Recent Developments in Climate Econometrics: Models and Results

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Overview of the Lectures

1. **General considerations on modelling/forecasting climate data**
2. Three example cases:
   - Case 1: The Tip of the Iceberg
   - Case 2: Climate Change and Agriculture
   - Case 3: Uncomfortable Temperatures
3. Some general conclusions
4. Spatial econometrics: the Spatial Autoregressive (SAR) Model
5. Assignment

Please... interact with me and each other!

How difficult is the climate? (Your answers)

1. Does the greenhouse effect exist? Why? Why not?
2. Are climate predictions difficult or easy?

How difficult is the climate? (My answers)

1. Does the greenhouse effect exist? Why? Why not?
   - Fourier (**1824**) - *Remarques Générales sur les Températures du Globe Terrestre et des Espaces Planétaires*
   - Denying GHG effect implies losing the ability to explain the Earth's and Venus' temperature
2. Are climate predictions difficult or easy?
   - A lot of the underlying physics is "well understood"
   - Business-as-usual or are we going to adapt/behave/pollute?

Broad classification of climate research

1. Predict climate variable under business-as-usual
   - sea-level
   - ice coverage of North pole
   - coral reef area

2. Determine relation between climate variables(s) and X and study the effect of climate change on X, where X can be
   - agriculture
   - health
   - stock returns
   - any variable under (1)

3. Policy evaluation (e.g. EU ETS)

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Case 1: The Tip of the Iceberg

Diebold and Rudebusch (2021), *Probability Assessments of an Ice-free Arctic: Comparing Statistical and Climate Model Projections*, Journal of Econometrics

Welcome to the climate casino...

Question: An ice-free arctic ocean will occur by...

a. 2040
b. 2060
c. 2080
d. never

Background

- North pole is warming about 2x faster (why?)
- Tricky, because...
  - Altering arctic ecosystem and habitat
  - Thawing permafrost is responsible for:
    - CO_2 and CH_4 emission (release+rotting)
    - bacteria+virus reactivation
  - Altering thermohaline circulation
  - Geopolitical implications (Artic shipping routes, newly accessible natural resources)

Data

- High ice albedo is nice for satellite measurement
- Brightness reading to decide between "ICE" and "NO ICE"
- Monthly data on Nov 1978–Oct 2019 on Sea Ice Extent (SIE)

The Econometric Model

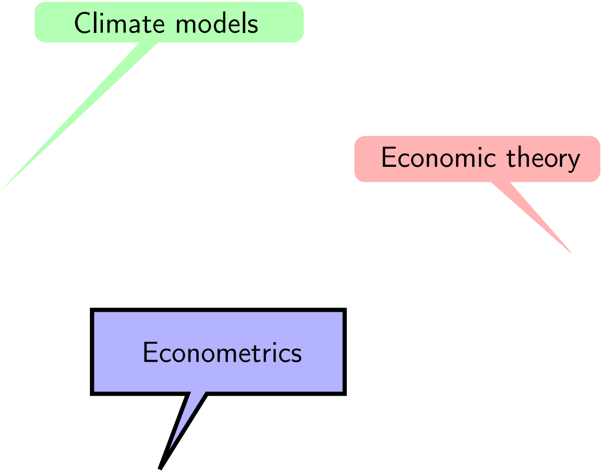
$$
\begin{aligned}
SIE_t^* &= \sum_{i=1}^{12} \delta_i D_{it} + \sum_{i=1}^{12} \gamma_j (D_{jt} \times TIME_t) \\
&\qquad + \left(\left(\sum_{k=1}^{12} \alpha_k (D_{kt} \times TIME_t^2) \right) \right) + \varepsilon_t \\
\varepsilon_t &= \rho \varepsilon_{t-1} + v_t \\
v_t &\sim iid(0, \sigma^2) \\
SIE_t &= max(SIE_t^*, 0)
\end{aligned}
$$

- D_{jt}: monthly dummy
- $TIME_t$: deterministic time trend

Some Findings by the Authors...

- Quadratic model has best fit (by AIC and BIC)
- Almost 60% chance of ice-free Arctic Ocean sometime during 2030s
- Different behaviour between statistical and Couple Model Intercomparison Project (CMIP5) findings. Ice thawing in statistical model is
  1. faster (vs. slower)
  2. accelerating (vs. slowing down)

Discussion



Case 2: Climate Change and Agriculture

Liang et al. (2017), *Determining Climate Effects on US Total Agricultural Productivity*, PNAS

Background

Question: How can climate change influence US agriculture? Which variables/processes are important?

