, 33 *GEOPHYSICAL RES. LETT.* L10703 (2006). See also, Damon H. Matthews and David W. Keith, *Carbon-Cycle Feedbacks Increase the Likelihood of a Warmer Future*, 34 *GEOPHYSICAL RES. LETT.* L09702 (2007).

120 McKitrick, *supra*, note 112, at 117-18.

121 McKitrick, *supra*, note 112, at 117-18.

A Prediction Market for Climate Outcomes

among other things, an increase in extremes that could cancel each out when averaged.

Expanding on this last caveat, this article proposes a more general policy of indexing a carbon tax to not just one temperature, but a broader set of non-manipulable climate outcomes. A broader "basket" of climate outcomes, not unlike a consumer price index, might be devised to be a better indicator of the state of the Earth's climate. The effects of climate change on humankind are not necessarily limited to a change in the global mean temperature, though that change in itself is likely a very good proxy for many indirectly harmful effects on humankind, such as those affecting sensitive species and ecosystems. But in thinking about what is directly and immediately worrisome about climate change, a number of other climatic effects leap to mind: (i) temperature *extremes*, so that there will be more extremely hot days that could prove fatal to vulnerable populations and result in forest die-back and forest fires;¹²² (ii) the possibility of more intense hurricanes and tropical storms;¹²³ (iii) the intensification of hydrological cycles, with the dual results that precipitation would become more intense (and less manageable, leading to more flooding and less water storage capabilities) and droughts longer and more severe;¹²⁴ (iv) sea level rises;¹²⁵ and (v) ocean acidification.¹²⁶ All of these effects are thought to be (though not uncontroversially) among the potential and anticipated effects of climate change, and absent a successful geo-engineering effort,¹²⁷ are outcomes that are non-manipulable. All of these effects are directly relatable to significant damages, though adaptation efforts¹²⁸ may alleviate some of the

¹²² CITE

¹²³ CITE

¹²⁴ CITE

¹²⁵ CITE

¹²⁶ CITE

¹²⁷ *Geo-engineering* is a general term used to describe a wide variety of measures aimed at reducing the atmospheric concentration of greenhouse gases, post-combustion or post-release, sometimes by directly removing greenhouse gases from the atmosphere, or reducing the amount of solar radiation that reaches the Earth. For example, one frequently-debated idea involves the promotion of ocean algal growth, which would promote the absorption of carbon dioxide, but would also have numerous side-effects for ocean biology and chemistry and ocean life. A much more innocuous form of geo-engineering involves painting roofs white to reflect sunlight. For a general discussion of geo-engineering, see, ROBERT HENSON, A ROUGH GUIDE TO CLIMATE CHANGE 211-12 (2d ed., 2008). A discussion of geo-engineering is in Section IV, *infra*.

¹²⁸ *Adaptation* is a general term used to describe all forms of adjustment to a climate-changed world the societies may undertake, now and in the future. For

A Prediction Market for Climate Outcomes

damages. For example, developed countries such as the United States could clearly do a better job of protecting its most vulnerable populations from heat waves.¹²⁹ All of these climatic events are monitored internationally, routinely, and reliably, so that even in remote parts of the planet weather anomalies are susceptible of measurement and counting.¹³⁰ Some details on exactly how this index would be constructed are discussed in Section IV, *infra*.

But there is even more that can be done with the idea of an indexed carbon tax. There is no reason to limit the amount of information created by market transactions to *contemporaneous* climate conditions. Because current emissions will contribute to higher future temperatures for centuries,¹³¹ it is important to obtain and evaluate, *right now*, climate

example, building sea walls is a way of adapting to higher sea levels, and has been frequently discussed as a way of protecting New York City from sea level rises. City of New York, PLANYC, Climate Change Initiatives: Launch a citywide strategic planning process for climate change adaptation. Online at http://www.nyc.gov/html/planyc2030/html/plan/climate_citywide.shtml. For a general discussion of adaptation, *see*, Henson, *supra*, note 53, at 299.

¹²⁹ CITE: And possibly a fn explanation? Heat waves kind of come out of nowhere.

Heat waves = high temperature extremes...

¹³⁰ United States Department of Commerce, National Climatic Data Center, Global Hazards, <http://www.ncdc.noaa.gov/sotc/?report=global&year=2010&month=8> (rainfall and flooding data, drought, extreme weather events); United States Department of Commerce, National Climatic Data Center, Global Precipitation Anomalies, <http://wlf.ncdc.noaa.gov/temp-and-precip/ghcn-gridded-prcp.html> (extreme rainfall and drought); United States Department of Commerce, National Climatic Data Center, Global Historical Climate Network, <http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/caption.php?fig=fig1> (showing map of 7,280 temperature monitoring stations throughout world); European Space Agency, Group for High-Resolution Sea Surface Temperatures, <http://www.ghrsst.org/GHRSST-PP-Data-Products.html> (sea surface temperatures); National Aeronautics and Space Administration, Goddard Institute for Space Studies, International Satellite Cloud Climatology Project <http://isccp.giss.nasa.gov/index.html> (data on clouds); National Aeronautics and Space Administration, Goddard Institute for Space Studies, GISS Surface Temperature Analysis, <http://data.giss.nasa.gov/gistemp/graphs/> (global temperatures); Unisys Corporation, Unisys Weather, <http://weather.unisys.com/hurricane/> (hurricanes and tropical storms); International Climate Variability Project, World Climate Research Program, <http://www.clivar.org/organization/extremes/extremes.php> (ocean surface and upper ocean thermal temperatures, global wind data) (all last accessed September 26, 2010).

¹³¹ Carbon dioxide has a residence in the Earth's atmosphere of hundreds of years, meaning that emissions of carbon dioxide now will form part of the Earth's stock of greenhouse gases for millennia, unless that carbon dioxide is removed somehow. *See*, IPCC Fourth Assessment Report: The Physical Science Basis, Frequently Asked Question 10.3, If Emissions of Greenhouse Gases are Reduced, How Quickly do Their

A Prediction Market for Climate Outcomes

science about *future conditions*. Professor McKittrick's indexed carbon tax would do this, but the signal would not be very clear. A temperature-indexed carbon tax, provided that a government is sufficiently committed to maintaining it for a long period of time, would induce emitters to plan for the future, and undertake capital investments that reflect their expectations about what the future temperature will be. When the American Electric Power Company ("AEP"), the largest carbon dioxide emitter in the world,¹³² invests in renewable energy sources such as wind farms, there could well be a reasonable inference that it anticipates a higher temperature in the future. But the signal would be muddled. AEP has, in fact, been investing heavily in renewable energy sources and carbon capture and storage technology.¹³³ But the primary reason for AEP's move towards renewable energies is almost certainly to begin to prepare a behemoth company for a future regulatory environment that will price carbon dioxide emissions. Teasing out the impact of an indexed carbon tax from AEP's other strategic decisions would be difficult. Something more is thus needed over and above the observation of capital investments made putatively in anticipation of a future tax liability.

There is thus a second part to this proposal: a cap-and-trade program for permits to emit a ton of carbon dioxide in future years, the exercise of which would displace the carbon tax liability for emitting one ton of carbon dioxide. Under this second part of the proposal, a batch of permits for each of many future years¹³⁴ will be auctioned off, every year. Once auctioned, the permits would be tradable until, of course, they are exercised in the year of their designated vintage. Emissions permit-trading is now a familiar part of environmental law, having formed the basis of the 1990 Clean Air Act Amendments and its pioneering program

Concentrations in the Atmosphere Decrease? Online:
http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-10-3.html (accessed April 24, 2011).

¹³² This conclusion is derived from running a query on an Excel spreadsheet that is downloadable from the website of the U.S. Environmental Protection Agency's "EGrid" project: <http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html> (accessed and download performed December 10, 2010).

¹³³ *AEP Doubles its Renewable Energy Goal to 2,000 MW*, RenewableEnergyWorld.com, April 29, 2009, online: <http://www.renewableenergyworld.com/rea/news/article/2009/04/aep-doubles-renewable-energy-goal-to-2000-mw> (accessed December 10, 2010).

¹³⁴ The issue of how many years in advance permits will be available is discussed in section IV, *infra*.

A Prediction Market for Climate Outcomes

for a cap-and-trade program for permits to emit sulfur dioxide.¹³⁵ Until recently, when the failure of the U.S. Congress to pass climate legislation torpedoed any potential for carbon credit trading, carbon credits were traded on the Chicago Climate Exchange.¹³⁶ The motivation for this part of the proposal is to tie market activity in tradable permits to future climate outcomes and thereby create a market for information about future climate outcomes. If emitters with future carbon tax liability are rational and risk-neutral, they should be willing to pay for tradable permits a price just slightly less than their anticipated liability under the indexed carbon tax.

This second part of the proposal induces emitters to forecast their own future carbon tax liabilities, and *reveal* their forecasts through the exchange of tradable permits. Such private forecasts are not oracles, of course. But the level of private concern over future climate conditions, as expressed through market prices for permits, is at least an unbiased opinion derived from self-interest.¹³⁷ The price bid by emitters for say, permits to emit in 2020, would speak volumes about private expectations of the consequences of climate change, free from, as climate skeptics claim, conspiracies by climate scientists to shore up their research grant fiefdoms,¹³⁸ or desires by radical environmentalists who really wish to use climate change as an excuse for imposing environmental restrictions.¹³⁹ The market price is a far stronger and clearer signal of future expectations than what would probably be mostly anecdotal information about which firms are worried about and planning for rising temperature taxes.

¹³⁵ Clean Air Act §§ 401 et seq.; 42 U.S.C. §§ 7651 et seq. (1990).

¹³⁶ Chicago Climate Exchange, <http://www.chicagoclimatex.com/> Carbon trading has been suspended in light of the failure of the United States to pass cap-and-trade legislation, or any climate policy at all. *Dwindling Interest to Shutter Chicago Climate Exchange*, GREENWIRE, November 17, 2010.

¹³⁷ CITE

¹³⁸ Roy W. Spencer, *On the House Vote to Defund the IPCC*, Roy Spencer, Ph.D Global Warming Blog, February 19, 2011, url: <http://www.drroyspencer.com/2011/02/on-the-house-vote-to-defund-the-ipcc/> ("The perpetual supply of climate change research money also biases them. Everyone in my business knows that as long as manmade climate change remains a serious threat, the money will continue to flow, and climate programs will continue to grow."). Roy Spencer is a climatologist, and one of the more voices in the skeptic camp that is more respected among climate scientists.

¹³⁹ See, McKittrick quote, text accompanying note 115, *supra*.

A Prediction Market for Climate Outcomes

There is one final benefit of this tax-and-cap-and-trade proposal that is worth emphasizing, as it achieves something unprecedented in *both* enhancing climate science, *and* accomplishing something far more effectively than any previous prediction market has accomplished. This proposal would create *a private market* for information and information processing about climate outcomes. Clearly, emitters with future carbon tax liabilities do not have and would unlikely develop the internal capacity to do their own climate outcome projections. At the same time, a carbon tax liability that is tied to future climate outcomes would compel most emitters to invest some money to investigate the likely extent of their liabilities. This could constitute a major source of funding for a new climate information market.

Those with direct and first-hand information about climate science — mostly climate scientists, but other highly-interested climate change wonks as well—would likely buy and sell permits, along the way aggregating information in an important way. But by and large, the most important traders in a market for permits issued under this proposal will be those carbon dioxide emitters that may have to rely on the permits for their future compliance with a carbon tax scheme, like AEP, the largest carbon dioxide emitter in the United States.¹⁴⁰ In 2005 AEP emitted approximately 161 million tons of CO₂;¹⁴¹ if one assumed a very modest carbon tax that was set to five dollars per ton at current climate outcomes,¹⁴² AEP's annual carbon tax liability would be about \$805 million. If climate outcomes increased by say, twenty-five percent, its annual carbon tax liability would top one billion dollars. All 101 electricity generators in the EPA's Egrid database would have a combined current carbon tax liability (assuming a rate of five dollars per ton of CO₂¹⁴³) of \$8.75 billion.¹⁴⁴

140 Emissions figures can be obtained from an Excel spreadsheet from the EPA's Egrid database, available at <http://www.epa.gov/cleanenergy/egrid/index.htm>. (last accessed September 24, 2010).

141 Obtained from an Excel spreadsheet, "eGRID2007V1_1_year05_aggregation.xls," from the EPA's Egrid database, available at <http://www.epa.gov/cleanenergy/egrid/index.htm>. (last accessed December 13, 2010).

142 The tax level-setting is discussed in section __, *infra*.

143 Egrid also measures methane emissions, which could provide a means for expanding the carbon tax to include methane emissions.

¹⁴⁴ **CITE NEEDED (likely just a reference to the spreadsheet discussed earlier).**

A Prediction Market for Climate Outcomes

Because of the amounts of money involved, it is the participation of large emitters in a cap-and-trade program for emissions futures that is likely to make or break the credibility of climate science. In essence, this proposal uses markets to turn the evaluation of climate science over to those emitters that will potentially rely on those permits for their emitting operations. Environmental advocates may chafe at the notion that the greatest greenhouse gas emitters will have such a large say in evaluating the quality of climate science, but \$8.75 billion is a lot of impetus for honestly evaluating climate science. As for the prickly personalities that debate climate science, Professor McKittrick and other climate skeptics would no doubt be pleased that those guilty of deceit or of shoddy climate science would be punished by being ignored.

IV. Implementation Issues and the Realpolitik of Carbon Taxes

As is the case with all legal policy, the devil is in the details. Whether this proposal succeeds in lending clarity and cohesiveness to climate science, and whether it succeeds in generating new climate information, depends vitally on how it is carried out. This article does not set out to produce a finished, policy-ready proposal, so some details are left to future work. But some principles and considerations are set out here to guide future development and implementation of this proposal. Subparts A and B in this section set out the key parameters in setting up the indexed carbon tax and the cap-and-trade program, respectively. This includes, critically, a discussion of the climate outcomes that would be made a part of the index, leaving some of the details for the Appendix. Subparts C through E in this section address critical questions that pertain to the effectiveness of this program. In closing out this section, subpart F addresses some of the political obstacles faced by this proposal.

A. Establishing the Carbon Tax

Implementing a carbon tax is, as I have argued in my other work, generally easier than setting up a cap-and-trade program.¹⁴⁵ Two fundamental questions, however, must be answered: who will be subject to the tax and how should the tax level be set? This proposal, as well, must answer a third critical question: what climate outcomes should be

¹⁴⁵ SHI-LING HSU, *THE CASE FOR A CARBON TAX: GETTING PAST OUR HANG-UPS TO EFFECTIVE CLIMATE POLICY* (Island Press, 2011).

