The Impacts of the International Climate Policies on Global Temperature

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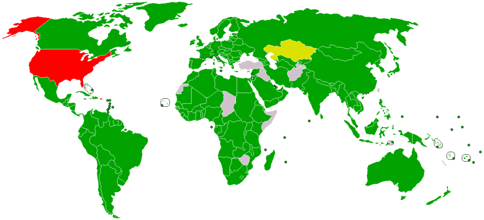
- Climate change has been at the forefront of global issues for several decades
- Kyoto Protocol: signed in 1997, went into effect in 2005, required all developed countries (except U.S.) to reduce emissions to 5% below 1990 levels
- Since then: annual Conference of Parties (COP) to assess progress in combating climate change, Doha Amendment (2012), Paris Agreement (2015)
- How effective are international climate policies?



Theoretical Framework - Our Theory

- Our metric of success: overall rates of global warming before and after Kyoto Protocol (previous studies have used reduction of GHG as their metric)
- Independent variable: rate of warming
- Dependent variable: time in years
- Causal mechanisms: reduction in greenhouse gas emissions, climate oscillations (sunspot cycles, El Niño, La Niña)
- Previous time-series analyses have shown that the Earth is warming at a significant rate; we add on to this fact by considering a major landmark event
- Theory: Kyoto has successfully decreased the rate of warming by
  1. lowering yearly rate of temperature change
  2. lowering impact of previous years negative effects

Theoretical Framework - Testing Process

- Build a model that determines the overall rate of climate change using monthly averages of global land surface temperature data from 1850 to 1999 (the inception of the Kyoto Protocol)
- Use this model to predict global temperature from 2000 to 2020
- Create a separate model, incorporating data from 2000 to 2020, to look at the actual rate of climate change
- This process will be done with two separate datasets: global and contiguous U.S.

Data - Source

- Berkeley Earth, an independent U.S. non-profit organization affiliated with the Lawrence Berkeley National Laboratory
- Data from 39,000 unique weather stations, combining 1.6 billion reports from 16 preexisting archives, then cleaned and filtered
- Can filter by country/major city - we will use global and U.S.
- Reports temperatures as anomalies, relative to Jan. 1951 - Dec. 1980 averages (8.60°C for global and 11.36°C for U.S.)
- We converted data to absolutes, then modify files to CSV format
- Key variables
  1. Year: starts in 1750, but only require 1850 - 2020
  2. Month: 1 (January) - 12 (December)
  3. Global_Avg_1: global one-year average land temperature in Celsius
  4. Global_Avg_Unc_1: the 95% confidence interval around the average, accounting for statistical and spatial under-sampling effects
- The contiguous U.S. versions of items 3 and 4 will also be used

Data - Exploratory Statistics

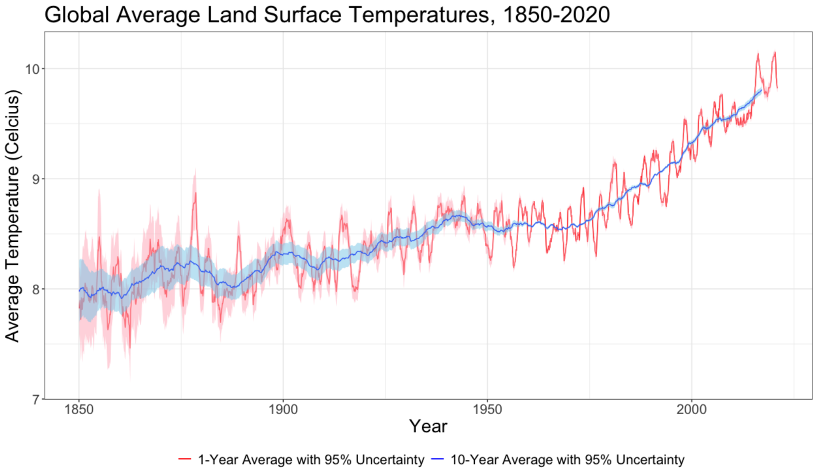


Figure: Global average land surface temperatures from 1850 - 2020. Note that the y-axis starts from 7°C in order to better see the trends.

