A project on economics and global climate change

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Background

- Widespread worry about global warming.
- Is it due to economic activity? The consensus among scientists seems to be yes (though there are differences in views).
- A set of questions follow:
  - Positive questions (e.g., what are the effects on the climate under different scenarios for economic activity; how does climate influence economic activity and our welfare?)
  - Normative questions (what can/should countries do, individually and as a group?)
- Natural scientists are not equipped to answer many of these questions (when incentives, and looking forward, matter), but we are!
- This project: an attempt to build a setting where these kinds of questions can be addressed quantitatively.
- Key: make use of modern macro methods—SED methods.

Why am I interested in this?

- A keen interest in wildlife (protecting polar bears, etc)?

  No. I hate polar bears. They are ferocious animals that eat humans if given a chance.

- Plus: Scandinavia would benefit from higher temperature!
- Seriously: comparative advantage, and I feel I/we should try!
- Work reported on here with/by John Hassler, Johan Gars, Conny Olovsson, and Tony Smith.
- Also part of MISTRA-SWECIA (project joint w/ natural scientists).

Starting point

- William Nordhaus: pioneering work building dynamic quantitative economy-climate models.
- Nordhaus's frontier model: the "RICE" model (Regional dynamic Integrated model of Climate and the Economy); see *Warming the World: Economic Models of Global Warming* by Nordhaus and Boyer.
    - Economic model: neoclassical setup with non-renewable resource ("oil"); micro-founded savings decisions based on standard preferences, finite time, deterministic.
        - 8 regions, making independent decisions.
        - Limited interaction between regions.
        - Climate enters as TFP (damage from global warming is expressed as lower TFP).
    - Climate model: based on the "carbon cycle" and on how CO_2 in the atmosphere influences the climate (temperature).
    - Numerical methods: big nonlinear equation solver (GAMS) of FOCs, resource constraints, etc.

Approach here

Build on Nordhaus's work, with several changes.

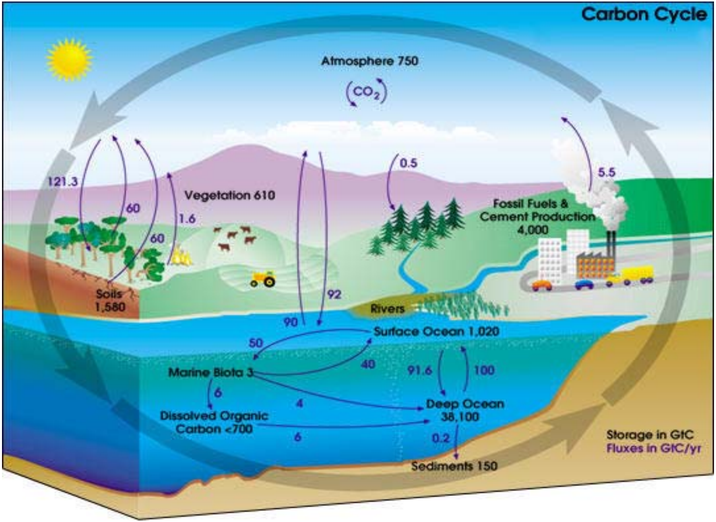
- Economic model:
  - Geographic/population structure at very high level of resolution.
  - Infinite horizon.
  - Uncertainty (about which specific regions are hit and how).
  - Interaction between regions (trade, insurance, migration, etc).
  - Richer modeling of effects of climate: more specific damages modeled explicitly.
  - Endogenous technical change.
  - Explicit analysis of policy.
  - Political economy?
- Climate model: build on Nordhaus (though much more disaggregated data needed).
- Numerical methods: heavy use of recursive methods; recursive competitive equilibrium (with externalities from energy use).

Remainder of presentation

1. A primer on the carbon cycle and how it is modeled in RICE.
2. A baseline one-region model: shows the essence of the neoclassical setting with a non-renewable resource.
3. Some remarks (taxation, endogenous technical change).
4. A model with many (a continuum of) regions, Bewley-Huggett-Aiyagari-style.
5. Early computational results (big project—we are far from done).
6. Concluding comments.

The carbon cycle

Planet Earth contains carbon in different forms. Carbon circulates between different storage deposits.



The carbon cycle, cont'd

- The CO_2 in the atmosphere is what influences our climate; need to understand determination of CO_2 concentration there, as function of human emissions/burning of fossil fuels.
- Only some parts of the deposits interact. Stylized picture at t:
  1. E (energy use) adds to M_A (carbon mass in atmosphere);
  2. part of M_A flows into M_U (upper oceans and biosphere);
  3. part of M_U flows back into M_A; part flows into M_L (deep oceans);
  4. part of M_L flows back into M_U.

