

Lecture Notes Lecture 1-3

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- Purpose; Study models of the interaction between the global economy and the climate to
 - provide understanding of important mechanisms,
 - analyze optimal policy.
- Involves result from both social and natural sciences.
- But we are economists – use our comparative advantage to contribute and critically analyze the economic side but take "conventional wisdom" from the natural science as given.
- Economics is key for analyzing effects of policy.

Economics is important for

- analyzing effects of policy,
- understanding endogenous adaptation and technical change,
- making forecasts.

- Climate change due to emissions is a true externality.
- A unit of emissions cause damages that are spread out globally,
- having a negligible direct effect on the emitter.
- A coordination problem. Likely to need policy.
- Taxes that internalizes the externality is one solution. Emission caps another.
- Problems:
 - 1 Incentive to cheat.
 - 2 Benefits and costs not evenly spread and difficult to verify.

A schematic IAM - Three building blocks

The economy

People who produce,
consume and invest

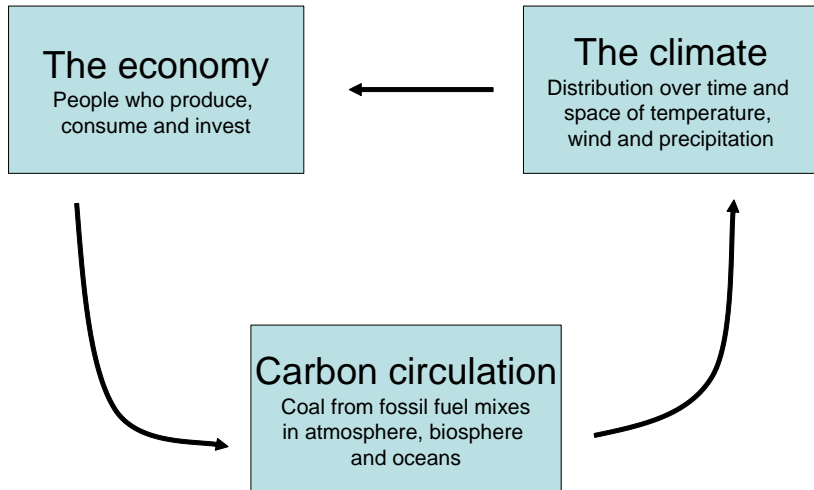
The climate

Distribution over time and
space of temperature,
wind and precipitation

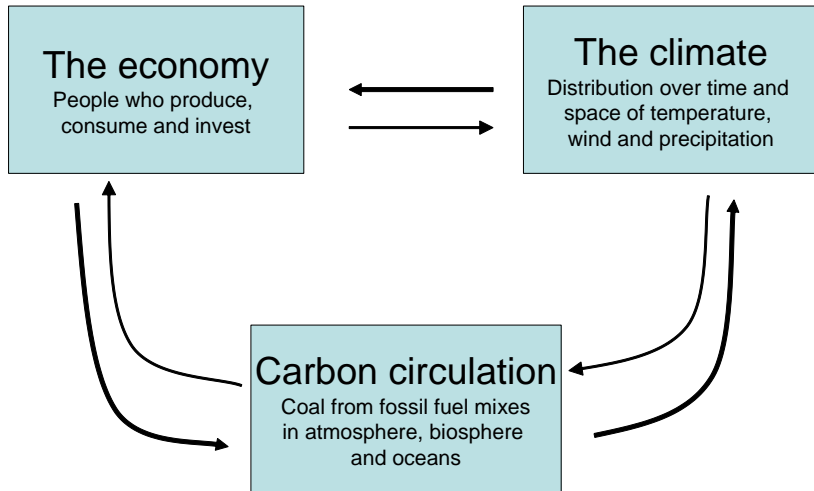
Carbon circulation

Coal from fossil fuel mixes
in atmosphere, biosphere
and oceans

A schematic IAM - interactions

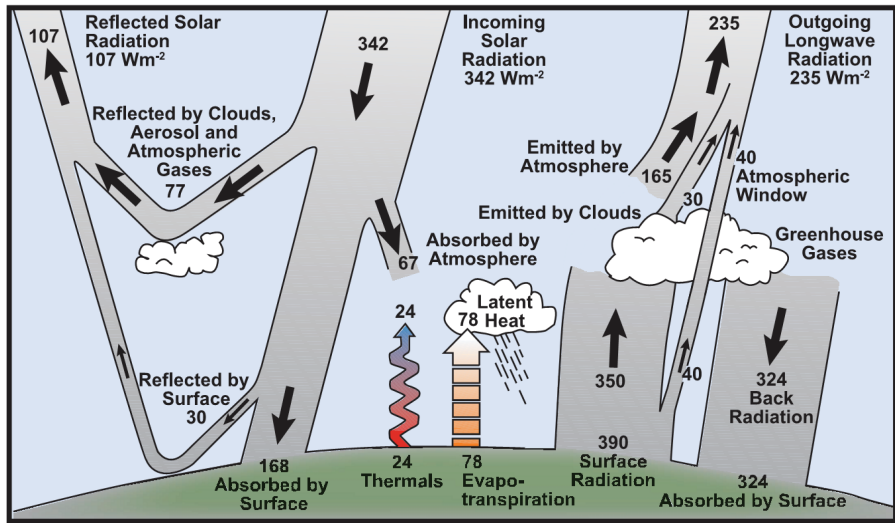


A schematic IAM - dynamic and bidirectional



- Energy balance:
 - Incoming Solar radiation ($342 \text{ W/m}^2 = 2400 \text{ kW}$ per football field), in steady state equals
 - Outgoing radiation, consisting of
 - direct reflection (1/3)
 - Longwave (heat) radiation (2/3).
 - The latter is a function of, in particular temperature and greenhouse gases.
 - Without greenhouse gases and atmosphere, ground temperature would be -19.
- Circulation model – energy transported by flows in air and water producing weather and climate.

Energy balance:1



From IPCC FAQ

Energy balance: greenhouse effect

- Most of longwave surface radiation is absorbed by clouds and greenhouse gases and re-emitted back.
- Strength depends on greenhouse gas concentration.
- Most important is water vapor. Second is CO₂.
- Human activities has increased concentration of CO₂ and methane.
- Increase is equivalent to increased incoming radiation (forcing) of 1.7 and 1 W/m², respectively.

Energy balance: feedback effect

- Gross flows are very large relative to direct effect.
- Creates feedback effects. Example, more CO₂ increase forcing, leads to
 - more water vaporization, increase greenhouse effect.
 - melting of icecaps, decrease direct surface reflection (albedo).
 - changed cloud formation, change back radiation and reflection.
- Feedback mechanisms are very important and been so historically.
- Direct effect of CO₂ emission, relatively certain. Not the case for feedback.

Energy balance: the simplest case

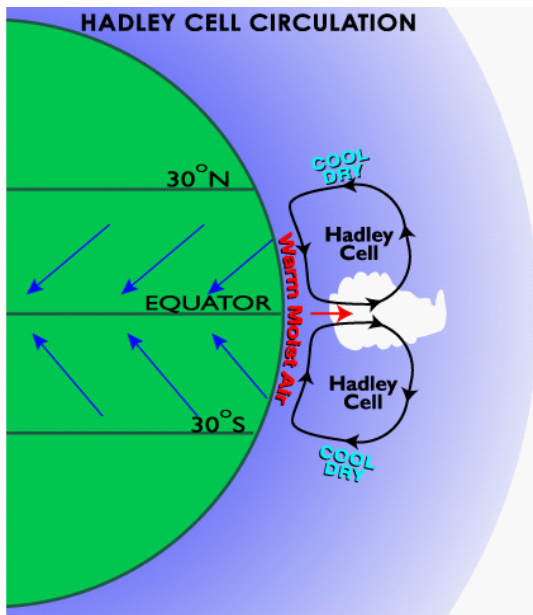
- Nordhaus DICE/RICE models.
- Part of most influential IAM.
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$$F_t = \eta \frac{\ln \frac{M_{A,t}}{M_{A,PI}}}{\ln(2)}$$

