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Prediction-Market-Based Quantification of Climate Change Consensus and Uncertainty

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Intrade is an online trading exchange that includes climate prediction markets. One such family of contracts can be described as "Global temperature anomaly for 2012 to be greater than x °C or more," where the figure x ranges in increments of .05 from .30 to 1.10 (relative to the 1951-1980 base period), based on data published by NASA GISS. Each market will settle at $10.00 if the published global temperature anomaly for 2012 is equal to or greater than x, and will otherwise settle at $0.00. Similar contracts will be available for 2013.

Global warming hypotheses can be cast as probabilistic predictions for future temperatures. The first modern such climate prediction is that of Broecker (1975), whose temperatures are easily separable from his CO2 growth scenario—which he overestimated—by interpolating his table of temperature as a function of CO2 concentration and projecting the current trend into the near future.

For the current concentration of 395 ppm, Broecker's equilibrium temperature anomaly prediction relative to pre-industrial is 1.05 °C, or about 0.75 °C relative to the GISS base period. His neglect of lag in response to the changes in radiative forcing was partially compensated by his low sensitivity of 2.4 °C, leading to a slight overestimate. Simple linear extrapolation of the current trend since 1975 yields an estimate of .65 ± .09 °C (net warming of .95 °C) for anthropogenic global warming with a normal distribution of random natural variability.

To evaluate an extreme case, we can estimate the prediction Broecker would have made if he had used the Lindzen & Choi (2009) climate sensitivity of 0.5 °C. The net post-industrial warming by 2012 would have been 0.21 °C, for an expected change of -0.09 from the GISS base period. This is the temperature to which the Earth would be expected to revert if the observed warming since the 19th century was merely due to random natural variability that coincidentally mimicked Broecker's anthropogenic change prediction for the past 36 years.

Assertions made outside the scientific literature can also be cast into predictions for 2012 temperatures, for example Carter's (2006) argument for a lack of warming since 1998 can be extrapolated to a 2012 value of 0.56 °C (net warming of .86 °C), and Easterbrook's (2010) claim of global cooling can be extrapolated to a 2012 value of .42 °C (net warming of .72 °C).

All contracts in the current market ensembles are consistent with net warming from pre-industrial temperatures. They are also capable of distinguishing the level of acceptance of the various global warming hypotheses, even by their respective proponents. Moreover, they can be used as a market-based consensus estimate of future warming and climate variability that is weighted according to level of risk taken on by those providing the estimates, while filtering out the opinions of individuals unwilling to accept any financial risk associated with being wrong.

How do Prediction Markets Work?

A prediction market allows the exchange of futures contracts on events. It is distinct from a typical futures market, which deals with contracts on commodities. A futures contract is a conditional IOU. In its simplest form, it is a binary "yes or no" proposition. It can be described as a straightforward bet on the outcome of an event, such as a presidential election or a football game. Whereas a typical bet is between to parties who negotiate the odds, a market allows contracts to be traded on an exchange in which multiple traders can offer contracts for sale and bid on contracts to buy. Trades are executed using the continuous double auction, the same mechanism by which stocks are traded on the New York Stock Exchange, and commodities contracts on the Chicago Mercantile Exchange. A second form of futures contract is a derivative, which settles at a value that depends on some underlying index, such as the total points scored in a game. Because of their use in sports betting, they are sometimes called "total points" contracts when used in prediction markets.

Binary Contracts

Because they are simple bets, binary contracts are the easiest to understand. They can be written as an IOU that is payable only if the some condition evaluates to .TRUE. and becomes void if it evaluates to .FALSE. The price of the contract--relative to its face value--can be interpreted as the consensus probability (at the time of the trade) that the condition will be true on the settlement date. As new information becomes available and opinions change, the price can fluctuate. When contracts are traded on an electronic exchange, the price can be plotted as a time series, or probability "ticker." Binary contracts can be written to assess the probability of a given quantitative outcome (such as point spread in a game, or global mean surface temperature of the Earth) but cannot directly determine its expectation value. The value of the point spread in a game is set by bookmakers to coincide with the best estimate. However, it can also result as a market-based emergent quantity from an ensemble of binary contracts that span a range of point spreads. Moreover, such an ensemble yields a cumulative probability density function (CDF) for the point differential. Likewise, an ensemble can be designed to yield a consensus, market-based CDF for future global mean surface temperature.