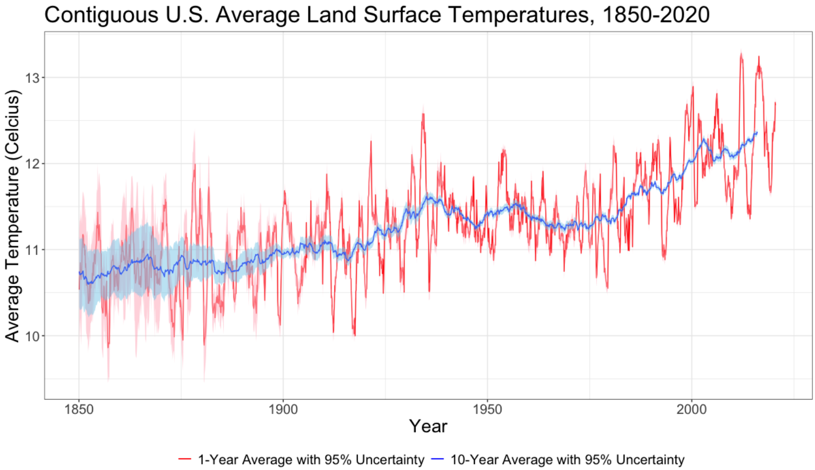


Figure: Contiguous U.S. average land surface temperatures from 1850 - 2020. Note that the y-axis starts from 9°C in order to better see the trends.

Data - Exploratory Statistics

Period	1850-1997	1997-2020	1850-2020
Global	8.42 (0.35)	9.61 (0.23)	8.56 (0.53)
Contiguous U.S.	11.16 (0.48)	12.23 (0.48)	11.30 (0.60)

Table: Average temperatures (°C); standard deviations in parentheses

Since	1850	1900	1950	1997
Global	1.09	1.26	1.82	2.84
Contiguous U.S.	0.98	1.23	1.42	2.56

Table: Mean rates of change (°C/Century)

- The first table shows that average temperatures are increasing from pre- to post-Kyoto
- The second shows mean rates of change have more than doubled, comparing the 1850 - 2020 average against the 1997 - 2020 average

Empirical Framework - ARMA Model

- Time-based model: $y_t = a_1 y_{t-1} + a_2 y_{t-2} \cdots + a_n y_{t-n} + w_t + \epsilon_t$
- Introduce backshift operator: define B to be an operator on any time-related variable y_t such that $By_t = y_{t-1}$. Then we can write

$$y_t = a_1 B y_t + a_2 B^2 y_t \cdots a_n B^n y_t + w_t$$

- Isolate w_t in terms of y_t: $y_t - (a_1 B y_t + a_2 B^2 y_t \cdots a_n B^n y_t) = w_t$
- Write our backshift operator as a polynomial expression in terms of B to get $\phi(B) y_t = w_t$, model will determine the best-fitting $\phi(B)$
- Drift term, w_t may also be affected by past drift terms
- Using same logic as before, we can incorporate this: $\phi(B) y_t = \theta(B) w_t + \epsilon_t$
- This is called ARMA (autorregressive moving average), which tries to determine the polynomials ϕ, θ that best model this result

Empirical Framework - Tests for Significance

- Unit root test - we need to test that our model converges well enough to predict past data (i.e. that variance isn't infinite). This occurs when the "roots" of $\phi(B)$ can be bounded. We can do a statistical test of significance on this
- ACF test - auto-correlation function measures the correlation and significance of each given coefficient to determine whether or not it belongs in the model

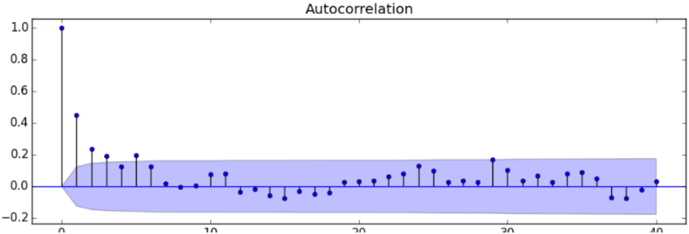


Figure: Example of an auto-correlation graph with 4 significant coefficients.

Empirical Framework - Model and Controls

- Our empirical method will compare two models
  1. ARMA(n_1, m_1) model built on data from 1850-present
  2. ARMA(n_2, m_2) model built on data from 2000-present
     *n_1, m_1, n_2, m_2 determined by ACF/PACF tests
  3. Determine if the rate of warming over the past 20 years has a statistically significant ($p < 0.05$) decrease from the predicted values
- We will test for the existence of alternative mechanisms that impact global climate temperature, such as sunspot cycles, El Niño, La Niña, and other climate oscillation patterns by looking at a periodogram
- We can use a psuedo-control on Kyoto to look at warming rates locally within the U.S., the last major developed nation to engage in climate change control, and the only one not in Kyoto