A Prediction Market for Climate Outcomes

included in the index that determines the level of the carbon tax? This subpart addresses these questions.

1. Who is Subject to the Tax?

A carbon tax is a liability based upon the quantity of carbon dioxide emitted, generally as a tax per ton of carbon dioxide ("CO₂") emitted. The carbon tax would be levied at some point along the chain of distribution of fossil fuels, the main fossil fuels being coal, natural gas, and petroleum, which account for over 80% of all greenhouse gas emissions in the U.S.¹⁴⁶ Where should the carbon tax be levied? There are a number of options. The cleanest option is to require permits far *upstream*, where: (i) coal is mined, (ii) natural gas is processed, (iii) petroleum is refined, and (iv) points of import for each of these fossil fuels.¹⁴⁷ By imposing the tax upstream, comprehensive regulation can be achieved by taxing (or requiring permits of) a relatively small number of entities in the United States:¹⁴⁸ 149 petroleum refiners,¹⁴⁹ 1,406 coal mines,¹⁵⁰ 530 natural gas processors,¹⁵¹ and points of importation. Fortunately, as an economic matter, the economic effects of an upstream carbon tax (or cap-and-trade program) can be demonstrated to be the

146 U.S. Environmental Protection Agency, 2010 U.S. Greenhouse Gas Inventory Report, Executive Summary 5-6 (Table ES-2, Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO₂ Eq. or million metric tons CO₂-Eq: 5,572.8 Mt CO₂ emitted for fossil fuel combustion divided by 6,958.6 Mt CO₂-Eq emitted Total); online: http://www.epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_Chapter2-Trends.pdf (accessed December 22, 2010).

147 This is the proposal put forth by a number of scholars, but most recently by Metcalf & Weisbach, *supra*, note 154.

148 Originally estimated in Metcalf & Weisbach, *supra*, note 154, at 1. An updating of the number of refineries, coal mines, and natural gas processors does not materially change this estimate.

149 U.S. Energy Information Administration, Refinery Capacity Report, Table 1, Number and Capacity of Operable Petroleum Refineries by PAD District and State as of January 1, 2010, online: http://www.eia.gov/pub/oil_gas/petroleum/data_publications/refinery_capacity_data/historical/2010/table1.pdf (accessed December 22, 2010).

150 U.S. Energy Information Administration, Annual Coal Report 2009, Table 1, Coal Production and Number of Mines by State and Mine Type, online: <http://www.eia.doe.gov/cneaf/coal/page/acr/table1.pdf> (accessed December 21, 2010).

151 U.S. Energy Information Administration, Natural Gas Processing: The Crucial Link Between Natural Gas Production and Its Transportation to Market 6 (Table 1: Natural Gas Processing Plant Capacity in the Lower 48 States, 1995 and 2004) online: http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2006/ngprocess/ngprocess.pdf (accessed December 22, 2010).

A Prediction Market for Climate Outcomes

roughly the same (*exactly* the same in theory) as a similarly comprehensive downstream carbon tax (or cap-and-trade program), and the administrative costs considerably less.¹⁵² For heavily-regulated and efficiently-traded energy commodities, tax burdens are passed up and down the chain of distribution with little friction. Pulling Canadian refiners, coal mines, and natural gas processors, and importers into this program would be a sensible extension for a country with a closely-integrated energy infrastructure, and accustomed to being a climate change policy-taker anyway.¹⁵³

A carbon tax could also, without much trouble and administrative expense, be expanded to include a number of other carbon dioxide-emitting activities, and other heat-trapping greenhouse gases.¹⁵⁴ It turns out, for example, that "fugitive emissions" of carbon dioxide from the cement-making process, those related to the chemical process used to ground up raw materials into cement, can be estimated with reasonable accuracy from the amount of lime used in the industrial process.¹⁵⁵ Similarly, regulating emissions from landfills by requiring the monitoring and measurement of emissions of methane, a greenhouse gas 25 times more powerful than carbon dioxide, is thought to be a manageable administrative task.¹⁵⁶ Imposing a carbon tax to cement manufacturers for fugitive emissions and to landfill operators for methane emissions would thus appear to be reasonable extensions. This proposal can thus be easily extended to cover a number of other greenhouse gas-emitting activities.

152 See, e.g., Metcalf & Weisbach, *supra*, note 154; Erin T. Mansur, *Upstream versus Downstream Implementation of Climate Policy*, NBER Working Paper Series, Vol. w16116, June 14, 2010. Available at SSRN: <http://ssrn.com/abstract=1626605> (accessed December 22, 2010).

153 Recently, Environment Canada announced that it would follow the in promulgating a set of greenhouse gas emissions regulations that the United States was implementing pursuant to its Clean Air Act. *Canada Might Follow U.S. EPA's Lead on GHG Permitting – Environment Minister*, Greenwire, November 29, 2010.

154 Gilbert Metcalf and David Weisbach, *The Design of a Carbon Tax*, 24 available on SSRN: <http://ssrn.com/abstract=1324854> (accessed February 14, 2011)

155 The statistical accuracy of carbon dioxide estimation methods is plus or minus 13%, with a 95% level of confidence. U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, p 4-4 – 4-6 (2010); <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>. See also, Metcalf & Weisbach, *supra*, note 154, at 30 (*citing* U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006, 2008*).

156 Metcalf & Weisbach, *supra*, note 154, at 29.

A Prediction Market for Climate Outcomes

2. The Carbon Tax Level

A carbon tax, as noted above, is a tax levied on a per-ton of CO₂ basis. But how much of a tax to levy per ton of CO₂ emissions? A Pigouvian¹⁵⁷ carbon tax would set the level at the amount of marginal social damages for each ton of CO₂ emitted.¹⁵⁸ However, the actual, present-value damages of climate change over the next hundred years or so are sharply disputed among economists studying the economics effects of climate change. Estimates are extremely sensitive to a number of assumptions, most prominently the appropriate discount rate to be used in weighting future costs and benefits.¹⁵⁹ The range of estimates of marginal social damages of a ton of CO₂ is huge: 2005 survey found a range of estimates from zero to over a thousand dollars per ton.¹⁶⁰ The best pair of bookends for the disagreement includes one estimate by economist William Nordhaus (\$7.50 per ton of CO₂)¹⁶¹ and one by Nicholas Stern,

157 A Pigouvian tax is a unitary tax levied to make an emitter pay for the damages caused by its emissions, which are often invisible, or "external" to the emitter. The purpose of a Pigouvian tax is to make emitters face these external, invisible costs, or "externalities," and make them pay – no more, no less. Alfred C. PIGOU, *THE ECONOMICS OF WELFARE* 131-135 (1928). Taxes that reflected the extent of negative externality thus became known as "Pigouvian" taxes. WILLIAM J. BAUMOL AND WALLACE E. OATES, *THE THEORY OF ENVIRONMENTAL POLICY* 21-23 (2d ed., 1988).

158 In theory, if the Pigouvian tax were to exactly price the marginal level of social damages, the tax rate would vary according to how much marginal damage was being imposed, right at that level of emissions. In practice, of course, such a floating rate would be administratively infeasible.

159 A plethora of modeling assumptions make huge differences in marginal damages estimates. One of the most influential studies, by William Nordhaus and Joseph Boyer, estimated in 2000 that the marginal social damages of the emission of one tone of CO₂ was \$2.48 (William D. Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* __ (2000)), and estimate that Nordhaus recently upped to about \$7.50 (WILLIAM D. NORDHAUS, *A QUESTION OF BALANCE* 90 (Table 5-4) (2008)). This contrasts quite dramatically with the estimate obtained by the UK government-commissioned Stern Review, by Nicholas Stern, a former chief economist with the World Bank, which estimated current marginal damages at about \$85/tCO₂ (in 2000 dollars, to provide a comparison with Nordhaus and Boyer) (NICHOLAS STERN, *THE STERN REVIEW ON THE ECONOMICS OF CLIMATE CHANGE* 287 (2007)). A very large part of this disparity can be accounted for by the two studies' difference in discount rates. Stern assume a pure rate of time preference of roughly zero (STERN, at *i*), while Nordhaus uses a more conventional rate of three percent (NORDHAUS, at 95).

160 Richard S.J. Tol, *The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties*, 33 *Energy Policy* 2064, 2068-69 (table 2) (2005).

161 WILLIAM D. NORDHAUS, *A QUESTION OF BALANCE* 90 (Table 5-4) (2008).

A Prediction Market for Climate Outcomes

the author of the UK-commissioned Stern Review (\$85 per ton).¹⁶² A number of methodological differences highlight a sharp intellectual divide between the two eminent economists,¹⁶³ but more than anything, the divide illustrates how challenging it would currently be to try and set a carbon tax at a level at which economists could agree that it constitutes a *comprehensive* policy response to climate change.

In part because of this, my other work has advocated for setting a low carbon tax that would be less controversial, and would serve as just a first step in addressing climate change.¹⁶⁴ Of course, even a small carbon tax is likely to generate political heat, but at least among climate change economists, there is likely to be wide agreement that a small carbon tax is better than nothing.¹⁶⁵ By the same reasoning, I also recommend that this proposal steer as clear as possible of political turmoil by initially setting the carbon tax at a low level. This proposal is not intended to be a climate policy to end all other policies, but to generate a market for climate information. The carbon tax or cap-and-trade liabilities under this proposal would therefore be in addition to that imposed by any other climate policies. Of course, if anomalous climate outcomes that are part of the index became frequent enough, the carbon tax would be pushed higher and become very expensive, and perhaps serve as a regulatory tool after all. But if that turns out to be the case, the costs of compliance would be the least of our worries.

¹⁶² NICHOLAS STERN, *THE STERN REVIEW ON THE ECONOMICS OF CLIMATE CHANGE* 287 (2007). A large part of the difference between the two estimates are due to the difference in assumed discount rates, with Stern using a very low discount rate (STERN, at *i*) and Nordhaus a more conventional one. (NORDHAUS, at 95).

¹⁶³ Both Nordhaus and Stern include estimates of the costs of catastrophic risks, but Stern assumed higher likelihoods and greater costs. The Stern Review included estimates of non-market impacts, which it describes as "impacts on the environment and human health," (STERN, at 143) which would include impacts on wildlife and unpriced effects on human health such as increased spread of disease due to climatic changes (STERN, at 287); Nordhaus finds these costs a bit speculative (NORDHAUS, at 95).

¹⁶⁴ HSU, *supra*, note 116.

¹⁶⁵ CITE. Any sort of support, (interview, article, newspaper) that shows the political and economic reactions to a suggested tax would be good here. A proposal by three think tanks of varying political orientations, the American Enterprise Institute, the Breakthrough Institute, and the Brookings Institution, introduced a "post-partisan" proposal after the collapse of climate proposals in the U.S. Congress in 2010. The proposal emphasized small subsidies and a small carbon tax. Steven Hayward, Jerry Muro, Ted Nordhaus and Michael Shellenberger, *Post-Partisan Power: How a Limited and Direct Approach to Energy Innovation Can Deliver Clean, Cheap Energy, Economic Prosperity and National Prosperity* (October 2010), online: <http://thebreakthrough.org/blog/Post-Partisan%20Power.pdf> (accessed April 26, 2011).

A Prediction Market for Climate Outcomes

A carbon tax in the neighborhood of Nordhaus's \$7.50 estimate of the marginal social damages seems to be a good starting point. A wide range of economists would agree that the marginal social damages are *at least* that and would endorse such a tax level.¹⁶⁶ The indexed carbon tax level should be adjusted for inflation to ensure that prices for tradable permits keep pace with market prices for other goods, thereby keeping constant the budgetary effects of the indexed carbon tax on emitters. Finally, to smooth out some of the potential volatility in this carbon tax, it could be indexed not just to the basket of outcomes from the previous year, but to a *moving average* of the climate outcomes over a period of time. While the moving average period may not, and need not capture very long-term climatic cycles, even an average of the previous five or ten years can smooth out some of the year-to-year variations in weather by diluting the effects of one or more exceptional years.¹⁶⁷

3. Which Climate Outcomes?

In addition to these two basic carbon tax questions, this proposal requires resolution of a third, more complicated matter: construction of the index to which the carbon tax level is linked. Towards this end, the basket of climate outcomes that make up the index should be composed of outcomes that: (i) are non-manipulable; and (ii) are or can be reliably, regularly, and uncontroversially counted or measured. Prediction markets can only function if the outcomes are clearly defined and the rules for adjudication are stable.¹⁶⁸ But beyond these basic reliability criteria, the question of which climate outcomes should be part of the index also forces us to confront the question of what exactly we wish the index to achieve. First, to keep the index focused on climate science, the climate outcomes included in the index should truly be climatological effects, and not second-order ecological events caused by climate changes. Second, the index should capture a broad array of climate conditions, while balancing the impacts that different outcomes will have on the index. That is, the index should provide a measure of all of the ways that climate change will affect humankind, but without over-

¹⁶⁶ CITE. Articles of economists endorsing a tax of a least that level? Don't think I can deliver that. Maybe: HSU, *supra*, note HSU, *supra*, note 116, at 194 (I'm attaching page proofs of my upcoming book)

¹⁶⁷ CITE. Something explaining how moving average smoothes out variation. I think that is kind of basic.

¹⁶⁸ Wolfers & Zitzewitz, *supra*, note 92, at 120.

A Prediction Market for Climate Outcomes

emphasizing any particular way that climate change will affect humankind.

As an example of how climate outcomes should be first-order climatological effects and not second-order ecological effects, one might consider the inclusion of forest fires as a climate outcome. Counting forest fires that become more frequent or more damaging due to warmer and drier weather,¹⁶⁹ counting the forestry industry losses from heat-stressed dieback,¹⁷⁰ or measuring the extent of infestations of pine beetles that have been able to survive the last decade's warmer winter temperatures¹⁷¹ may seem more relevant and more directly connected to human loss. Not only that, but a solid body of research seems to support the notion that a climate-changed future will lead to these ecological outcomes.¹⁷² focusing on outcomes that are more closely linked to the increase in greenhouse gases would ensure that the index is a gauge of the real, unavoidable threats posed by climate change. If the index could be changed by, for example, a widespread change in fire suppression practices, then it would not be an index of climate change, but an index of climate change and how humans respond to it. Similarly, while forest fires and the pine-beetle outbreaks can be reasonably tied to climate change, so can monoculture-dominated forestry practices.¹⁷³ Including second-order outcomes would make for a noisier prediction market in which human interventions could interfere with the market signals on the quality and importance of climate science.