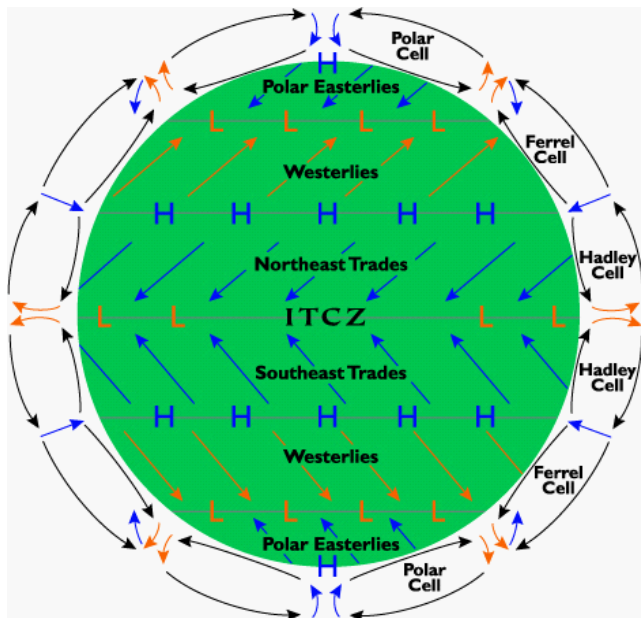
- $\eta = 4.1 W/m^2$. Measures the effect of a doubling of CO₂ concentration.

- Circulation models.
- Energy is not evenly radiated to the earth. Highest around equator.
- Creates systematic flows of air and water.
- Used to forecast weather – but also climate.

Climate models: Circulation cells 1



Climate models: Circulation cells 2

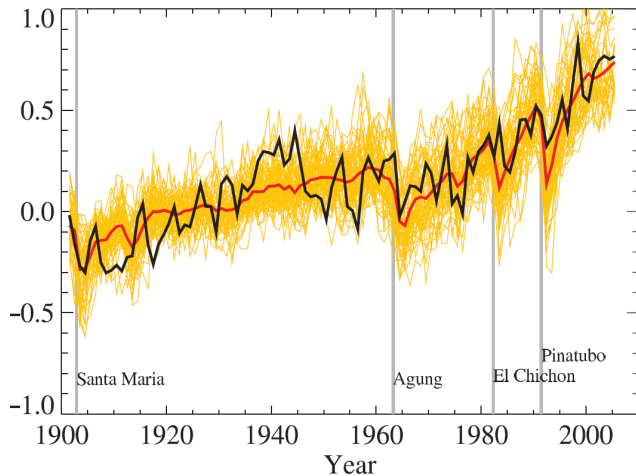


Climate models: key points

- Building on deterministic laws of physics but chaotic in nature. This implies:
 - A butterfly effect – small variation in initial state e.g., distribution of energy, leads to unsystematic large differences in weather a few weeks later.
 - Unconditional distribution stable, e.g., mean and variance of temperature and wind speeds.
 - Best forecast is unconditional distribution for forecasts beyond a few weeks.
- State-of-the art climate models build on same principles.
- Due to uncertainty about various feedback mechanisms – there are different models with different forecasts.
- May be particularly good/bad at particular variables.

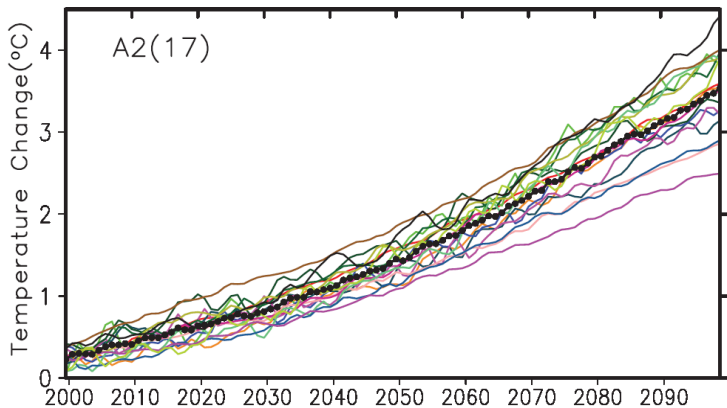
Climate models: model and historic data

Global mean temperature from 58 simulations from 14 models (red average, black data)



Climate models: model forecasts and data

Global mean temperature from simulations from IPCC ensemble of models.



Climate models: what variables are important?

- Often Global Mean Temperature is the focus of attention.
- Perhaps not the most important variable.
- In principle the whole spatial and temporal distribution of weather outcomes important.
- Often frequency and severity of extreme events are key for damages.
- More difficult to predict.
- Correlation over time and space important.