Futures contract

If the Denver Broncos win against the Oakland Raiders on December 6, 2012, this contract is worth $10. If they lose, the contract is void.

When selling for $7.50, consensus probability = 0.75.

Futures contract

If the Denver Broncos beat the Oakland Raiders by 8 points or more on December 6, 2012, this contract is worth $10. If not, the contract is void.

When selling for $5.00, consensus probability = 0.50.

Derivative Contracts

Derivative contracts provide a mechanism by which the best estimate of a future quantity can be determined by market consensus without requiring an entire ensemble. Unlike a binary contract, the derivative price can be mapped onto the underlying index. For example, if the settlement price of the contract is proportional to the total points scored in a game, then the price of a trade is a direct measure of the current market-based prediction of that quantity. By analogy, a "total points" climate contract can be created to find the market-based consensus for future global mean surface temperature.

Futures contract

The holder of this contract will receive $0.10 for every point scored in the game between the Denver Broncos and the Oakland Raiders on December 6, 2012.

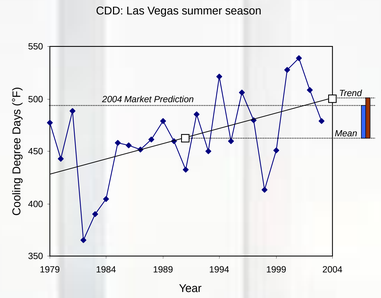
When selling for $4.10, consensus estimate = 41 total points.

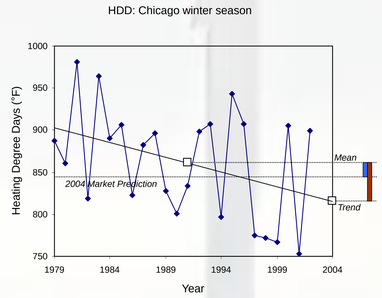
Weather Derivatives

Weather derivatives came into use in the late 1990s, partly in response to the strong El Niño of 1997-1998. It was primarily driven by the utility industry, whose earnings are highly dependent on weather. Monthly and seasonal temperature contracts began trading on the Chicago Mercantile Exchange in 1999. These consist of Heating Degree Day (HDD) and Cooling Degree Day (CDD) contracts for various US, Canadian, European, and Japanese cities. HDD and CDD are temperature indexes that are intended to represent heating and cooling costs, respectively. The daily HDD is used in the winter, and is the difference between that day's mean temperature and 65°F. The index is summed over the number of days during period of the contract. CDD is calculated analogously. For the CME contracts, these indexes are simplified to make use of published daily high and low temperatures:

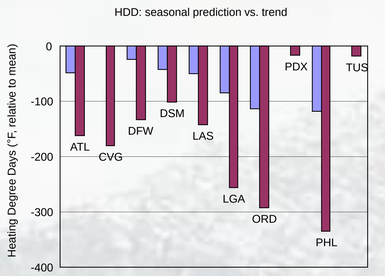
$$HDD = \sum \max[0, 65(°F) - \tfrac{1}{2}(T_{hi} + T_{lo}) - 65°F)]$$

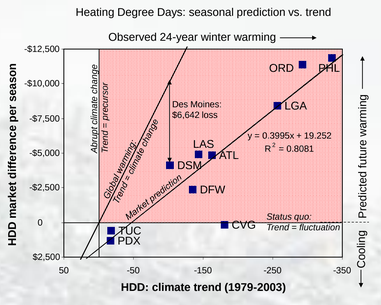
These quantities have no rigorous physical meaning, but are strongly correlated to energy consumption and are widely used to settle derivative contracts.