Secondly, some attention should be paid to the relationship among the different climate outcomes that make up the index. Where climate outcomes are not *orthogonal* to each other—where they are statistically or climatically related, some accounting should be employed so that different aspects of the same climate phenomenon are not double-counted or over-weighted. For example, extreme droughts *and* extreme

169 Anthony L. Westerling, *Wildfires*, Ch. 8 in SCHNEIDER et al, *supra*, note 1.

170 Oliver L. Philips, et al, *Drought Sensitivity of the Amazon Rainforest*, 323 *Science* 1344 (2009).

171 Molly O. Baringer, Derek S. Arndt & Michael R. Johnson, *Abstract*, in STATE OF THE CLIMATE 2009 91 *Bull. Amer. Meteor. Soc.* S11 (2010).

¹⁷² *Supra*, notes 169-171.

173 C.S. Holling and Gary K. Keefe, *Command and Control and the Pathology of Natural Resource Management*, 10 *Conservation Biology* 328, (1996); John Nowak, Christopher Asaro, Kier Klepzig, and Ronald Billings, *The Southern Pine Beetle Prevention Initiative: Working for Healthier Forests*, 106 *J. Forestry* 261, 262-63 (2008).

A Prediction Market for Climate Outcomes

rainfall events are both part of the same climate phenomenon: the intensification of the hydrologic cycle,¹⁷⁴ and are thus not orthogonal. Including both extreme rainfalls and extreme droughts in the index is useful, because the two types of events may not occur in lockstep, and will likely occur in different parts of the world, but some underweighting is appropriate. And to some extent, some non-orthogonality will be unavoidable—given the limits of climate science, we may not even know if outcomes are orthogonal or not. But some attention to the relatedness of different climate outcomes is warranted.

Based on these criteria and taking these factors into consideration, the carbon tax should be indexed to the following six types of climate outcomes. A precise weighting of the six climate outcomes is left to future development. Some supplementary discussion of these outcomes is set out in the Appendix.

1. Global mean temperature. The core part of Professor McKittrick's proposal¹⁷⁵ is surely on the mark: if one were to pick just one proxy for the severity of climate change, temperature would almost certainly be the best one. In the simplest physical terms, trapping heat within the Earth's atmosphere means that more energy is staying within the Earth's system, which means that the temperature will rise. Trapped heat will have other effects, so that temperature alone would not form a complete index, but it is surely a fundamental indicator of climate change.

The most general and reliable temperature statistic is the global mean temperature, which is the average temperature, averaged over an entire year and averaged over the entire planet. This is not necessarily a straightforward measurement; weather monitoring in some places in the world is spotty, and because weather stations are irregularly spaced throughout the world, some statistical manipulation is necessary to reconstruct the temperature that evenly represents the whole planet. This has been the source of considerable controversy but, as discussed in the Appendix, should not interfere with the construction of this element of the index.

¹⁷⁴ **CITE NEEDED** Thomas G. Huntington, *Evidence for Intensification of the Global Water Cycle: Review and Synthesis*, 319 *J. Hydrology* 83, 83 (2006).

¹⁷⁵ **CITE NEEDED (likely just referring to an earlier citation)** McKittrick, *supra*, note 112, at 118.

A Prediction Market for Climate Outcomes

It should be noted that because temperature is such a good proxy, it is clearly not orthogonal to other climate outcomes.¹⁷⁶ But this is not a reason to exclude temperature. Some climate outcomes, such as harm to ecosystems and loss of biological diversity, would be difficult to quantify and include in an index. It would thus be appropriate to weight temperature readings to try and reflect these unquantifiable harms that are orthogonal to other climate outcomes.

2. *Days of unusually high or low temperatures.* While global mean temperature is a vital statistic, using just one temperature paints an incomplete picture in several ways. First, it fails to capture the full range of climate effects that are regionally unique. Temperature changes in a climate-changed world will be heterogeneous. Polar regions will probably experience the most dramatic climatic changes,¹⁷⁷ so that a single temperature reading will not quite reflect the degree of change in the polar regions.

Second, climate change is not limited to warming and may impose as much harm from unusually low temperatures as it does high temperatures.¹⁷⁸ Relying only on one temperature tends to allow these two types of opposite extremes to cancel each other out, leading to an underreporting of temperature anomalies that impose harm.¹⁷⁹ Finally, just as positive and negative extremes tend to cancel each other out, time-averaging naturally volatile temperature readings tends to smooth out and conceal the extreme events that are the most serious source of climate harm. High temperature extremes are associated with many costly climate effects, such as forest fires,¹⁸⁰ heat waves that lead to deaths in vulnerable human populations,¹⁸¹ and a variety of ecological

¹⁷⁶ CITE

¹⁷⁷ For example, *see*, Fourth Assessment, *supra*, note 31, at 766-67 (figs. 10.8 and 10.9).

¹⁷⁸ For example, current climate conditions sustain an Atlantic Ocean circulatory pattern that keeps Europe warm by bringing warm air northward from the tropics. One potential effect of climate change would be the shutdown of this circulatory pattern – the Atlantic Thermohaline Circulation – which would plunge much of Europe into uninhabitably cold temperatures. *See, e.g.*, Henson, *supra*, note 53, at 119-122.

¹⁷⁹ CITE. One simple *See* citation could cover this I think.

¹⁸⁰ *Supra*, note 169.

¹⁸¹ It was estimated that the summer heat wave that struck Moscow in 2010 nearly doubled the number of daily deaths. BBC News, *Death Rates Doubles in Moscow as Heat Wave Continues*, August 9, 2010, <http://www.bbc.co.uk/news/world-europe-10912658> (accessed February 16, 2011). Total deaths from the heat wave have been estimated to be 7,000 for Moscow alone and 15,000 for Russia, and decrease Russian

A Prediction Market for Climate Outcomes

effects that impose indirect but potentially large costs upon society.¹⁸² Unusually low temperature extremes as well, widely considered to be a part of climate change,¹⁸³ also impose costs on cities, agricultural industries, and other staples of society that are ill-prepared to deal with cold-weather events such as record frosts and snowfalls.¹⁸⁴ Some statistical transformation needs to be made of the raw temperature data.

The index should include a broad basket of temperature readings from weather stations throughout the world, to capture all of the different regional changes. And to make this data meaningful, the raw temperature readings should be transformed into *counts of days with extreme temperatures*. For each reporting weather station made a part of the index, an annual (or periodic moving average) count should be made of days in which *unusually high* and *unusually low* temperatures are reached. This definition of this climate outcome operationalizes regional variations in climate change, cold as well as hot anomalies, and the truly harmful events—extreme temperature (hot and cold) situations. Further details on quantifying this climate outcome is provided in the Appendix.

3. *Extreme rainfall and drought events.* One of the ironies of climate change is that it will make water, a basic necessity to all forms of life, both more abundant and more scarce. In neither case, however, will it be

GDP by \$15 billion. Lucian Kim and Maria Levitov, *Russian Heat Wave May Kill 15,000, Shave \$15 Billion off GDP*, Bloomberg News, August 10, 2010, <http://www.bloomberg.com/news/2010-08-10/russia-may-lose-15-000-lives-15-billion-of-economic-output-in-heat-wave.html> (accessed February 16, 2011).

¹⁸² For example, damages to wetlands could undermine some of the ecosystem services that are provided, such as water filtration and flood control, and as a feeding ground for migratory waterfowl. Climate change could affect water systems that are major water sources for population centers. And finally, loss of biological diversity worldwide could deprive humankind of a wide variety of ways, such as depriving it of medicinal resources, by disrupting predator-prey relationships so that pests become more prevalent or by allowing some pests to become disease vectors. See, e.g., Rik Leemans, *Ecosystems*, Ch. 4 in CLIMATE CHANGE SCIENCE AND POLICY 57-61 (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009).

¹⁸³ National Oceanic and Atmospheric Administration, *The Fact About Snowstorms and Climate Change*, (no date), url: http://www.noaa.gov/features/02_monitoring/snowstorms.html (accessed February 25, 2011); Henson, *supra*, note 53, at 55-56.

¹⁸⁴ An unusual number of snowstorms affecting New York City imposed substantial costs, including loss of revenue from parking meters buried under snow. Manny Fernandex, *Crime Down, Bills Up: How Snow Affects the City*, N.Y. TIMES, February 10, 2011, at A23.

A Prediction Market for Climate Outcomes

helpful. Climate change will intensify the hydrological cycle, leading to *both* increased instances of flooding and drought, and probably in different places, making water supply management much more difficult (if not impossible).¹⁸⁵ Again, if one were to simply take a total rainfall number as a climate outcome, the aggregated number would conceal the extremes that are most harmful. Part of the index should thus capture the occurrence of precipitation extremes, just as it captures temperature extremes.

Costs from extreme rainfall events and drought in the U.S. could be as much as 0.5 percent of GDP,¹⁸⁶ or about \$70 billion.¹⁸⁷ Of the two, extreme drought seems less manageable as life without water, even with heroic conservation, is impossible. Adapting to extreme rainfall, however, would only be more manageable if infrastructure to capture and store water were dramatically upgraded or fundamentally altered,¹⁸⁸ measures which are probably out of the reach of most developing countries. The different nature of harms of extreme rainfall and drought seems to warrant separate measurement in the index. Again, details on how to define and count extreme rainfall events and droughts are set forth in the Appendix.

4. *Rises in sea level.* If there is one climate outcome that has thrown a scare into people, it is the prospect of rising sea levels that jeopardize trillions of dollars of real estate worldwide.¹⁸⁹ In reality, the most expensive real estate is in developed countries, and developed countries have the resources and the engineering skills to construct sea walls which would be constructed to protect certain cities.¹⁹⁰ While climate

¹⁸⁵ See, e.g., Henson, *supra*, note 53, at 58; Peter Gleick, *Water*, Ch. 6 in CLIMATE CHANGE SCIENCE AND POLICY 75-76 (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009).

¹⁸⁶ Gleick, *supra*, note 185, at 78.

¹⁸⁷ The estimated 2009 GDP of the United States is slightly over \$14 trillion. U.S. Central Intelligence Agency, *The World Factbook, United States*, online: <https://www.cia.gov/library/publications/the-world-factbook/geos/us.html> (accessed January 3, 2011).

¹⁸⁸ CITE support for statement about infrastructure to capture and store water needing updated.

¹⁸⁹ TIM LENTON, ANTHONY FOOTITT, ANDREW DLUGOLECKI, MAJOR TIPPING POINTS IN THE EARTH'S CLIMATE SYSTEM AND CONSEQUENCES FOR THE INSURANCE SECTOR 37 (World Wildlife Fund, Washington D.C., 2009) (estimating a loss of \$1 trillion for New York City alone); (available online at https://www.allianz.com/static-resources/en/press/media/documents/tipping_points.pdf (accessed January 3, 2011).

¹⁹⁰ CITE NEEDED? Id.

A Prediction Market for Climate Outcomes

change may tax the capacity of dikes in the Netherlands, some of which have been designed to withstand 10,000 years' worth of storms,¹⁹¹ some engineering solutions do seem imaginable, if unattractive and possibly uneconomical.¹⁹² Perhaps most ominously, rising sea levels could lead to civil unrest, as some of the most vulnerable populations in low-lying areas such as the Ganges Delta in Eastern India and Bangladesh,¹⁹³ would find permanent migration necessary. Low-lying island countries such as the Maldives and Tuvalu could find it necessary to find entirely new homes for their permanently displaced populace, imposing an entirely new set of economic and diplomatic challenges.¹⁹⁴

Moreover, for larger sea level rises, even some advanced countries will face enormous costs. With a rise of six meters in mean sea level, much of what is presently Florida would be uninhabitable.¹⁹⁵ As there is still a fair amount of disagreement among climate scientists about the range of possible sea level rises attributable to climate change, larger values cannot be ruled out. Climate scientist James Hansen even believes that with a 3° C increase in mean global temperatures, enough glacial melting at the poles could occur to bring on a catastrophic 25-meter increase in mean sea levels,¹⁹⁶ orders of magnitude greater than the IPCC's estimate of 18 to 55 millimeters, or 7 to 23 inches.¹⁹⁷ Few climate scientists share Hansen's level of alarm,¹⁹⁸ but nor is it dismissed as impossible. Apart from the potential for harm from sea level rises, it is this kind of scientific uncertainty that might be best run through a prediction market.

5. *Ocean acidity.* As CO₂ concentrations increase in the atmosphere, oceans absorb much of the carbon dioxide, taking up an estimated 500 gigatons of CO₂, about thirty percent of fossil fuel emissions since

191 Krystian W. Pilarczyk, *Introduction*, 15, *Dikes and Revetments: Design, Maintenance and Safety Assessment* (1998), online: http://books.google.com/books?id=VJhTkRoCbGsC&lpg=PA1&ots=uU_QKk-Y5O&dq=netherlands%20ministry%20dikes&pg=PP1#v=onepage&q=netherlands%20ministry%20dikes&f=false.

¹⁹² CITE. Perhaps give some examples of these engineering solutions or a nice, comprehensive source outlining them? Id.

193 Henson, *supra*, note 53, at 115.

194 Henson, *supra*, note 53, at 112-113.

195 Henson, *supra*, note 53, at 114.

196 James E. Hansen, *Scientific Evidence and Sea Level Rise*, 2 *Env. Res. Letters* 024002 (2007).

197 Fourth Assessment, *supra*, note 31, at 45 (Table 3.1).

198 Henson, *supra*, note 53, at 118.

A Prediction Market for Climate Outcomes

1800.¹⁹⁹ This absorption has come at a cost of increasing the acidity of the ocean, decreasing the mean pH of the world's oceans by 0.1.²⁰⁰ This is a subtle but potentially much more costly and harmful effect than a rise in sea level, as the disruption of marine ecosystems could lead to a crash in marine food chains²⁰¹ that sustain an enormous fraction of the world's population, and currently contributing almost \$250 billion to the world economy.²⁰² Coral reefs, in particular, are believed to be vulnerable to even small changes in acidity, and are believed to play an important role in maintaining biological diversity in oceans.²⁰³ If a severe decline in ocean life and a serious disruption to the marine food chain occurs, the damages would well exceed \$250 billion, since the value of something like food is far greater than what the market price would suggest, especially when it becomes scarce.²⁰⁴ While it is difficult to ascertain how harmful changes in acidity will be to humankind, this is clearly an important climate effect to include in an index.