Results - Periodogram

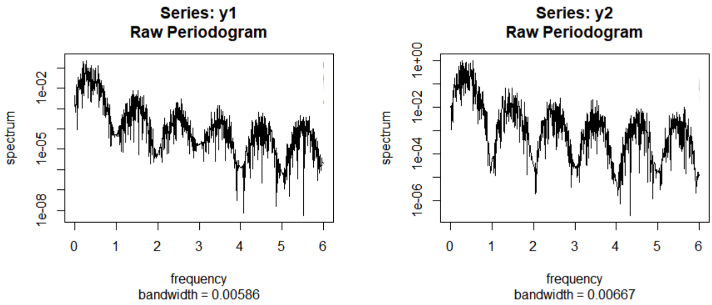


Figure: Periodograms showing periodic cycles for global (left) and U.S. (right).

- Outside of our annual cycle, the periodogram revealed no statistically significant frequencies in its domain
- This indicates that cycles like El Niño and sunspot irradience do not have a significant impact on the auto-regression trends in our model

Results - Outside Cycles

- We also want to ensure there's no fractional cycles, like half-months to account for
- Take the logged linear approximation of our periodogram cycle to show that there's no fractional trend
- Observe a line with slope -0.019, a statistically insignificant trend that indicates we can use our $AR(12)$ assumption

Results - ACF/PACF Testing

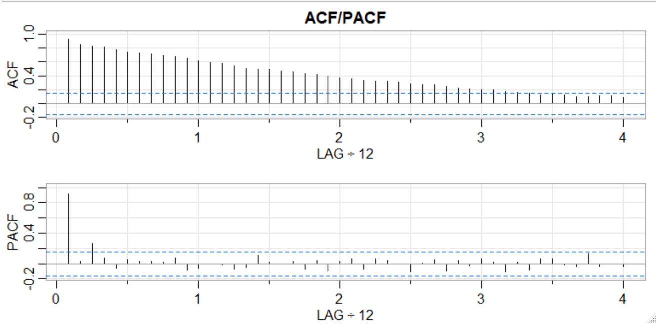


Figure: Auto-correlation and partial auto-correlation graphs.

- The ACF trailed off after 12 months, indicating that the past 12 months moving average has a statistically significant correlation with the current temperature
- Thus, we build an $ARMA(12, 12)$ model after trending out an annual cycle

Results - Selected Model and Significance

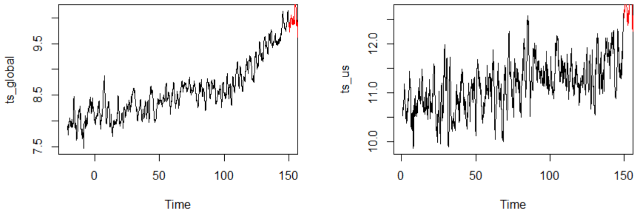


Figure: Predicted global (left) and U.S. (right) temperatures using the 1850 - 1999 models are highlighted in red.

- Over the span of our cycle, the moving average component within global data from 1850-1999 (note that the x-axis is labelled as years after 1850) was $w_t \approx 1.35$, with standard error ≈ 0.03
- Our average w_t coefficients over 2000-present was $w_t \approx 1.42$
- This falls outside the 95% confidence interval, indicating there is a statistically significant change in the trend for global climate change

Results - Cross-Model Comparison

- By comparison, we look at our control group on just the U.S.
- The moving average component within global data from 1850-1999 was $w_t \approx 1.17$, with standard error ≈ 0.05
- Our average w_t coefficients over 2000-present was $w_t \approx 1.55$
- This falls outside the 95% confidence interval, indicating there is a statistically significant change in the trend for global climate change.
- Keep in mind, w_t is an interpretation of how much the moving average is affected by previous changes, not a statement on the rate of climate change itself
- These conclusions tell us that in both the case of global data and U.S. specific data, we have significant reason to believe that the change rate of warming has been impacted in a statistically significant way post-Kyoto
- Looking at the predictive models on the other page, we see that that the predicted results using the 1850 - 1999 model are higher than the predicted results using the 2000 - 2020 model
- This indicates that the trends we observe with current data show a pattern of warming slowdown

Conclusion

- Unfortunately, we cannot completely prove causality with a topic like climate change since the scope of possible factors is so large (country-specific policies, environmental targets from corporations)
- U.S. model was not significantly different from the global model
- These issues present limitations to our results
- We can conclude that warming trends shifted post-Kyoto but we can't use U.S. as a control on that statement, so it is difficult to infer causality
- For future studies, it would be more practical to observed the effect of international policies locally
- Example: select a country and consider how international policy changed how that country tackles climate change and consider major industries and companies that operate in that country