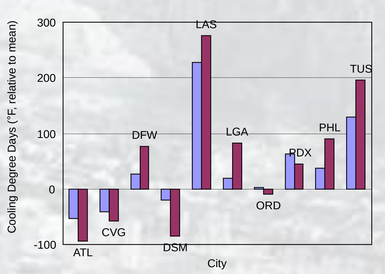


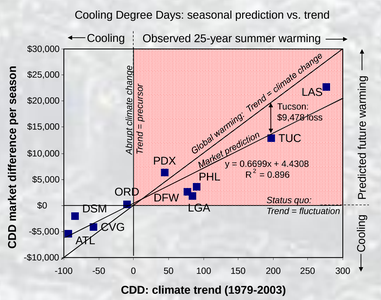


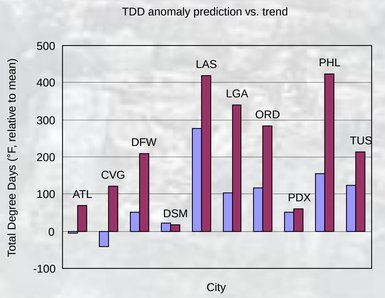
Companies have long recognized this connection, and the weather derivative market was created to allow explicit investment in weather risk. Utility companies, for example, suffer sharp declines in earnings during mild winters, so there is a market for hedge funds that allow them to trade profits during severe seasons for losses during mild seasons. Likewise, insurance companies are "betting" on the likelihood of catastrophic events. The capitalization of such investments provide a means of quantitatively estimating the economic costs of weather, and the breakpoints and indexes provide a market-based prediction of the future. Prices of some commodities, such as corn, correlate almost entirely on summer temperatures. Weather derivatives provide the opportunity to swap risk between economic sectors, leading to sufficient liquidity to discover a robust price and probability.

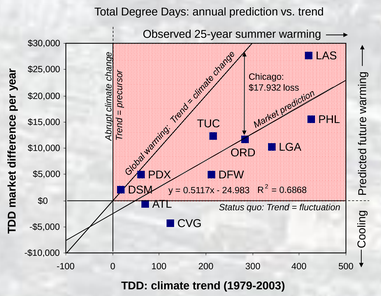












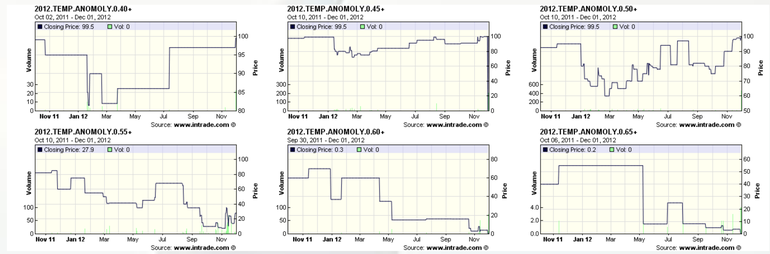
One fundamental predictor is Sea Surface Temperature (SST) in the equatorial Pacific, which shows precursor trends associated with the El Nino / Southern Oscillation (ENSO), and strongly influences both temperature and precipitation in the continental U.S. It is no coincidence that weather derivative markets surged during the winter of 1997-1998, one of the strongest El Nino events on record, when utility companies were exposed to high risk of earnings declines due to an exceptionally mild winter. Another fundamental predictor is global climate change, which influences the index to the extent that investors accept the science behind it. Because investors are putting their money on the outcome, the market amplifies the opinions of the individuals with the best information and filters out the noise.

To test the hypothesis that expectations for global warming are factored into the market, the historical CDD index for July 2004 was compared to the aggregate 24 year average CDD index for the nine U.S. cities that were traded on the CME at that time. The closing index for August 6, 2003 was chosen, but the numbers change from day to day. Because the index corresponds to nearly a year in the future, the relative influence of long-range weather forecast data is minimized. Significantly, 7 of 9 cities are expected by investors (dominated by the energy sector) to be warmer than the 24-year average. The average daily temperature anomaly expectation is about .4°F, which is remarkably close to the measured global trend in the latter part of the 20th century. To form a robust conclusion about the market response to global warming will require that large quantities of such index data be analyzed and other influences removed. Likewise, estimates of market perceptions of economic costs can be derived from volume data.