6. *Hurricanes above a certain intensity level.* Hurricanes are hypothesized to increase in severity with increases in sea surface temperature, and increases in sea surface temperature are believed to be a consequence of the trapping of heat by greenhouse gases.²⁰⁵ But there is

¹⁹⁹ Carol Turley, *Marine Ecosystems*, Ch. 5 in CLIMATE CHANGE SCIENCE AND POLICY 68 (S.H. Schneider, A. Rosencranz, M.D. Mastrandrea & K. Kuntz-Duriseti, eds., Island Press, 2009).

²⁰⁰ Henson, *supra*, note 53, at 124.

²⁰¹ See, e.g., Ulf Riebesell, Ingrid Zondervan, Bjorn Rost, Pillepe D. Tortell, Richard E. Zeebe, & Francois M. M. Morel, *Reduced calcification of Marine Plankton in Response to Increased Atmospheric CO₂* 407 *Nature* 364 (2000); Christopher L. Sabine, et al, *The Oceanic Sink for Anthropogenic CO₂*, 305 *Science* 367 (2005); The Royal Society, *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide*, Policy Document 12/05, online: http://royalsociety.org/Report_WF.aspx?pageid=9633&terms=ocean+acidification (accessed January 3, 2011).

²⁰² Andrew J. Dyck & U. Rashid Sumaila, *Economic Impact of Ocean Fish Populations in the Global Fishery* 12 *J. Bioeconomics* 227, 227 (2010).

²⁰³ Henson, *supra*, note 53, at 125-126.

²⁰⁴ CITE. How is the \$250 billion reached?

²⁰⁵ See, e.g., Judith A. Curry, Peter J. Webster, and G. J. Holland, *Mixing Politics and Science in Testing the Hypothesis that Greenhouse Warming is Causing a Global Increase in Hurricane Intensity*, 87 *Bull. Amer. Meteorological Soc.* 1025, 1032 (2006); Thomas R. Knutson, *Has Global Affected Atlantic Hurricane Activity?* National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, Global Warming and Hurricanes, url: <http://www.gfdl.noaa.gov/global-warming-and-hurricanes> (accessed January 20, 2011); Kerry Emanuel, *Increasing Destructiveness of Tropical Cyclones Over the Past 30 Years*, 436 *Nature* 686 (2005).

A Prediction Market for Climate Outcomes

no current scientific consensus on a link between hurricanes and climate change.²⁰⁶ There is, however, a great deal of attention and research, especially following the publication in 2005 of two articles, one by M.I.T. atmospheric scientist Kerry Emanuel,²⁰⁷ and one by a team at Georgia Tech,²⁰⁸ which coincided with Hurricane Katrina (which has *not* been attributed to climate change). Current thinking among most climate scientists studying the effects of climate change on hurricanes is that climate change may produce more intense hurricanes, but not necessarily more of them.²⁰⁹ An index of climate outcomes may thus include a count of *more severe* hurricanes, not a raw count of all hurricanes.

As discussed above, "deadliness" and "costliness" are not the correct ways to think about *inherent* climate harm. The existence of potential avoidance and mitigation actions, *ex ante* and *ex post*, mean that these measures could be internally inconsistent, varying from one hurricane to the next depending on the irrelevant (climatically) factor of where the hurricanes made landfall.²¹⁰ Nevertheless, if there is a link between hurricanes and climate change, it is one of the few climate outcomes that would be orthogonal to global mean temperature, and would capture a climate harm not captured by other outcomes.

Constructing an index for a carbon tax thus turns out to be a fairly tricky exercise. It raises not only some mundane but also some unexpectedly philosophical questions about climate change that challenge what we fear, know and wish to know about climate change. Answering these

²⁰⁶ Judith A. Curry, Peter J. Webster, and G. J. Holland, *Mixing Politics and Science in Testing the Hypothesis that Greenhouse Warming is Causing a Global Increase in Hurricane Intensity*, 87 Bull. Amer. Meteorological Soc. 1025, 1032 (2006). A significant problem is that the worldwide record of storms is not very long, dating back only to 1851 for U.S. storms, *id.*, and 1949 for global storms, Unisys Corporation, Unisys Weather, Hurricane/Tropical Data, url: <http://weather.unisys.com/hurricane/> (accessed February 25, 2011).

²⁰⁷ Kerry Emanuel, *Increasing Destructiveness of Tropical Cyclones Over the Past 30 Years*, 436 Nature 686 (2005).

²⁰⁸ Peter J. Webster, G. J. Holland, Judith A. Curry, and Hai-Ru Chang, *Changes in Tropical Cyclone Number, Duration and Intensity in a Warming Environment*, 309 Science 1044 (2005).

²⁰⁹ *Supra*, note **Error! Bookmark not defined.**; *supra* notes 206-207.

²¹⁰ **CITE?** Jerry D. Jarrell, Max Mayfield, Edward N. Rappaport, and Christopher Landsea, *NOAA Technical Memorandum NWS TPC-1: The Deadliest, Costliest, and Most Intense United States Hurricanes from 1900 to 2004*, <http://www.aoml.noaa.gov/hrd/Landsea/deadly/index.html> (accessed December 17, 2010).

A Prediction Market for Climate Outcomes

questions with precision is not as important as the overall goal of the proposal—to run climate science through a market filter, and neutralize the political partisanship and disingenuous posturing that has tainted the debate. However, because the problem of climate change is so important, and the stakes so large, it is worth spending some time to get the details of the indexed carbon tax right.

B. The Cap-and-Trade Program

The establishment of a cap-and-trade program to act as essentially a prediction market for future climate outcomes gives rise to the other set of tricky implementation questions. As a cap-and-trade program, it raises the usual implementation questions, plus those that are unique to this program's situation in a carbon tax environment. One of the usual implementation questions is that of which entities should be covered by the cap-and-trade program. For most cap-and-trade programs, being subject to a cap-and-trade program is a burden; in this program, the cap-and-trade program is for permits that represent an exemption to the indexed carbon tax. Permits can thus be redeemed by whomever is subject to the carbon tax. As the indexed carbon tax is proposed to apply upstream to all coal mines, natural gas processors, oil refiners, and fossil fuel importers,²¹¹ then these are the entities that must be allowed to hold permits in lieu of paying the carbon tax. Of course, other entities and other people are allowed to buy and sell permits; this proposal depends vitally on widespread market participation as a means of aggregating the widely disparate pieces of information about climate science. The program scoping question thus resolved by virtue of its link to the carbon tax, this article now turns to the remaining issues involved in setting up the cap-and-trade program: the initial allocation of permits and the timing and quantity of permits to be issued.

1. Initial Allocation of Permits

The first and most obvious implementation question for setting up a cap-and-trade program is how to make the initial allocation of permits. Should they be auctioned or given away for free? If given away for free, should they "grandfathered" on the basis of historical emissions, or on the basis of some other politically-devised method of allocation?²¹² As an economic matter and a distributional matter, auctioning permits is

²¹¹ *Supra*, notes 149-151 and text accompanying.

²¹² Cites; Metcalf & Weisbach, *supra*, note 152.

A Prediction Market for Climate Outcomes

almost always superior to giving them away for free. Not only does the latter effect a transfer from taxpayers to wealthy individuals (shareholders of emitting firms), but also produces some economically distortionary effects.²¹³ As a political economy matter, however, giving away permits to purchase political support, under the guise of "transition relief," is usually viewed as being necessary in order to obtain even a remote chance of legislative passage in the United States.²¹⁴ It is apparently lost on no one that when a cap-and-trade program gives away permits, the legislature is essentially printing money, albeit an undetermined amount.²¹⁵

The cap-and-trade part of this proposal differs from an ordinary cap-and-trade program in two respects that might render the free allocation of permits a little less irresistible, and auctioning a little more politically palatable. First, the carbon tax is to be initially set at a low level, so that the permit prices will be low, and their value as transition relief for emitters concomitantly low. Second, permit prices in this program will not be driven by scarcity as it is in pure cap-and-trade programs, but rather expectations of future climate outcomes. The trading market for permits to emit in the distant future could be very thin. Those emitters given free permits may conclude that the simplest option in the near term is to wait and see what happens in the near- and medium-run. If that turns out to be a common strategy, then the value of those free permits may be quite low. With low prices, it would also make the economic pain of buying permits less acute. A thin trading market would also mean that the market would be missing an important opportunity to collect a valuable piece of information: the auction price. For these reasons, the permits to emit in future years in this proposal should be auctioned rather than given away for free.

213 See, e.g., Dallas Burtraw, Richard Sweeney & Margaret Walls, *The Incidence of U.S. Climate Policy: Alternative Uses of a Cap-and-Trade Auction*, RFF 09-17-REV, Available at SSRN: <http://ssrn.com/abstract=1392251> (accessed December 23, 2010); Hsu, *supra*, note 116, at ____.

214 Hsu, *supra*, note 116, at _____. One of the recent bills floated in the Senate in 2010 was a measure sponsored by Senators Cantwell and Collins, which proposed to auction most allowances and distribute the proceeds to taxpayers. The Carbon Limits and Energy for America's Renewal Act, S. 2877, downloadable from: <http://thomas.loc.gov/cgi-bin/query/z?c111:S.2877>:. (accessed August 4, 2010).

²¹⁵ This statement could benefit from a citation – either a past example or article speaking on cap-and-trade permits. Hsu, *supra*, note 116, at 62.

A Prediction Market for Climate Outcomes

2. How Far in Advance Should Permits Be Available?

As the point of a cap-and-trade program is to process information about future climate conditions, it is important to decide how far in advance permits should be available. Of course, if permits were not tradable, then asking firms to bid on permits many years in advance would seem to ask too much in terms of information.²¹⁶ But it is the information about climate science will be gleaned from the trading activity and prices subsequent to the initial acquisition through auction. Obviously, as the vintage year of a permit approaches, one should expect the price of the permit to be a better estimate of the actual prices, and a better anticipation of climate outcomes. Just as obviously, in evaluating the market signals produced by this program, some consideration must be made of the time value of money. If a firm is buying a permit to avoid a carbon tax thirty or forty years in the future, then it can be expected to discount that future carbon tax liability substantially, paying much less for permits to emit far in the future than they would for permits to emit in the next year or two.

As a starting point, the failed American Climate and Energy Security Act of 2009²¹⁷ (a.k.a. Waxman-Markey, after the co-sponsors) and the American Power Act²¹⁸ (a.k.a. Kerry-Lieberman, after the co-sponsors) contemplated a cap-and-trade system out to 2050. Also, California's AB 32, its landmark climate change legislation, includes a cap-and-trade program, contemplates a reduction of greenhouse emissions by 80%, by the year 2050.²¹⁹ An auction of permits forty years in advance would thus *prima facie* seem reasonable.

There is the objection that such a long time horizon seems Pollyannaish since emitters may not believe that this proposal, if enacted, would stay intact for forty years. If that were the case, then there would be very little interest in bidding for permits more than a few years down the road. Waxman-Markey and Kerry-Lieberman, one might snort, could afford to be unrealistically optimistic because even if one believed that targets in

²¹⁶ CITE. That's an assertion, I don't have a cite

²¹⁷ H.R. 2454, The American Clean Energy and Security Act of 2009, online at http://energycommerce.house.gov/Press_111/20090515/hr2454.pdf.

²¹⁸ H.R. 2454, §321, amending the Clean Air Act by adding section 782(a), (c) & (d) (2009). American Power Act, S. ____ § 2101, amending the Clean Air Act by adding section 781, online: <http://kerry.senate.gov/imo/media/doc/APAbill3.pdf>.

²¹⁹ California Environmental Protection Agency, Air Resources Board, *Cap-and-Trade*, url: <http://www.arb.ca.gov/cc/capandtrade/capandtrade.htm> (accessed April 30, 2011).

A Prediction Market for Climate Outcomes

2050 would remain intact, many near- and medium-term greenhouse gas emission reductions would take place, and those reductions were the most important objective of climate legislation anyway.

The response to this objection is that participation in a program like this would create its own policy stability: those that spend money on buying auctioned permits would oppose an abandonment of a program such as this, as that would leave them with valueless permits. This would especially be true if some emitters or speculators felt that they had been clever enough to have obtained future permits at a low price, and stand to lose out if the program is stopped. Unlike most cap-and-trade programs, this proposal explicitly contemplates making emitters think far in advance, and plan for fairly distant future. Once investments are made in reliance on this program, dismantling it would become politically and perhaps economically costly. So a cap-and-trade program could be designed with a little bit of optimism about the prospects for its survival and credibility. And since the purpose of a cap-and-trade program is to generate and evaluate information about climate conditions with long time horizons, this program would not be useful unless it sold permits for vintage years far in the future. Looking ahead forty years, as did the Waxman-Markey and Kerry-Lieberman bills, does not seem overly optimistic.

3. How Many Permits Should be Available for a Vintage Year?

It is worth being careful about how many permits to make available for each vintage year. A target amount of permits would have to be large enough to create a real market, one that is large enough to mobilize interest in evaluating climate science. The number of available permits should be large enough to ensure a robust market that reveals significant information about opinions of climate science. Nor should the number of available permits be too large. A surfeit of permits could drive the market price below the indexed carbon tax, which would create the risk that this hybrid program would simply morph into a pure cap-and-trade program. This program would lose the benefit of having the cap-and-trade program actually reveals information about opinions of climate science.

This overallocation danger should also be borne in mind when considering the possibility of another, more ambitious climate policy

A Prediction Market for Climate Outcomes

with an explicit goal of reducing greenhouse gases (unlike this proposal, which is primarily aimed at generating information about climate science). Any time, for any reason, if emissions fall below the number of extant permits available, the price of permits will be driven to near zero.²²⁰ For example, if a more ambitious policy drives emissions lower than the number of extant permits under this tax-and-cap-and-trade program, then there will be more permits available than are needed to permit emissions. There would be no scarcity of permits at all, and no prices to generate information about climate science, stripping this proposal of any informational benefits. So determining the extant number of permits to make available involves a moving target, taking into account the possibility of future policy advances that might curtail future emissions.

A little back-of-the-envelope math would help the reader gain a rough idea of how many permits should be available for each year. Consider that world emissions of CO₂ were approximately 29.5 gigatons of CO₂ in 2006, 5.9 of which were emitted by the United States.²²¹ Even if, assuming optimistically that some legislation such as Waxman-Markey comes back to pass in a future Congress and that an 80 percent reduction is achieved, that would still mean that roughly 1.2 Gt of CO₂ would be emitted in the United States in 2050. If the cap-and-trade program issued, say, *a third* of that emissions total, 400 million permits of vintage year 2050 should be made available. In the interests of maintaining some consistency in terms of the amount of climate information generated for each future year, the number of permits available each vintage year should be uniform, necessitating some scheduling of permit auctions. A proposed scheduling is set forth in the Appendix.