  Ignored here: the very long run whereby fossil fuels are recreated.
- Note: long run implied by the above is a situation with $E = 0$ (because there is no oil left) $\Rightarrow$ steady level of M_A. Turns out: this level is not disastrous in terms of its climate effects.
  However: now we are seeing very high and increasing M_As due to high recent E levels.
- Thus: it's all about transition.

The rest: forcing, the linear system, ...

- Radiative forcing: how CO_2 affects climate, as captured by T (temperature). T is influenced by M_A (and other greenhouse gases/aerosols, but less important).
- A simple dynamic system (slight simplification of RICE):

$$\begin{bmatrix} M_{A,t} \\ M_{U,t} \\ M_{L,t} \\ T_t \end{bmatrix} = \begin{bmatrix} \phi_{11} & \phi_{21} & 0 & 0 \\ 1-\phi_{11} & 1-\phi_{21}-\phi_{23} & \phi_{32} & 0 \\ 0 & \phi_{23} & 1-\phi_{32} & 0 \\ 0 & 0 & 0 & 1-\sigma_1\lambda \end{bmatrix} \begin{bmatrix} M_{A,t-1} \\ M_{U,t-1} \\ M_{L,t-1} \\ T_{t-1} \end{bmatrix}$$

$$+ \begin{bmatrix} E_{t-1} \\ 0 \\ 0 \\ \sigma_1 F_t, \end{bmatrix};$$

the "forcing" variable, F, is given by M_A and O (other GHG), through

$$F_t = \eta \frac{\ln\left(M_{A,t}\right) - \ln\left(M_A^{1750}\right)}{\ln 2} + O_t.$$

…and damages

Nordhaus estimates region-specific damages:

$$D_{t,j} = \theta_{1,j} T_t + \theta_{2,j} T_t^2,$$

which influence production multiplicatively: net output net of the damages is

$$\frac{1}{1 + D_{t,j}} \left[Y_{t,j} - G_{t,j} \right]$$

where G is the cost of producing carbon energy.

This is a summary way of capturing the total effects of adverse effects on health/life quality, life expectancy, production, depreciation, etc., from the increased incidence and severity of storms, floods, droughts and heat waves, and so on.

The fact that different regions are hit very differently is key (Scandinavia may benefit; Bangladesh may go under).

It seems important to model these things in more detail. Initially, we adopt Nordhaus's formulation.

The one-region model, no climate variable

The planning problem (version of Dasgupta and Heal, 1974):

$$\max_{\{C_t, K_{t+1}, E_t, R_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\sigma} - 1}{1-\sigma}$$

subject to

$$C_t + K_{t+1} = \gamma_a^t K_t^{\alpha} E_t^{\gamma} + (1-\delta) K_t$$

$$R_{t+1} = R_t - E_t.$$

Note: no costs of extracting E (R is a "cake"). Results:

1. Exact balanced growth: C and K grow/shrink, and R and E shrink, at constant rates.
2. It is an "endogenous-growth" model!
3. Positive C growth made possible by high enough γ_a.
4. With $\sigma = 1$ and $\delta = 1$, constant savings rate ($\alpha\beta$) and constant extraction rate (β) are optimal.
5. Balanced growth due to Cobb-Douglas ass'n (with CES, energy-augmenting technical progress needed).

The one-region model, cont'd

- We analyze this problem, including dynamics, with DP.
- We use a transformation: because of homogeneity, we can guess and verify that

$$V(K, R, a) = Y^{1-\sigma} \tilde{V}(y),$$

  where $Y \equiv aK^{\alpha} R^{\gamma}$ and $y \equiv Y/K$. The transformation saves on states and is key for computation (compact state domain).
- We can then state a DP problem in $\tilde{V}(y)$. It is easily solved with standard methods.
- For this economy, welfare theorems apply. Let R be sold competitively. Decentralization involves usual components of recursive competitive equilibrium (RCE): (i) individual portfolio behavior (investment vs. buying stock in oil companies); (ii) aggregate law of motion for state y; (iii) price function for oil, $\tilde{P}(y)$.

  $\Rightarrow$ "Hotelling formula": P grows at rate of interest (for oil producer to be indifferent between selling at t and $t+1$).