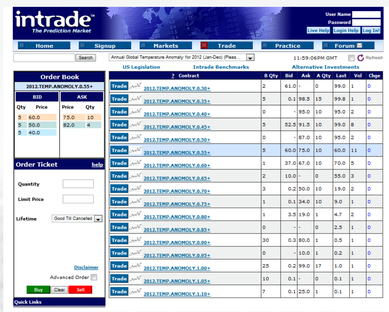
Climate Futures

Binary Ensembles

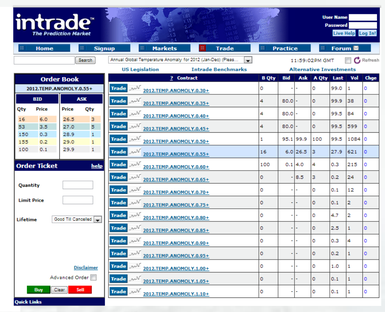
All 17 contracts in the newly-opened Intrade market ensemble are consistent with net warming from pre-industrial temperatures. Contracts were initialized in October, 2010 by entering buy and sell orders straddling a price determined by a linear regression to the temperature trend, assuming a normal distribution of interannual variability. The only contracts with significant trading volume were the six temperatures closest to the expectation value. Price ticker time series are shown for these six.



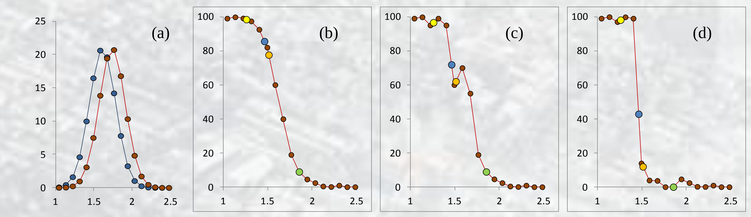
There is no unique defensible method to aggregate various published climate sensitivity PDFs into a single consensus function. However, the PDF for a well-defined future temperature can be aggregated using ensembles of binary prediction contracts, which can in turn be used to constrain the consensus climate sensitivity PDF. Below are images of the trading page for 2012 global mean surface temperature at 11:59 pm UTC on 30 Nov. 2011 and one year later.



Trading page, Nov. 30, 2011



Trading page, Nov. 30, 2012



Temperature probability distributions (above) can be extracted from the contract prices. (a) PDF of linear regression forecast of NASA GISS global mean surface temperature anomaly (°F) assuming normal distribution of interannual variability for 2012 (blue) and 2016 (red). (b) Initial values of market prices for 2012, initialized in October, 2010. (c) Market values on Nov. 30, 2011. (d) Market values on Nov. 30, 2012. The value that would have been predicted by Broecker (1975) if he had used Lindzen and Choi (2009) climate sensitivity is below the bottom temperature range. Yellow = value based on projections by Easterbrook (2008). Blue = value based on Plass (1955). Orange = value based on Carter's (2006) statement that global warming stopped in 1998. Green = value based on Broecker (1975). The lack of monotonicity of the market-based curves is a consequence of insufficient liquidity. Use of climate prediction markets as hedging instruments by stakeholders in climate change and carbon trading may be required to provide the liquidity necessary to make this a viable method.

Climate Derivatives

By analogy with weather derivatives, I have now proposed climate derivatives "total points" contracts to be traded on Intrade using the ten-year lagging average of the global land temperature anomalies published by NOAA/NCDC. This is a more climatologically-relevant index and potentially serves as a prototype for hedging instruments that can be used by industries and governments to help defray the cost of adaptation to climate change. I intend to report results from these contracts at the 2013 AGU Fall Meeting.

References

Broecker, WS, (1975), Climatic change: Are we on the brink of a pronounced global warming? *Science* 189, 460-463.
Lindzen, RS and Y-S Choi, (2009), On the determination of climate feedbacks from ERBE data. *Geophys. Res. Lett.* 36., L16705.