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- **Temperature and precipitation** changes affect crop growth
  - California transforming more-and-more into a desert, increasing fertility in Alaska
  - The weather is becoming more extreme: droughts, heat waves and floods are more frequent
- **CO_2 fertilization**
- "*Thus, the United States is now getting roughly 2.5 times as much agricultural product from the same resource base as it was in 1948*" (Liang et al. (2017), page E2286)

Data

- **Total factor productivity (TFP) of agriculture**: ratio of output over input (read: agricultural efficiency)
  - yearly observations for 1951–2011
  - TFP is trending (compare to quote on previous slide)

- US climate data: daily **average air temperature (TA)** and daily **cumulative precipitation (PR)** anomalies
  - daily observations (available for 1895–2013)
  - spatial data with 0.26° resolution

The Econometric Roadmap

1. Use spatial climate data to define climate indices
2. Construct multivariate regression to model the relationship between climate indices and *changes* in agricultural TFP
3. Close the circle using climate projections...

Step 1: Constructing Climate Indices

a. For each grid point, compute correlation between TFP change and the climate series (TA and PR)[1]

b. Select all grid points with a correlation less than -0.361 or above 0.361 and cluster these into regions

c. Average over selected grid points within regions

[1] Anomalies are calculated w.r.t. the seasonal mean.

Step 2: The Regression Model

A linear regression model, the result for 1951–1980 period is:

$$TFPC[1] = 0.006 + 0.0076\,TA_{SON.NA} - 0.0098\,PR_{SON.TX} - 0.0075\,TA_{MAM.CX}$$

Comments:

1. Regions: Northeast through Midwest and mid-Atlantic (NA), Texas (TX), California, Oregon, Nevada, Arizona and western New Mexico (CY)
2. Seasons: September-October-November (SON), March-April-May (MAM)
3. Strongly correlated indices were dropped

Question: What about the signs? Do we expect positive/negative signs?

Step 3: Bring in the Climate Projections

- Climate projections from the **Coupled Model Intercomparison Project Phase 5 (CMIP5)**
  - collection of high-resolution climate models
  - scenarios: RCP4.5 (medium) and RCP8.5 (high)

- ... and closing the circle:

$$\begin{bmatrix}\text{CMIP5}\\\text{projections}\end{bmatrix} \Longrightarrow \begin{bmatrix}\text{climate index}\\\text{projections}\end{bmatrix} \Longrightarrow \begin{bmatrix}\text{TFP}\\\text{projections}\end{bmatrix}.$$

Question: What is implicitly assumed in this analysis?

Some Findings by the Authors...

1. Analysis for both 1951–1980 and 1981–2010
   - Four vs. eight relevant climate indices
   - R^2 are 49.3% and 70.4%, respectively

   "*... suggests that agricultural productivity has become more sensitive to climate in recent years*"

2. "*... TFP could fall to pre-1980 levels by 2050 even when accounting for present rates of innovation*"

Discussion Points

- Is agriculture economically important?
  - Farming accounted for $\pm 10\%$ of GDP in 1929 and $<1\%$ by 2010 (Nordhaus (2013), page 88)

- Are these results for US specific?

- Mitigation and adaptation. Is agriculture **manageable**?

Case 3: Uncomfortable Temperatures

Zhao et al. (2021), *Global, Regional, and National Burden of Mortality Associated with Non-optimal Ambient Temperatures from 2000 to 2019: A Three-stage Modelling Study*, The Lancet: Planetary Health

Background

- Climate stress directly impacts mortality through heat waves, pollution, and floods
- Indirect effects linked to changes in living standards (read: deteriorating living conditions due to climate change)

… Three-stage Modelling Study - STAGE 1

=> Extract temperature influence <=

- Y_{it}: death count in location i on day t
- Assume $Y_{it} = \text{POI}(\mu_{it})$ with

$$\log(\mu_{it}) = \alpha + \underbrace{cb(Temp_{it})}_{\text{temperature effect}} + \underbrace{ns(Time_{it}) + \beta DOW_{it}}_{\text{time effect}}$$