The one-region model with climate

- Add the equations for the climate system, and damages. Note: adds 5 state variables (4 new ones, plus level re-enters).
- Study the planning problem (same # of controls, but more states!): $\tilde{V}(y, M_A, M_U, M_L, T, R)$. Doable (but not done); carbon cycle, climate dynamics very slow.
- Study the decentralized problem: RCE with an externality. Need to find equilibrium price functions etc; should be eminently doable too. Use planning problem as a start.
- We conjecture that recursive methods will be very helpful for finding dynamics (compared to shooting algorithm).
- Aggregate shocks feasible to study too.
- At this point, we have a quantitative, modern-macro, model ready for answering questions.
- More readily interpretable (for us!) than GAMS output.

Important first applications that are ongoing

1. Tax policy.
   - First thoughts: a constant tax on energy of no use. (Easy to verify.) Reason: no extraction costs, and tax cancels in Hotelling formula.
   - Taxes *are* useful but it's all about the *timing* of taxation.
2. Directed technical change: energy saving vs. saving in other inputs (along the lines of work by Acemoglu, 2003), and CES technology.
   - Energy share is NOT constant in the data. Less substitutability than Cobb-Douglas leads to equilibrium efforts to save energy, and to balanced growth.
   - Related: R&D toward developing alternative sources of energy. (Here even constant taxes may become important.)

The many-region model

Main idea: use Bewley-Huggett-Aiyagari-style (heterogeneous-agent) model with a *continuum* of geographical locations.

Initially, at least: no aggregate (global) uncertainty. But each location has idiosyncratic (climate and TFP) shocks. Riskfree asset available.

More precisely:

- Each location: "planner", representing local competitive eq'm.
- Most countries as we know them would consist of many locations.
- Heterogeneity:
  1. Geography, implying differing sensitivities to climate variations.
  2. TFP/economic development differences across locations.
  3. Define trade/insurance/factor/capital mobility areas potentially.

  Note: in standard model of this type, ex-ante equal agents; here not (or at least VERY persistent differences). Not a big problem computationally.

So, in brief: a quantitative neoclassical model of the world.

So far, and a conjecture:

We have a LONG ways to go!

So far, we solved the continuum version of the one-region model *without* climate variables, and for a *steady state*.

For $\delta = 0.1$, $\gamma = 0.05$, $\beta = 0.99$, $\sigma = 2$, $\alpha = 0.36$, serial correlation of idiosyncratic TFP shocks 0.9, std. dev. 5%:

1. Deterministic model: $q = 0.9361$, $p = 0.3269$, $y = 0.3633$, $g = 1.0284$.
2. Model with shocks: $q = 0.9383$, $p = 0.3403$, $y = 0.3538$, $g = 1.0286$.

Thus, small differences.

Conjecture: since partial insurance works effectively, approximate aggregation is likely to hold. Thus, aggregate dynamics in this continuum-locality model and one-region world are likely similar.

The many-region model with climate

- In RCE, individual location's value function: $V(z_1, z_2, \omega; \tilde{\Gamma}, y, M_A, M_U, M_L, R)$. Here,
  1. z_1 is idiosyncratic TFP,
  2. z_2 is idiosyncratic climate (influenced by M_A), and
  3. $\tilde{\Gamma}$ is world distribution of *relative wealth levels* and zs. (T is now replaced by the z_2s.)
  4. Note that z_2 is endogenous now (but not for a small agent: a global externality).
- Calibration will be daunting but exciting. There is detailed economic data at fine resolution, and detailed climate data (collected by satellites); natural scientists stand ready to assist.
- We are quite hopeful that approximate aggregation ("$\tilde{\Gamma}$ does not matter") will help greatly in computing the transition dynamics for the world model. Thus, the dynamics may simply be very close to those of the one-region model above!

Conclusions

- An area where macroeconomic tools—dynamic methods and quantitative analysis—are sorely needed.
- We need quantitative (general-equilibrium) models of the world economy; there are not many out there.
- Large interest from the general public (e.g., Stern report, 2006), and yet relatively few competing quantitative analyses.
- Let's take responsibility as scientists and contribute where other sciences cannot deliver!
- We believe that large advances are possible relative to the current state of the art.
- We have no particular priors; this could mainly be about redistribution across regions (costs of relocation though), and tradeoff between welfare of current and future generations not obvious (future generations likely much better off than we are anyway). We will simply report findings, for different generations (need OG structure too), as economists know how to.

MISTRA SWECIA

CLIMATE, IMPACTS & ADAPTATION