Is this enough of a market to meet the program's goals of generating interest from emitters in participating? Assuming just for the purpose of a rough calculation, a trading price of \$5 per permit—that the best forecasts for the indexed carbon tax would be about \$5 per ton—the cap-and-trade program would create a \$2 billion market, \$50 million of which is added each year. As noted earlier, AEP's 2005 emissions annual

²²⁰ CITE. I understand this is logical but it still seems like a cite would be useful. Seems like this is explained in the sentences that follow.

²²¹ World Resources Institute, Climate Analysis Indicators Tool, Yearly Emissions: <http://cait.wri.org/cait.php?page=yearly> (world emissions are obtained by dividing U.S. emissions by its fraction of world emissions) (last accessed September 27, 2010).

A Prediction Market for Climate Outcomes

carbon tax liability about \$805 million,²²² assuming that they do not reduce emissions, and the top 101 emitters about \$8.75 billion.²²³ It could be much higher if dangerous climate outcomes become unexpectedly frequent. That would appear to be enough to mobilize interest in forecasting climate outcomes, and the resulting indexed carbon tax.

Cap-and-trade programs invariably require resolution of a number of design issues. This article proposes the simplest resolutions of two fundamental cap-and-trade design issues: allocation of permits (by auction) and who is covered (everyone, upstream). In addition, this article suggests some parameters for some of the design issues that are specific to this proposal, ones that will determine how useful this program is to aggregating and processing climate science.

C. Competitiveness and Trade Concerns

This proposal has been described as the subject of a piece of national legislation. It could also be a state or provincial program or a regional program among states and provinces. In any case, an important consideration in adopting this proposal is what, if anything, to do about the competitiveness of firms vis-à-vis those outside of the jurisdiction that do not face the costs of a carbon pricing program such as this one. This part addresses this problem, working from an assumption that the program is a national one.

The climate change problem is unique in the overwhelming incentive it produces to free-ride. The harder one country tries to reduce its carbon dioxide emissions by reducing fossil fuel use, the greater downward pressure on fossil fuel prices, due to the resulting decrease in demand; the greater the temptation for other countries, especially developing ones, to snap up the suddenly abundant and cheap fossil fuel.²²⁴ And finally, this proposal would appear to even further exacerbate that cruel dynamic: a carbon indexed to climate outcomes could very increase in part *because* of the emissions of other, non-cooperating countries, since carbon dioxide emissions anywhere contribute to climate changes

²²² Egrid: <http://www.epa.gov/rdee/energy-resources/egrid/index.html>)

²²³ CITE numbers – may be cited previously – if so use a supra cite. *Supra*, note 144.

²²⁴ See, e.g., Shi-Ling Hsu, *A Game-theoretic Model of International Climate Change Negotiations*, __ N.Y.U. Envtl. L.J. __ (2011). Available on SSRN: <http://ssrn.com/abstract=1573054>.

A Prediction Market for Climate Outcomes

everywhere. American industries subjected to this tax-and-cap-and-trade program could wind up paying more carbon taxes *because* China is uncooperative and emitting greater amounts of carbon dioxide.

There are two responses built into the structure of this proposal: (i) the revenues from both the carbon tax and the auction proceeds from the cap-and-trade part can be used for transitional relief; and (ii) this tax-and-cap-and-trade program, if implemented, may provide a legitimate basis for levying a border tax adjustment on imports from countries that do not price carbon.²²⁵

First and foremost, this tax-and-cap-and-trade proposal, like other proposals, creates a source of revenue. As suggested earlier, some of these revenues can be targeted at communities that suffer damages from climate events, or to fund adaptation measures. But another potential use for the revenues is to provide some relief for industries that face competitive pressures from firms in countries that do not price carbon. What little evidence that is able to rise above the hand-wringing suggests that the amount of "offshoring" of both manufacturing and emissions is relatively small, and possibly exaggerated to serve protectionist purposes.²²⁶ Nevertheless, to the extent that this policy could provide some palliative for industries feeling a bit vulnerable, it is an advantage that many other climate policies do not have. Granted, while transition relief provided from the proceeds of this proposal could not make emitters whole, it could provide some incentives and support for carbon-intensive and trade-exposed industries to re-examine old assumptions about the need to emit greenhouse gases. And the revenues available to accomplish this are not trivial; even at a low carbon tax rate of \$5 per ton, if it covered all fossil fuel emissions in the U.S., the combined

²²⁵ This latter consideration does not apply if the proposal is carried out as a state or provincial or regional program.

²²⁶ Trevor Houser, Rob Bradley, Britt Childs, Jacob Werksman, and Robert Heilmayr, *Leveling the Carbon Playing Field: International Competition and US Climate Policy Design* 10 (Peterson Institute, 2008); available online: http://pdf.wri.org/leveling_the_carbon_playing_field.pdf. Only 18 percent of the steel, aluminum, cement, paper, and basic chemicals produced in the world are internationally traded. *Id.*, at 77. Although carbon pricing *could* increase this amount, it is not widely believed among economists to be likely to have much of an effect. Joost Pauwelyn, *U.S. Federal Climate Policy and Competitiveness Concerns: the Limits and Options of International Trade Law*, Working paper, Nicholas Institute for Environmental Policy Solutions 6 (April 2007), online at <http://www.nicholas.duke.edu/institute/internationaltradelaw.pdf>.

A Prediction Market for Climate Outcomes

proceeds from the tax and the cap-and-trade would total about \$25 billion annually at present emission rates.²²⁷ Even a small portion of that could go a long way towards transition relief.

Second, a carbon tax provides perhaps the best legal chance under international trade rules to levy a border tax adjustment on imports from countries that do not price carbon. World Trade Organization panels (and predecessor GATT panels) have had a mixed record when it comes to allowing countries to protect domestic industries disadvantaged by stronger environmental regulations at home.²²⁸ While WTO and predecessor GATT panels have been stingy in permitting trade relief on environmental grounds, based on provisions under the "environmental exceptions" article XX,²²⁹ they have been somewhat less skeptical when reviewing border tax adjustments under Article II.²³⁰ Article II.2(a) of the General Agreement on Tariffs and Trade (GATT) provides that GATT's prohibitions on tariffs do not prevent a country "from imposing at any time on the importation of any product... a charge equivalent to an *internal tax* ... in respect of the like domestic product or in respect of an article from which the imported product has been manufactured or produced in whole or in part."²³¹ "Internal taxes" are commonly interpreted as including sales taxes, excise taxes, or value-added taxes.

The question is thus whether a carbon tax could be likened to other "internal" taxes that would justify a border tax adjustment under Article II. The international trade jurisprudence, such as it were, is sketchy and incomplete. From the literature that has emerged on this possibility, the consensus is a resounding "maybe."²³² What does seem clear, however, is that a carbon tax is less vulnerable to a WTO challenge than many

²²⁷ **CITE NEEDED**

²²⁸ Daniel C. Esty, *Bridging the Trade-Environment Divide*, 15 J. ECON. PERSP. 113, 114 (2001); George Hoberg, *Trade, Harmonization, and Domestic Autonomy in Environmental Policy*, 3 J. Comp. Pol'y Analysis 191, 195-207 (2001).

²²⁹ General Agreement of Tariffs and Trade, Art. XX (1948).

²³⁰ Pauwelyn, *supra*, note 226, at 2.

²³¹ General Agreement of Tariffs and Trade, Art. II (1948).

²³² Houser, et al, *supra*, note 226, at 30; Pauwelyn, *supra*, note 226, at 17-23; Roland Ismer & Karsten Neuhoff, *Border Tax Adjustment: a Feasible Way to Support Stringent Emission Trading*, 24 Eur. J. Law & Econ. 137, 143-49 (2007); Gavin Goh, *The World Trade Organization, Kyoto, and Energy Tax Adjustments at the Border*, 38 J. World Trade 395, 422-23 (2004); GARY CLYDE HUFBAUER, STEVE CHARNOVITZ, AND JISUM KIM, GLOBAL WARMING AND THE WORLD TRADING SYSTEM 39-46 (2009). *But see*, DANIEL, C. ESTY, GREENING THE GATT—TRADE, ENVIRONMENT AND THE FUTURE. 168 (1994).

A Prediction Market for Climate Outcomes

other climate policies, in that it seeks to equalize a tax burden across trade borders. For cap-and-trade programs in which allowances are distributed for free, either on the basis of historical emissions or on some other politically-derived formula, it would be difficult to make the case that a border tax adjustment sought to equalize a burden, since domestic emitters would already be benefitting from free allowances. In this regard, this tax-and-cap-and-trade program, insofar as it imposes unambiguous, unitary charges, would be a better platform from which to justify a border tax adjustment than other policies.

At least on an international level, then, this tax-and-cap-and-trade proposal would thus appear to have some economic resources and legal footing on which to address competitiveness and trade concerns. Even if such concerns are exaggerated, it cannot be an inefficient move to equalize carbon pricing burdens across borders, and could well prove to be helpful in recruiting international cooperation on greenhouse gas emissions reduction.

D. How Well Will the Market Work?

As noted earlier, recent market travails have cast a shadow over markets as allocative mechanisms.²³³ More so than in the past, people distrust market prices as fundamental indicators of inherent value.²³⁴ In the long run, however, markets still provide the best chance of ascertaining value. There is still no institution that more *rationally* evaluates value.

One objection is that irrationalities do creep into market evaluations, and the outcome can be spectacularly bad.²³⁵ When analysts' valuations are *systemically* errant—when they are systemically based on other analysts' errant evaluations—assumptions of widespread rationality break down and a long chain of inaccurate valuations cascade throughout a market, skewing prices. When a critical piece of corrective information finally emerges, prices can be crushed almost instantaneously in an electronic era. But systemic error can persist for a long time before a correction. As

²³³ CITE NEEDED. Internal citation. *Supra*, Section II.

²³⁴ CITE NEEDED. *Supra*, Section II.

²³⁵ CITE. Perhaps to someone who makes this argument well? Or an article that summarizes it? SUROWIECKI, *supra*, note 96, at 41-43 (2004).

A Prediction Market for Climate Outcomes

Keynes famously remarked, "[m]arkets can stay irrational longer than you can stay solvent."²³⁶

According to James Surowiecki, the author of the book *The Wisdom of Crowds*, the danger of systemic and cascading breakdowns in market accuracy emerges when evaluations lose independence from each other.²³⁷ The strength of markets and the advantage of the many are only present when a diverse body of people, thinking *independently*, make their own evaluations. Independence is so important because it ensures that "groupthink" does not form, and that ideas are genuinely tested before individuals begin to adopt them.²³⁸

In this way, a prediction market in future climate outcomes—the cap-and-trade program—would make virtue out of the exasperatingly deep divide between climate scientists and climate skeptics. Climate skeptics would, in all likelihood, make the market for climate information *better*, even if in the end they are proven wrong in their skepticism (obviously, climate skeptics would substitute the word "scientists" for "skeptics" in the previous sentence). It is the intellectual *challenge* posed to ideas that strengthen them. This was the way that the concept of the marketplace for ideas was supposed to work.²³⁹ Something seems to have gone wrong in the marketplace for climate ideas, and a prediction market is likely to at least improve the situation. Because climate science and climate skepticism are both brutally cross-examined, a market in climate science would seem to be a poor host for *systemic* errors.

Markets can, in addition to suffering systemic error, be subject to conscious manipulation. Abramowicz discusses the possibility of market manipulation and reviews the literature on market manipulations,

²³⁶ Maureen O'Hara, *Bubbles: Some Perspective (and Loose Talk) from History*, 21 Rev. Financ. Stud. 11, (2008).

²³⁷ CITE to Surowiecki SUROWIECKI, *supra*, note 96, at 41-43 (2004).

²³⁸ SUROWIECKI, *supra*, note 96, at 41-43 (2004).

²³⁹ The widely-used market metaphor to support legal arguments for the First Amendment right to freedom of expression is attributed to a dissenting opinion by Justice Oliver Wendell Holmes, in *Abrams v. United States*, 250 U.S. 616 (1919), but was never actually used by Holmes. In *Keyishian v. Board of Regents*, another U.S. Supreme Court case, this one involving the constitutionality of university requirement that its faculty members certify that they were not Communists, Justice Brennan wrote that "[t]he classroom is peculiarly the 'marketplace of ideas.' The Nation's future depends upon leaders trained through wide exposure to that robust exchange of ideas which discovers truth 'out of a multitude of tongues, [rather] than through any kind of authoritative selection.'" 385 U.S. 589, 603 (1967).

A Prediction Market for Climate Outcomes

particularly in prediction markets.²⁴⁰ His tentative conclusion is that in markets possessing a great deal of public information, the empirical evidence does not support a fear of long-term effects from manipulation.²⁴¹ If that is the case, then climate science, deriving mostly from published data and analysis, should be a market that is uniquely insulated from manipulation.²⁴² Would-be manipulators would be faced with trying to move prices in the face of an enormous amount of information, far more information that is ever made public with regard to the millions of publicly-traded firms whose shares are traded throughout the world.

A brief thought experiment in imagining a market for climate outcomes would provide some reassurance that a prediction market in climate science would be even less susceptible of manipulation. The findings and assertions of climate science are almost completely public (even if climate skeptics charge that climate scientists have been secretive about their data). Under the Abramowicz analysis of prediction markets, this predominance of public information would pose a significant obstacle for market manipulators hoping to bias a perception. The task of biasing opinion for a long enough period of time to profit would be enormously difficult as it would be facing a barrage of countervailing assertions every day (from both climate scientists and climate skeptics). While some industry groups and ideological groups have succeeded in biasing public opinion against concern about climate change,²⁴³ convincing those with a material interest in accuracy—such as AEP, with its potentially billions of dollars of annual carbon tax liability—would be an entirely different matter with a continuing trove of research being produced daily.

Second, the sheer size of just a domestic U.S. market would make sustained market manipulation exorbitantly costly. By the rough back-of-the-envelope calculations above,²⁴⁴ a market of about \$2 billion for *each vintage year*, and with a huge number of market participants likely to trade in emissions permits, it is inconceivable that anybody would find it worthwhile to try and sway the market in any meaningful fashion.

²⁴⁰ Cite to Abramowicz. Abramowicz, *supra*, note 92, at 28-32.