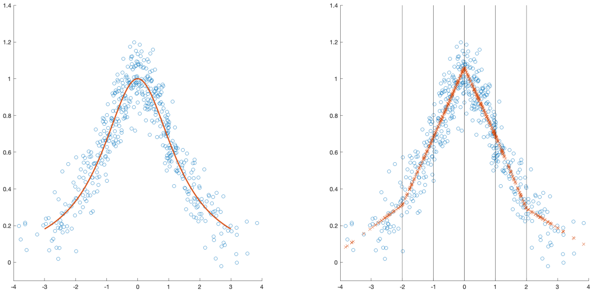
where

- $cb(Temp_{it})$ is a spline on temperature for 0–21 lag days
- $ns(Time_{it})$ is a spline function on time
- DOW_{it} are the days of the week

On Splines (1)

- For *unknown* $g(\cdot)$, consider $Y_i = g(X_i) + \epsilon_i$
- Consider the following chain of thoughts:
  1. If $g(\cdot)$ is smooth, then around x^*, we have
     $$g(x) \approx g(x^*) + g'(x^*)(x - x^*). \qquad (1)$$
     This locally approximates $g(x)$ by a line (polynomial of order 1)
  2. But... (1) is only useful for $x \approx x^*$
  3. Solution: take more points

On Splines (2)



- Linear spline with knots at -2, -1, 0 , 1, and 2.
- OLS regression on constant, x, and $(x - x^{(j)})1_{\{x > x^{(j)}\}}$ as regressors ($x^{(j)}$ denoting j^{th} knot)
- Cubic splines are famous

On Splines (3)

- We can play a similar trick on coefficients:

$$Conc_t = \beta_1 Sleep_{t-1} + \beta_2 Sleep_{t-2} + \ldots + \beta_7 Sleep_{t-7} + \varepsilon_t,$$

where

$$\beta_j = b_0 + b_1 j + b_2 (j-3) 1_{\{j>3\}} \qquad (j = 1, \ldots, 7).$$

- Patterned way of describing the influence of past sleep on current concentration

... Three-stage Modelling Study - STAGE 1 (revisited)

=> Extract temperature influence <=

- Y_{it}: death count in location i on day t
- Assume $Y_{it} = \text{POI}(\mu_{it})$ with

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where

- $cb(Temp_{it})$ is a spline on temperature for 0–21 lag days (over time and temperature percentiles)
- $ns(Time_{it})$ is a spline function on time
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... Three-stage Modelling Study - STAGE 2 (1)

=> Relation to predictors <=

- For each of the 750 locations, we obtain a set of coefficients describing $cb(Temp_{it})$
- To illustrate, imagine analyzing

$$Conc_t = \beta_1 Sleep_{t-1} + \beta_2 Sleep_{t-2} + \ldots + \beta_7 Sleep_{t-7} + \varepsilon_t,$$
$$\beta_j = b_0 + b_1 j + b_2 (j-3) 1_{\{j>3\}} \qquad (j = 1, \ldots, 7).$$

for all students in this room. We have $(\hat{b}_0^{(1)}, \hat{b}_1^{(1)}, \hat{b}_2^{(1)})$, $(\hat{b}_0^{(2)}, \hat{b}_1^{(2)}, \hat{b}_2^{(2)})$, etc.

... Three-stage Modelling Study - STAGE 2 (2)

- Does age effect concentration?

$$\hat{b}_k^i = \alpha + \beta age_i + \eta_i, \qquad i = 1, \ldots, n$$

- Related to paper, explain temperature coefficients using:
  1. continent dummy
  2. climate classifier
  3. GDP per capita
  4. yearly average of daily temperature
  5. range of daily temperature

... Three-stage Modelling Study - STAGE 3

- ... and closing the circle:

$$\begin{bmatrix} \text{Temp} \\ \text{continent dummy} \\ \text{climate classifier} \\ \text{GDP per capita} \\ \text{yearly average of daily temperature} \\ \text{range of daily temperature} \end{bmatrix} \implies \left[\mu_{it}\right].$$

- Temperature spline also provides a temperature with lowest μ_{it}
  - $Temp > Temp_{opt} \implies$ heat-related deaths
  - $Temp < Temp_{opt} \implies$ cold-related deaths

Some Findings by the Authors...

1. Most excess deaths are related to cold temperatures
2. Temperature increases during 2000-2019 decreased global excess death
3. But... look at their Figure 1

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My Conclusions

- The **blessings and curses** of economic growth
  - Carbon tax can resolve the "*tragedy of the commons*"
    - guide technological innovations
    - consumer and producer signalling
    - ... maybe also some peace of mind?
- Climate resilience dependence on **manageability** (and by extension on wealth?)
- Econometrics has a role in climate change modelling, especially on the economic side

Next lecture...

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