Climate models: reduced form

- Does not model circulation. Easier to use – can be calibrated to match global circulation model.
- Used by us and Nordhaus.

$$T_t = (1 - \sigma_1 (\lambda + \sigma_2)) T_{t-1} + \sigma_1 \sigma_2 T_{L,t-1} + \sigma_1 F_t$$

$$T_{L,t} = (1 - \sigma_3) T_{L,t-1} + \sigma_3 T_{t-1} = T_{L,t-1} + \sigma_3 (T_{t-1} - T_{L,t-1})$$

- Can show that in the long run $T = \frac{F}{\lambda}$.
- A typical number for $\frac{\eta}{\lambda} = 3^\circ C$, i.e., a doubling of CO_2 leads to 3 degrees temperature increase.
- Other parameters $\sigma_1 = 0.23, \sigma_2 = 0.44, \sigma_3 = 0.05 \lambda = 4.1/3$.

- Climate change is a global phenomenon and affects the economy in a large number of ways.
- Two ways to estimate total effects:
 - bottom up – quantifying all potential effects and summing.
 - reduced form – looking at correlation between natural variation in climate to estimate effects on GDP and other variables.
- Approaches have different pros and cons. Complementary.

Nordhaus damages in RICE– a bottom up approach

- Divide effects into: 1. Agriculture, 2. Sea-level rise, 3. Other market sectors, 4. Health, 5. Non-market amenity impacts, 6. Human settlements and eco-systems, 7., Catastrophes.
- 13 regions; U.S., OECD Europe, Eastern Europe, Japan, Russia, China, Africa, India, Other high income, Other middle, Other low middle income, Low income, and High Income OPEC
- For each sector i and region j a function $\theta_{ij}(T, y_j)$ is estimated, measuring the damage or willingness to pay as a % of GDP for damages at temperature increase T and GDP level y_j . It is assumed that

$$\theta_{ij}(T, y_j) = Q_{ij}(T) \left(\frac{y_j(t)}{y_j(1995)} \right)^{\eta_i}$$

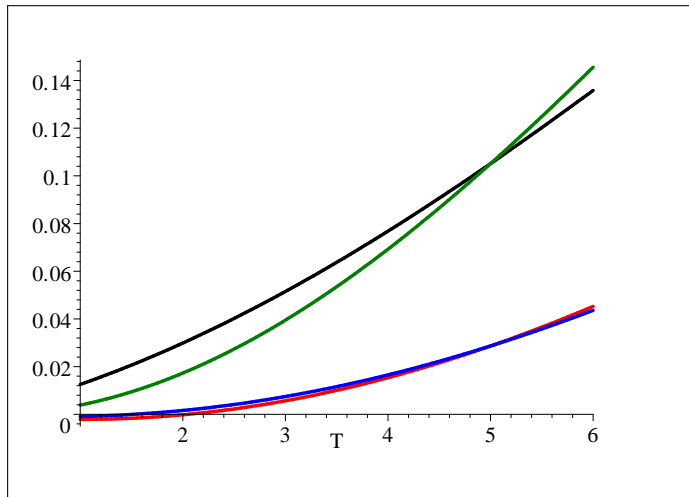
- Most studied. Damage depends on; CO_2 , temperature, precipitation and adaptation.
- Nordhaus summarize various studies, getting e.g., a doubling of CO_2 (increasing GMT around 3 degrees) reduces agricultural output as a share of GDP by 0.07% in the U.S., -0.51% in China, -0.87% in Russia, 1.54% in India, 0.06% in Africa.
- Generally negative effects if initial temp is above 11.5°C .
- Comparing studies for different temperature changes – a quadratic curve is fitted for each region.
- Income elasticity η_i assumed to be -0.1.

- Similar approach but typically less studies to rely on.
- Does not add up to very much for a temperature increase of 2.5 degrees. Global population based values $\sum_j w_j Q_{ij}$ (2.5), Ag =0.17%, Other m =0.23%, Coast =0.12%, Health 0.56% Non-market -0.03, Settlem. 0.1.
- Large heterogeneity. Over 1% loss in agriculture in India and Lower middle Income (Brazil and others). 3% loss due to health in Africa.
- Total damage zero or negative in U.S.and China. Large (around 3%) in Africa and India.
- Catastrophic impacts added.