²⁴¹ Abramowicz, *supra*, note 92, at 28-32.

²⁴² CITE. Support for this connection would be nice, or at least an explanation of how this connection was made.

²⁴³ See, e.g., Boykoff & Boykoff, *supra*, note 20.

²⁴⁴ Text accompanying note 222, *supra*.

A Prediction Market for Climate Outcomes

Finally, for a cap-and-trade program whose value is indexed to a large *basket* of climate outcomes, one would have to not only skew one piece of information, but manipulate information about three or four or five climate outcomes.

Perhaps most relevantly, the few emissions permit markets that have been implemented thus far have shown no signs of either manipulation or cascading breakdowns due to systemic bias and error.²⁴⁵ The SO₂ trading program has never drawn suspicions of market manipulation, even while attracting a considerable number of speculators that were not involved in the electricity generating industry at all.²⁴⁶ Nor have other subsequent programs, such as the European Union Emissions Trading System or the much smaller (and therefore potentially vulnerable) Regional Greenhouse Gas Initiative, involving only power plants in ten northeastern U.S. states.²⁴⁷ Prices have in some cases been volatile,²⁴⁸ and the source of consternation for some investors, but in no instance has a price movement been sustained for a long time or been cause for suspicion.

Finally, a question related to systemic error and manipulation is the question of whether there is enough information on which to trade. Is there or would there be enough climate science on which to trade? On what basis would firms buy permits to emit forty years in the future?

In thinking about this problem it is worth bearing in mind that not only do markets knit together disparate information, and not only create incentives to reveal information, but also create incentives to generate *new* information.²⁴⁹ Beyond public monies, private firms have already begun to get involved in the climate monitoring business.²⁵⁰ The prospect of more climate information may seem daunting to those already inundated by climate science, but few climate researchers, even

²⁴⁵ It's difficult to prove a negative but a cite would be good here. It is difficult to prove a negative. Since no one has tried, I don't have a cite.

²⁴⁶ A. DENNY ELLERMAN, ET AL., *MARKETS FOR CLEAN AIR* ____ (2000); Jacob Kreutzer, environmentalists and speculators? 62 *NYU Annual Survey of American Law* 138?

²⁴⁷ Regional Greenhouse Gas Initiative, <http://www.rggi.org/home>.

²⁴⁸ Hsu, *supra*, note 116, at 71.

²⁴⁹ CITE. *Supra*, notes 87-91 and text accompanying.

²⁵⁰ Lauren Morello, *Measuring Greenhouse Gases, a New Business Venture*, *ClimateWire*, January 12, 2011.

A Prediction Market for Climate Outcomes

as they advocate for strong policies to reduce greenhouse gases, would deny that huge data gaps remain.²⁵¹

Again, because of the unprecedented size of this prediction market, the demand for new and better and more predictive climate science will become apparent. Future multi-billion-dollar carbon tax liabilities, even when discounted, will draw in even more climate researchers, potentially working in areas in which climate science is currently somewhat sketchy, or areas in which funding agencies may have completely overlooked.

It is also worth bearing in mind that publicly-traded stocks are traded robustly, and are based upon long, long-term projections of profitability that may seem unrealistic.²⁵² Google currently has a market capitalization of about \$200 billion,²⁵³ with revenues of only \$27 billion, and net income available to common shareholders of about \$8 billion.²⁵⁴ In such a fast-moving industry, what exactly makes people think Google's profitability is so sustainable for five, ten, twenty or forty years, as to warrant this size of investment, especially in a rapidly changing industry such as information technology? How do people even hazard a guess as to what the industry will look like two or three decades from now, and whether Google will even exist, let alone be as dominant then as it is now? Analysts will cite statistics and compare Google's figures with that of other companies, but in the end, investors believe that somehow, this company is sustainable for many years.

In markets, we cope with uncertainty by somehow taking our best guesses. This is what is needed in climate science. The lack of a credible institution that forces us to take our best guess about future climate conditions, in the face of uncertainty, is precisely the problem with climate policy. Are the data flaws so great, so that costly action is premature, as the climate skeptics argue, or are the risks so great that much more immediate action is warranted, as climate scientists generally

251 Quinn Schiermeier, *The Real Holes in Climate Science*, 463 *Nature* 284 (2010) ("Researchers say it is difficult to talk openly about holes in understanding. 'Of course there are gaps in our knowledge about Earth's climate system and its components, and yes, nothing has been made clear enough to the public,' says Gavin Schmidt, a climate modeller at NASA's Goddard Institute for Space Studies in New York...").

252 SUROWIECKI, *supra*, note 96, at ___.

253 Yahoo! Finance, Google, Inc., <http://finance.yahoo.com/q/ks?s=GOOG> (accessed January 17, 2011, print view on file with author).

254 *Id.*

A Prediction Market for Climate Outcomes

argue? Doing nothing is the default policy. Doing nothing is also the stock market's equivalent of stashing one's money in their mattress, a myopic strategy that almost every investor recognizes as a sure-fire money-loser.

E. What Kinds of Information Will Be Reflected in Trading Activity?

Although the primary purpose of this proposal is to process, evaluate and generate climate science, the trading activity of future permits will also reflect the emergence of other important pieces of information. Many kinds of events, not just scientific discoveries about climate science, have the potential to affect forecasts of the number and frequency of dangerous climate outcomes. This section discusses some of the types of events that may affect trading prices. These effects are side effects, and unwelcome ones, since they mix the effects of climate science with other effects, diluting the signal for climate science. Ideally, this proposal would filter out developments not related to discoveries and evaluations unrelated to climate science, but for some of these events it may be difficult to separate out the effects of these events.²⁵⁵ Dilution of the signal for climate science is unavoidable.

This inevitability underscores again the need to keep the index simple, and to use it to focus on fundamental indicators of climate change. But beyond that, maybe it is not such a bad thing that this prediction market captures events other than just climate science. Again, in the seemingly constant chatter of information about all kinds of developments in climate science, technology, and policy, what is the layperson to make of it all? A prediction market can help. After all, a wide variety of things are said about addressing climate change (or not), and there is again, precious little rational evaluation of the seriousness of these things, and there is still a lay public wondering what to think.²⁵⁶

²⁵⁵ There is the possibility that the effects of some events that could affect climate outcomes could be captured by a separate contingent prediction market. Separate contingent markets could allow for trading in shares of outcomes only if a specified condition occurred. So, for example, if the election of Sarah Palin as U.S. President were likely to lead to a dismantling of this program, then a separate contingent prediction market could be established for those outcomes contingent upon her election. For a review of contingent prediction markets, *see*, Wolfers & Zitzewitz, *supra*, note 92, at 122-24.

²⁵⁶ *See, supra*, notes 1-2 and text accompanying.

A Prediction Market for Climate Outcomes

Viewed in this vein, a prediction market for climate outcomes could aid in the more rational discussion of technological developments and their potential to reduce greenhouse gases. A prediction market could actually act as an arbiter of the quality of climate technologies, a role that markets have historically played with great effectiveness. Because the index is keyed to climate outcomes, this prediction market would judge climate technologies ultimately by their ability to change the climate. This information is, like credible evaluations of climate science, currently scarce.

Climate technologies currently fall into two very broad categories: (i) *mitigation* technologies, which reduce emissions, or (ii) post-emission *geo-engineering* strategies to directly reduce the risk of climate change, either by physically or chemically removing greenhouse gases from the Earth's atmosphere, or reducing the heat-generating effects of solar radiation.²⁵⁷ Carbon capture and storage (CCS) technology is an example of an emissions reduction technology. CCS aims to *extract* the carbon dioxide from fossil fuels (mostly coal) and store it in underground caverns or some other geologically appropriate space, where it will remain for an effective eternity and avoid affecting the Earth's climate.²⁵⁸ What should we make of this technology? Perhaps more pertinent, how much should governments spend to subsidize the development of this technology? The answers offered to this question have not been sensible, except in a nakedly political sense.

Some in Congress seem to have fallen in love with CCS technology, and some have even likened its development to that of the atomic bomb, necessitating a super-research effort. In a 2009 floor speech, U.S. Senator Lamar Alexander said "we should launch another mini-Manhattan Project and reserve a Nobel Prize for the scientist who can get rid of the carbon from existing coal plants, because coal provides half our energy."²⁵⁹ This seems overenthusiastic. The most ballyhooed pilot American CCS project, FutureGen, has lost its two biggest industry

²⁵⁷ *Supra*, note 127.

²⁵⁸ World Resources Institute, Carbon Capture and Sequestration (CCS) (no date), <http://www.wri.org/project/carbon-capture-sequestration> (accessed February 25, 2011).

²⁵⁹ U.S. Senator Lamar Alexander, Floor Statements, April 22, 2009, online at http://alexander.senate.gov/public/index.cfm?FuseAction=Speeches.Detail&Speech_id=6e0de357-4757-49bb-adb1-3b5e795a81d4&Month=4&Year=2009 (also on file with author).

A Prediction Market for Climate Outcomes

backers, AEP and the Southern Company.²⁶⁰ This is a shocking development involving the two largest coal users in the United States.²⁶¹ And yet, FutureGen has suffered a never-ending series of twists and turns, the news alternately holding out the promise of rescuing the coal industry and at times sounding the death knell of the whole idea.²⁶² How seriously do we take information about advances and setbacks with respect to CCS? Markets may provide a badly-needed reality check.

A prediction market for climate outcomes would also evaluate geo-engineering technologies, and perhaps be an even better arbiter, since the only thing that geo-engineering projects are supposed to do is reduce the concentration of greenhouse gases. One technology currently under consideration is "industrial air capture" technology, which literally sucks carbon dioxide right out of the air for sequestration.²⁶³ This is accomplished by exposing some alkaline chemical compounds capable of reacting with ambient carbon dioxide to form new compounds, from which the absorbed carbon dioxide can be captured and stored.²⁶⁴ The concentration of carbon dioxide in the air is very low,²⁶⁵ so capturing the carbon dioxide directly from the air is an inherently clumsy engineering task. However, air capture technology be deployed anywhere, so it can be strategically placed near geologic formations susceptible of carbon dioxide storage, and can utilize renewable energy technologies away

²⁶⁰ CITE. May just be the citation below and then an *id.* Mark Chediak and Katarzynska Klimasinska, AEP to exit clean coal project, Tulsa World, June 25, 2009. The U.S. Department of Energy has nevertheless pledged \$1 billion in support of the project. Christa Marshall, *DOE Commits \$1 B to FutureGen*, CLIMATEWIRE, September 29, 2010.

²⁶¹ Mark Chediak and Katarzynska Klimasinska, AEP to exit clean coal project, Tulsa World, June 25, 2009. The U.S. Department of Energy has nevertheless pledged \$1 billion in support of the project. Christa Marshall, *DOE Commits \$1 B to FutureGen*, CLIMATEWIRE, September 29, 2010.

²⁶² Might be good to give news examples of the savior/death knell descriptions. Mark Chediak and Katarzynska Klimasinska, AEP to exit clean coal project, Tulsa World, June 25, 2009. The U.S. Department of Energy has nevertheless pledged \$1 billion in support of the project. Christa Marshall, *DOE Commits \$1 B to FutureGen*, CLIMATEWIRE, September 29, 2010.

²⁶³ Air capture literally pulls carbon dioxide out of the air for storage. David Keith, *Why Capture CO₂ From the Atmosphere?* 325 SCIENCE 1654 (2009).

²⁶⁴ Keith, *supra*, note 263, at 326.

²⁶⁵ Carbon dioxide concentrations are currently at about 390 parts per million. National Oceanic and Atmospheric Administration, Earth System Research Laboratory, Trends in Atmospheric Carbon Dioxide, Recent Mauna Loa CO₂ (January 2011) url: <http://www.esrl.noaa.gov/gmd/ccgg/trends/> (accessed February 26, 2011).

A Prediction Market for Climate Outcomes

from the grid.²⁶⁶ Air capture technology is more clearly benign and free from side-effects than other geo-engineering technologies that have been proposed.²⁶⁷ Finally, air capture is a technology that can be employed unilaterally, and is thus a way around the seemingly intractable international diplomacy problems that plague climate change.²⁶⁸ But it is expensive—even more so than CCS.²⁶⁹ How excited should we be about *this* technology?

This proposal introduces a financial incentive for people to critically evaluate these and other truly climate-altering technologies. As some that have become discouraged by the one-step-forward-two-steps-backward pace of international climate negotiations, the ability of geo-engineering technologies to allow unilateral action is, going forward, going to remain a policy option. Market evaluations of the feasibility of these technologies cannot be a bad thing. A market signal may provide policymakers information about what markets think about the potential of certain technologies to affect climate outcomes. It could well be that the most significant thing a market in future permits can do is yawn while Washington pundits and overnight physicists in the United States Congress scream: "this is a game-changing technology!"²⁷⁰

266 Keith, *supra*, note 263, at 326.

267 For example, one geo-engineering idea that has been discussed is "iron fertilization," the seeding of oceans with iron, to facilitate the growth of carbon dioxide-absorbing phytoplankton. While this could result in the absorption of carbon dioxide, it would also likely dramatically alter the balance of ocean life by changing, among other things, the acidity of the ocean. Henson, *supra*, note 53, at 330.

268 Scott Barrett, *Climate Treaties and Backstop Technologies*, CESifo Working Paper No. 3003 p. 4 (2010), Available at SSRN: <http://ssrn.com/abstract=158796>.

269 Barrett, *supra*, note 268, at 3.

270 Supposed "game-changing" technologies have included: electric vehicle batteries (Jason Plautz, *States see rebirth in battery manufacturing*, GREENWIRE, July 12, 2010 ("This is a game-changer for Michigan. It's the birth of an industry")), electricity storage technology generally (Lea Radick, *Some energy storage solutions may be 'game-changers' industry leaders say*, CLIMATEWIRE, March 13, 2009), shale gas (Nathan Gronewold, *Industry needs federal help to avoid continued slump*, GREENWIRE, June 29, 2010; Mike Soraghan, *Shale plays create 'new world' for energy industry*, GREENWIRE, March 11, 2010 ("Nearly every presenter at the conference has found a way to describe shale as a 'game changer.'"), Mike Soraghan, *U.S. shale boom could go global, shifting geopolitics*, GREENWIRE, March 9, 2010 ("Shale gas in Ukraine could be a game-changer")), small nuclear reactors (Katherine Ling, *House panel to focus on small reactors, future R&D at DOE*, ENERGY & ENVIRONMENT DAILY, May 17, 2010), nuclear reactors that burn spent fuel (Peter Behr, *A reactor that burns depleted fuel emerges as a potential 'game-changer'*, CLIMATEWIRE, February 23, 2010), underground coal combustion (Peter Behr, *A reactor that burns depleted fuel*

A Prediction Market for Climate Outcomes

Secondly, in addition to providing information about technologies, a prediction might also provide information about policy developments. Again, this is not altogether welcome, as it dilutes the signal for climate science, but again, it is unavoidable. The political rise of climate skeptics such as Sarah Palin²⁷¹ may dampen prices because of the prospect of her dismantling this program, if it is in place if she is elected President. One response to this has already been made: that this program will generate vested interests that could make its termination politically costly.²⁷² Another response is that if a Palin presidency occurs, and this program is terminated, then we are no worse off than we would be never having had this program, and perhaps better off for the information collected while the program was in place.

To again put this inevitability in a more positive light, a prediction market might be helpful in interpreting policy events. Markets may signal their beliefs in the significance of certain actions or statements. For example, the rather childish (and internationally criticized) behavior of Chinese representatives at the Copenhagen meeting²⁷³ might be a signal that China is prepared to live in a future world with climate change. On the other hand, China has raced past all other countries (including the United States) in investment in renewable energy technologies, possibly signaling its preparation for a low-carbon

emerges as a potential 'game-changer', CLIMATEWIRE, February 23, 2010), ocean thermal power (Saqib Rahim, *Is 'ocean thermal' power ready for its day in the sun?* CLIMATEWIRE, February 11, 2009), a transmission line linkage (Peter Behr, *Proposal to link nation's grid sparks a debate*, CLIMATEWIRE, February 3, 2010; Peter Behr, *Electric 'game-changer' gets FERC scrutiny*, CLIMATEWIRE, December 23, 2009), and General Motors' plug-in hybrid vehicle (Josh Voorhees, *Plug-in hybrids likely to stay expensive for decades – report*, GREENWIRE, December 14, 2009).

²⁷¹ **CITE NEEDED?** See, e.g., Sarah Palin, *Sarah Palin on the politicization of the Copenhagen climate conference*, WashingtonPost.com, December 9, 2009, online: <http://www.washingtonpost.com/wp-dyn/content/article/2009/12/08/AR2009120803402.html> (accessed May 2, 2011).

²⁷² **CITE NEEDED. Cite to previous discussion** *Supra*, section IV.B.2.

²⁷³ During negotiations at the Copenhagen conference of parties, Chinese Premier Wen Jiabao twice snubbed world leaders by sending an aide instead of attending in person, prompting President Obama to arrive unannounced and uninvited outside the Premier's office and the call to the Premier from outside, "Mr Premier? Are you ready to meet me?" Peter Maer, *Impromptu Moments Shaped Copenhagen Accord*, CBSNews.com, December 20, 2009, online at <http://www.cbsnews.com/stories/2009/12/20/politics/main6000506.shtml>.

A Prediction Market for Climate Outcomes

future.²⁷⁴ Which way is China heading? It is not a crazy thought to entertain that a prediction market might make a more objective guess and a better projection than climate pundits, China-watchers, and even perhaps the Chinese State Council.²⁷⁵

F. The Politics of Carbon Taxes and Cap-and-Trade

Carbon taxes would appear to be a continuing taboo subject. My other work on carbon taxes acknowledges these political realities.²⁷⁶ At the same time, there are a set of countervailing realities that American politicians will have to confront eventually. First, rising deficits and the now-ever-present concern of investors with sovereign debt problems may push carbon taxes out of the taboo category and into the "necessary evil" category, as jurisdictions look for ways to bridge their yawning budget gaps.²⁷⁷ Other possibilities for revenue raising also raise the heretofore taboo "tax" word. Second, if other nations begin to either cobble together some sort of climate policy—as Europeans will continue to do²⁷⁸—and other nations begin to foster a low-carbon economy—as China's investments in renewable energy seem to be aimed at doing²⁷⁹—then Americans, Canadians, and other laggards may find themselves at political and economic disadvantages. Finally, a carbon tax can be made to start out (with present climate outcomes) at a low level. A low-enough indexed carbon tax could conceivably fly under the threshold of indignation that could doom most climate policies. A \$5 per ton tax, for example, translates to a five-cent increase in the price of a gallon of

²⁷⁴ Lisa Friedman, *China leads major countries with \$34.6 billion invested in clean technology*, CLIMATEWIRE, March 25, 2010 (citing: Pew Charitable Trusts, *Who's Winning the Clean Energy Race? Growth, Competition, and Opportunity in the World's Largest Economies* (March 25, 2010); online at http://www.eenews.net/features/documents/2010/03/25/document_cw_03.pdf).

²⁷⁵ The State Council, composed of the Premier, the Vice Premier, and a number of ministers, is thought to be the central brain trust of Chinese government. http://www.gov.cn/english/2008-03/16/content_921792.htm.

²⁷⁶ CITE NEEDED. HSU, *supra*, note 116 at 181-91.

²⁷⁷ May need cites for the deficit and debt references. See, e.g., Christa Marshall, *British Columbia survives 3 years and \$848 million of carbon taxes*, CLIMATEWIRE, March 22, 2011 ("A huge question we are facing is how to deal with budget problems," [University of Michigan professor Barry] Rabe said. "Where are states going to get money? They don't have many choices, and carbon is one place to look.").

²⁷⁸ CITE NEEDED. I don't think I can support -- these are assertions

²⁷⁹ CITE NEEDED. I don't think I can support -- these are assertions

A Prediction Market for Climate Outcomes

gasoline.²⁸⁰ For a household that consumes the 2001 U.S. average of 1143 gallons per year,²⁸¹ this breaks down to an average increase of about \$56 per year in fuel costs. At some point, shrill cries of a carbon tax increasing gasoline prices have to confront the reality that its actual cost would be relatively modest.

Perhaps most importantly, this proposal would enjoy one critical political and optical advantage over other carbon tax proposals. Indexed as it is to destructive climate outcomes, all or a portion of proceeds of this carbon tax could be earmarked for disaster assistance for victims of climate outcomes. It could be considerably easier to sell a carbon tax that is viewed as being a funding mechanism for climate-related disaster (or even disaster unrelated to climate) such as hurricanes or droughts.²⁸² Such a tax seems much more linked to ameliorating a problem than it is a simple consumption tax burden and a government money-grab.

More generally, carbon taxes must, for lack of any alternatives, soon emerge as an acceptable option. It is tempting to dismiss any carbon tax as politically unpalatable at this juncture. But even a moment's reflection would suggest considerable potential for introducing a carbon tax. In the Canadian province of British Columbia, North America's first carbon tax is being phased in from a level of about \$10 (Cdn) per ton up to about \$30 (Cdn) per ton, over five years, ending in 2012.²⁸³ The governing

²⁸⁰ **CITE NEEDED** **Explaining how you reached this calculation.** \$5 on a ton of carbon dioxide One US gallon of gasoline contains about 2.42 kg of carbon. North Carolina State University, Bioenergy Conversion Factors, online: <http://www.ces.ncsu.edu/forestry/biomass/pubs/WB008.pdf> (accessed May 3, 2011). One kilogram of carbon is 5.34 pounds of carbon, which is 0.00266 short tons. The molecular weight of carbon is 12, while the molecular weight of carbon dioxide is 44. WebQC.org, Molecular Weights, <http://www.webqc.org/mmcalc.php> (accessed May 3, 2011). Burning one gallon of gasoline thus emits 0.00266 short tons of carbon, and 0.00978 short tons of carbon dioxide. A carbon tax of \$5 per ton of carbon dioxide would thus result in a carbon tax of 4.89 cents per gallon.

²⁸¹ U.S. Energy Information Administration, Household Vehicles Energy Use: Latest Data and Trends (Table A2) (2005); online: http://www.eia.doe.gov/emeu/rtecs/nhts_survey/2001/tablefiles/table-a02.pdf. This only averages consumption among U.S. households *that own a car*. The average per household with and without cars would be lower.

²⁸² **Cite?** Some sort of support – scholarly work or article – indicating this is true would make this statement stand out. I am not sure what assertion would need support. The assertion I make is unsubstantiated – that a carbon tax would be easier to sell as something.

²⁸³ **CITE.** Ideally whatever statute or mechanism is implementing, but article or news would work. **CITE NEEDED** B.C. Carbon Tax Act, S.B.C., 2008.

A Prediction Market for Climate Outcomes

political party that introduced the carbon tax, the Liberal Party, has survived the political storm, even picking up some support along the way,²⁸⁴ suggesting that the resistance to a carbon tax in this range may not be immovable. One key to the success of the governing Liberal Party of British Columbia is that it was the more conservative of the two parties vying for power in the province. By outflanking its more liberal and environmentally active rival party, the Liberal Party split the voters of its rival along environmental lines, and undermined its traditionally solid and large base of environmental voters.²⁸⁵ Despite the label of "Liberal" for the governing party, American conservatives might take note of this political success.

V. Conclusion

It is no exaggeration to say that markets inexplicably work. How exactly does information travel from one market participant to another, what form does that information take, and how does it get translated into prices? Nobody knows. As economist Maureen O'Hara has quipped: "we know [m]arkets work in practice, but we are not sure how they work in theory."²⁸⁶ This proposal aims to tap into the mysterious efficiency of markets. This article has left a number of details to future thought and design, but has sketched out the basic parameters of a simple idea: impose a carbon tax, specify that the carbon tax will be indexed to the number of climate outcomes, and offer to the taxed entities the opportunity to purchase emissions permits to emit in lieu of paying a tax. These permits would be tradable after their initial auction. The idea of this proposal is to use the trading activity of the future emissions permits to generate some credible forecasts about what the indexed carbon tax will be, and hence, what climate outcomes will be.

We are probably better off not giving in to cynicism when considering the arguments of those with whom we disagree about climate science, however tempting it is to think that the "other side" is just nuts or corrupt. However, the vast uncertainties, the enormous political stakes involved, and the very core personal values implicated by the problem of climate change, not to mention the large investments that both climate advocates and climate skeptics have in their particular substantive

²⁸⁴ **CITE NEEDED** Hsu, *supra*, note 116, at 187.

²⁸⁵ **CITE NEEDED** Id.

²⁸⁶ Maureen O'Hara, Making Market Microstructure Matter, 28(2) Financial Mgmt 83, 83 (1999).

A Prediction Market for Climate Outcomes

positions, give rise to a situation in which anybody can accuse anybody of taking a subjective interpretation of climate science. It is truly challenging under these circumstances to take a benign view of those with whom we disagree. This proposal, more than even addressing the problem of reducing greenhouse gases, addresses the question of whom we truly believe, and how sure we are of our beliefs.

Markets are inherently imperfect, so the information generated by this proposal will be imperfect. It is not as if this cap-and-trade market will reveal the true climate science. Rather, what this proposal does is provide objective information about what *everyone else thinks*. This information network aspect, similar to the information network embedded in market prices, is *feedback* more than it is information, and serves as a challenge to our beliefs. While McKittrick's proposal of a temperature-indexed carbon tax is meant to tap into nature as an "arbiter," this proposal goes further and taps into *both* nature and markets as arbiters. Nature gets to determine the level of the carbon tax, but markets get to make important forecasts about what Nature will do in the future.

Appendix A Construction of the Carbon Tax Index and Cap-and-Trade Schedule

1. Global mean temperature.

As noted in Section IV, constructing a global mean temperature statistic raises thorny issues because temperature-taking is not uniform across the planet,²⁸⁷ and in some countries where it is taken the data is spotty and unreliable.²⁸⁸ Moreover, countries are sometimes reluctant to release their raw climate data except with confidentiality agreements that protect the proprietary interests. How does one "clean," or adjust data that is obviously faulty, without being accused of tampering? This has been the plight of the Climatic Research Unit ("CRU") at the University of East

²⁸⁷ Cite. Perhaps with examples? I just don't have this. I can't find even any statement from one of these data centers talking about how they have to make adjustments because weather data is non-uniform.

²⁸⁸ Cite (likely just a cross-reference to Section IV)

A Prediction Market for Climate Outcomes

Anglia, and its beleaguered director, Dr. Phil Jones,²⁸⁹ foci of the "Climategate" controversy.²⁹⁰ The CRU data is a compilation of raw temperature readings compiled into 5° x 5° grid boxes for most of the land surface of the Earth.²⁹¹ While CRU makes its compilation publicly available, it irked climate skeptics by refusing to divulge its raw data.²⁹² The problem was that CRU's raw data from weather stations throughout the world were provided by the national meteorological services of each country under the condition that the data not be publicly disseminated.²⁹³ Even demands by climate skeptics that CRU share its code would allow people to reverse engineer the publicly-available data and re-create the raw data, violating the confidentiality agreements.

Other datasets exist,²⁹⁴ but they are not free of controversy, either. McKittrick proposes to use an average temperature calculated from a dataset maintained by researchers at the University of Alabama at Huntsville ("UAH"), Roy Spencer and John Christy, which uses publicly available data from NOAA satellites, and infers temperatures at different altitudes.²⁹⁵ The controversy surrounding this dataset stems from its deployment in past studies that seem to have shown no increase in global temperatures.²⁹⁶ Frank Wentz and Matthias Schabel have argued that part of the cooling trend can be attributed to the orbital decay of the satellites from which the readings were taken.²⁹⁷ Spencer and Christy made adjustments to their analysis, but have made other adjustments that suggest that there is no warming trend, at least in the troposphere above

289 Climatic Research Unit, University of East Anglia, Data: Temperature, url: <http://www.cru.uea.ac.uk/cru/data/temperature/> (accessed February 18, 2011).

290 *See, supra*, notes 16-17 and text accompanying.

²⁹¹ Cite.CITE NEEDED *Supra*, note 289.

²⁹² CITE. *Supra*, notes 16-17

293 Lauren Morello, 'Climategate' Scientist Admits 'Awful Emails,' But Peers Say IPCC Conclusions Remain Sound, *ClimateWire*, March 2, 2010. *See also, supra*, note 17.

294 For a brief description of the main datasets, *see* Henson, *supra*, note 53, at 179-81. The most comprehensive one is collected by the World Meteorological Organization, and compiled by the National Climate Data Center of NOAA.

295 McKittrick, *supra*, note 112, at 117-18. McKittrick's specific proposal would average the temperature of the tropical troposphere, the lowest layer of the atmosphere – the one touching the Earth's surface – over the tropical belt (between the Tropic of Capricorn and the Tropic of Cancer) around the Earth.

296 Spencer & Christy, *supra*, note 14.

297 Frank Wentz & Matthias Schabel, *Effects of Orbital Decay on Satellite-derived Lower-troposphere Temperature Trends*, 394 *Nature* 661 (1998).

A Prediction Market for Climate Outcomes

ground level.²⁹⁸ A subsequent special report from the National Academy of Sciences concluded that it was possible that both sets of data were correct—that the surface temperatures may have warmed more quickly than tropospheric temperatures.²⁹⁹ Subsequent analyses of the data now appear to have reconciled it with other datasets.³⁰⁰

These are live controversies that need to be addressed, but for purposes of indexing a carbon tax, they seem susceptible of resolution. There is no disagreement in principle, even between climate scientists and climate skeptics (which of course include scientists) that the use of some global temperature measure is a fundamental indicator of climate change. At a minimum, the UAH data, which has now been tested and reconciled with other datasets, and which Professor McKittrick proposes to be used for an index, would seem to be a reasonable beginning point.

2. Days of unusually high or low temperatures.

"Unusual" implies some comparison with historical standards and would obviously be location-specific, as the average for a polar location would be much lower than the average for a tropical one. Fortunately, the Expert Team on Climate Change Detection and Indices ("ETCCDI"), a working group of climate scientists attempting to collect and process temperature data throughout the world,³⁰¹ provides a head start on thinking about temperature extremes. Seeking to process raw temperature and precipitation data in a way that does not violate confidentiality agreements that inevitably come with the data, the ETCCDI have developed an index of 27 outcomes (the ETCCDI calls them "indices"), through which to run the data, and create a separate database.³⁰² In other words, the "indices" are a transformation of the raw

298 John R. Christy, William B. Norris, Roy W. Spencer, and Justin J. Hnilo, *Tropospheric Temperature Change Since 1979 from Tropical Radiosonde and Satellite Measurements*, 112 J. GEOPHYS. RES. D06102 (2007) doi:10.1029/2005JD006881.

299 NATIONAL ACADEMY OF SCIENCES, RECONCILING OBSERVATIONS OF GLOBAL TEMPERATURE CHANGE 2 (2000); downloaded from <http://www.nap.edu/catalog/9755.html> (accessed February 25, 2011).

300 Henson describes the UAH data and documents the controversy among climate scientists on the reliability of the UAH dataset. Henson, *supra*, note 53, at 183-85.

301 The CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices, <http://cccma.seos.uvic.ca/ETCCDI/index.shtml> (accessed February 15, 2011).

³⁰² CITE. Preferably from ETCCDI. NEEDED Id.

A Prediction Market for Climate Outcomes

data—a way of presenting the same information without the raw data itself.

Included in the ETCCDI basket of "indices" are a number of statistics aimed at measuring the duration and severity of temperature and precipitation anomalies (both extreme precipitation and drought).³⁰³ Prominent among the indices are two that suit the purpose of this proposal well:

1. The percentage of days in which the daily maximum temperature was *higher than* 90 percent of the following: the daily maximum temperature readings for that same calendar day in the base years 1961 to 1990, plus the two days before and the two days after that calendar day, also in the years 1961 to 1990;³⁰⁴ and
2. The percentage of days in which the daily minimum temperature was *lower than* 90 percent of the same set of temperature readings.³⁰⁵

For example, if the 90th percentile of all daily maximums from June 13 to June 17, 1961 to 1990, was 88 degrees, then any June 15 with a daily maximum temperature of 89 degrees or more would be counted as an "unusually high" day. By the same token, if the 10th percentile for all daily minimums from March 2 to March 6, 1961 to 1990, was 13 degrees, any March 4 on which the daily minimum was 12 degrees or lower would be counted as an "unusual low".³⁰⁶

These two indices measure the extremes of heat and cold—the hottest it gets on hot days, and the coldest it gets on cold days. It is also possible to include some measure of the persistence of such heat and cold, by also including the *minimum* temperature on *hot* days,³⁰⁷ and the *maximum* temperature on *cold* days.³⁰⁸ Using the same method of comparing daily measurements against an historical 5-day window centered upon the

³⁰³ CITE. Likely, again, to ETCCDI. *Supra*, note 301 (indices # 17-27).

304 *Supra*, note 301 (index # 13).

305 *Supra*, note 301 (index # 10).

³⁰⁶ Is this example from ETCCDI? If so, cite to that. If not, perhaps a *see* signal then cite back to ETCCDI process. No, this is an illustrative example I made up.

307 *Supra*, note 301 (index # 12).

308 *Supra*, note 301 (index # 11).

A Prediction Market for Climate Outcomes

calendar day in which the measurement is taken, the ETCCDI aims to provide some measurement of how persistently hot and cold days can be without relief.³⁰⁹

The ETCCDI work is a work in progress. In constructing an index, it is also important to consider how to choose locations from which data will be processed and become part of the index. As ETCCDI continue to work with and process datasets, this question is also one which requires deft resolution.

3. Extreme rainfall and drought events.

Even "flooding" and "drought" are somewhat subjective terms, and require some formal definition. A number of indices taking into account drought are possible, but it is useful to refer again to the work of the ETCCDI. As with #2 (days of unusually high or low temperatures), some transformation of raw data is necessary. As with #2, it seems desirable to compare data with historical records of precipitation in the comparable time of year, so that the precipitation in wet areas such as coastal British Columbia are evaluated in the context of how wet it has been in the past. With dry areas, however, extreme and prolonged dryness render this way of counting dry days statistically difficult. If it has historically been bone-dry in Phoenix every single summer for the entire period of 1961 to 1990,³¹⁰ there will be no 90th percentile, or any other percentile. There is no such thing as "unusually dry" when looking at summers in Phoenix.

Consistent with the objectives of this climate index, two statistics under consideration by ETCCDI seem helpful in measuring extreme rainfalls and droughts:

1. The total number of days in which the precipitation is greater than 99 percent of all wet days (defined as getting more than one millimeter of rain, just a very small amount) in the entire period from 1961 to 1990.³¹¹ In other words, extreme rain is

³⁰⁹ CITE. ETCCDI. Again, like note 340, an illustrative example I made up.

³¹⁰ CITE NEEDED From 1971 to 2000, average rainfall in Phoenix was as follows: April, 0.25 inches; May, 0.16 inches, June, 0.09 inches, July, 0.99 inches, and August, 0.94 inches. About.com, *Phoenix, Does it Rain in Phoenix, AZ?* url: <http://phoenix.about.com/od/weather/qt/rain.htm> (accessed May 4, 2011).

³¹¹ Cite. May just be this 232 index 26. No, just an illustrative example.

A Prediction Market for Climate Outcomes

evaluated against the wettest days in the entire thirty-year period from 1961 to 1990;³¹²

2. The *length* of droughts, number of consecutive days in which there was less than one millimeter of rain.³¹³

The Bureau of Meteorology in Australia is able to get around the statistical dryness problem by aggregating data over a region and averaging it over an entire year. The Bureau defines a drought as rainfall over three consecutive months that is in the lowest ten percent of what has been recorded for that region in the past.³¹⁴ Of course, droughts could be extremely long periods of time with very limited rainfall. The economically vital Murray-Darling basin in Australia experienced almost a decade of low rainfall (though not all of it within the definition of "drought").³¹⁵

4. Sea level rise.

As oceans warm along with the rest of the planet, they expand in volume, accounting for a significant part of sea level rises to date.³¹⁶ This much is not in doubt, but the contribution of melting, land-based glaciers is cause for concern, and may cause oceans to rise by several meters, rather than several inches.³¹⁷

As with other climate indicators meant to measure something on a planetary scale, measuring sea levels is surprisingly difficult. Because of tectonic changes in land and ocean beds, using land as a reference point is flawed, so using tidal gauges—putting a measuring stick in the ocean and taking periodic measurements—is inadequate.³¹⁸ More advanced systems now use satellite data to measure mean sea levels with error of

312 *Supra*, note 301 (index # 26).

313 *Supra*, note 301 (index # 23).

314 Australian Government, Bureau of Meteorology, Rainfall Deficiencies and Drought Information (accessed January 3, 2011).

315 Australian Government, Bureau of Meteorology, Drought Statement, December 3, 2008, online: <http://www.bom.gov.au/climate/drought/archive/20081203.shtml> (accessed January 3, 2011).

316 Sydney Levitus, John I. Antonov, Julian Wang, Thomas L. Delworth, Keith W. Dixon, and Anthony J. Broccoli, *Anthropogenic Warming of Earth's Climate System*, 292 *Science* 267, 268 (Table 1) (2001).

317 Henson, *supra*, note 53, at 111-18.

318 Henson, *supra*, note 53, at 107-08.

A Prediction Market for Climate Outcomes

less than one millimeter.³¹⁹ For purposes of measuring ocean level rises, satellite data collected by several governments do not, unlike other climate data, seem to be controversial.³²⁰

5. Ocean acidity.

Measuring the average pH of the world's oceans is not, at this time, a particularly controversial exercise, in part because so little attention has been focused on this subject.³²¹ With oceans occupying 75% of the Earth's surface,³²² and given the importance of ocean life to humankind, ocean chemistry would appear to be a vital statistic to include in an index of climate outcomes.

6. Hurricanes above a certain intensity level

Hurricane intensity is commonly measured using the Saffir-Simpson Hurricane Wind Scale, which rates hurricane strength on the basis of the maximum *sustained* wind speed during a hurricane.³²³ A category 3 hurricane is one in which the peak wind speeds are 111 to 130 miles per hour, category 4 in which peak speeds are 131 to 155, and category 5 in which the peak speeds are greater than 155 miles per hour.³²⁴ A "major" hurricane is a category 3, 4, or 5 storm.³²⁵ Between 1900 and 2000, 24 of

³¹⁹ Henson, *supra*, note 53, at 108.

³²⁰ Might want to cite to a broader authority on this, simply because it seems like it could be a "deep" topic. I think the brevity here is fine. You can get rid of this sentence altogether if that is your preference. It is hard to cite a source supporting a negative.

³²¹ Henson, *supra*, note 53, at 124.

³²² Cite. A simple statistic but a statistic still – worth citing one of the many works that states this fact. National Oceanic and Atmospheric Administration, *Ocean*, url: <http://www.noaa.gov/ocean.html> ("The ocean covers 71% of the Earth's surface...") (accessed May 4, 2011).

³²³ CITE. To source illustrating commonality of use of scale and, hopefully, one explaining the scale in detail. National Weather Service, *The Saffir-Simpson Hurricane Wind Scale*, url: <http://www.nhc.noaa.gov/sshws.shtml> (accessed May 4, 2011).

³²⁴ National Oceanic and Atmospheric Administration, National Weather Service, National Hurricane Center, Saffir-Simpson Hurricane Wind Scale, url: <http://www.nhc.noaa.gov/sshws.shtml> (accessed February 25, 2011). The National Hurricane Center's Saffir-Simpson Hurricane Wind Scale states that in hurricanes of category 4 or category 5 strength, "Catastrophic damage will occur," and that in hurricanes of category 3 strength, "Devastating damage will occur."

³²⁵ Jerry D. Jarrell, Max Mayfield, Edward N. Rappaport, and Christopher Landsea, *NOAA Technical Memorandum NWS TPC-1: The Deadliest, Costliest, and Most Intense United States Hurricanes from 1900 to 2004*,

A Prediction Market for Climate Outcomes

30 of the deadliest hurricanes were category 3 or higher, 10 of the 12 deadliest, category 4 or higher.³²⁶

In most cases, the bulk of the damage from hurricanes comes from the storm surges that inundate coastal areas, and account for the vast majority of deaths directly attributable to hurricanes.³²⁷ The old Saffir-Simpson scale used to incorporated central pressures and storm surges as part of the index.³²⁸ To avoid confusion, however, and because storm surges vary greatly by topography, the index was simplified to only include hurricane peak wind speeds.³²⁹ Using a simpler index, focusing on wind speed would be consistent with the objectives of this index of climate outcomes.

Counting hurricanes has been done uncontroversially, if inconsistently, for over a century. A number of hurricane-tracking sites exist, but the best global compilation of hurricane data is maintained by a private security management firm, Unisys.³³⁰ Unisys compiles information about hurricanes in each of the six major oceanic regions, collecting data from a number of national and international sources.³³¹ While the relatively short (for climate data) history handicaps efforts to attribute hurricanes to climate change, it is clearly long enough to support construction of an index including hurricane data.

Appendix B **Cap-and-trade Permit Auction Schedule**

If 400 million permits for each vintage year were to be issued each of the forty years preceding the vintage date, ten million would have to be issued each year. So starting in the year 2012, ten million 2052 permits would be auctioned per year, ending in the year 2051. But what about all of the years prior to 2052? For some years, more than ten million permits

<http://www.aoml.noaa.gov/hrd/Landsea/deadly/index.html> (accessed December 17, 2010).

³²⁶ Jarrell, et al, *supra*, note 325.

³²⁷ Jarrell, et al, *supra*, note 325.

³²⁸ Cite – about old scale. National Weather Service, *The Saffir-Simpson Hurricane Wind Scale*, url: <http://www.nhc.noaa.gov/sshws.shtml> (accessed May 4, 2011).

³²⁹ *Supra*, note 324.

³³⁰ Unisys, Unisys Weather, Hurricane/Tropical Data, <http://weather.unisys.com/hurricane/> (accessed February 25, 2011).

³³¹ CITE. Preferably from Unisys. Id.

A Prediction Market for Climate Outcomes

for a vintage year would have to be issued. For 2014 permits, should the bulk of them be auctioned in 2012 or 2013? To maximize the amount of information garnered by this prediction market, and to make sure the permit markets are as healthy as possible, the bulk of them should be issued in 2012—390 million, with the remaining ten million to be auctioned in 2013. Also in 2012, 380 million permits to emit in 2014 would be auctioned, with ten million in each of the following years. In other words, 2012 should be the year in which all excess permits are issued, with ten million permits for every vintage year being issued in each successive year. The schedule is set forth below in Table 1.

Table 1
Schedule of Permit Auctions

Year of auction	Vintage Years							
	2013	2014	2015	•••	2050	2051	2052	2053
2012	400m	390m	380m	•••	30m	20m	10m	
2013		10m	10m	•••	10m	10m	10m	10m
2014			10m	•••	10m	10m	10m	10m
• • •					• • •	• • •	• • •	• • •
2049					10m	10m	10m	10m
2050						10m	10m	10m
2051							10m	10m
2052								10m