- Survey to experts. "What is the probability of permanent 25% loss in output if global warming is 3 and 6 degrees respectively?"
- Varied answers with mean 0.6 and 3.4%. (median 0.5 and 2.0). Arbitrarily doubled and damage increased to 30% globally.
- Distributed over regions reflecting different vulnerability.
- Assuming risk aversion of 4 translated into willingness to pay to avoid risk.
- Leads to 1.02% and 6.94% WTP for 2.5 and 6 degrees warming globally.
- India twice as willing, US and China less than half.

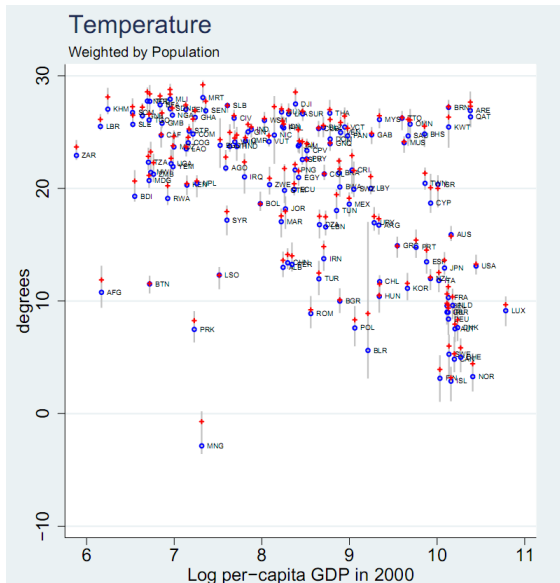
Nordhaus Summary

- $Q(T) = \left[1 - \frac{1}{1 + \theta_1 T + \theta_2 T^2} \right]$ $\theta_1 = -4.5 * 10^{-3}$ and $\theta_2 = 3.5 * 10^{-3}$.
Giving (Blue-USA, Red-Chi, Green-Eur, Black-LI)



- Idea is to use natural temporal variation in climate and correlate with economic outcomes.
- Cross-section not realistic (8.5 % lower GDP per degree Celsius).
- Not very much done.
- Dell, Jones and Olken. NBER WP 14132.
- Monthly data on weather from 1900, 0.5 degree spatial resolution (interpolation) (use 50 last yearly obs).
- Economic data from Penn World Tables, 136 countries.

Substantial natural variation



- Assume

$$Y_{it} = e^{\beta T_{it}} A_{it} L_{it}$$
$$\frac{\Delta A_{it}}{A_{it}} = g_i + \gamma T_{it}$$

- Implies

$$g_{it} = g_i + (\beta + \gamma) T_{it} - \beta T_{it-1}$$

- Also allow more slowly decaying effects (more lags) and different effects for poor and rich countries.

- Strong effects – a degree higher temperature leads to 1% less growth. Stronger when more lags are introduced.
- But only in poor countries (below median at start).
- Persists for at least 10 years.

Table 2: Main panel results

	Dependent variable is the annual growth rate						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Temperature	-0.197 (0.216)	0.219 (0.210)			0.208 (0.212)	0.130 (0.203)	0.177 (0.232)
<i>Temperature interacted with...</i>							
Poor country dummy		-1.305*** (0.479)			-1.282*** (0.482)	-1.303*** (0.477)	-1.400*** (0.526)
Hot country dummy						0.262 (0.411)	
Agricultural country dummy							-0.120 (0.390)
Precipitation			-0.019 (0.040)	-0.071* (0.040)	-0.072* (0.042)	-0.125** (0.053)	-0.088* (0.050)
<i>Precipitation interacted with...</i>							
Poor country dummy				0.118 (0.075)	0.102 (0.076)	0.096 (0.076)	0.142 (0.093)
Hot country dummy						0.081 (0.070)	
Agricultural country dummy							0.006 (0.077)
Observations	6014	6014	6014	6014	6014	6014	5432
R-squared	0.14	0.14	0.14	0.14	0.15	0.15	0.15
Temperature effect in poor countries		-1.087** (0.442)			-1.074** (0.446)	-1.173*** (0.404)	-1.223** (0.525)
Precipitation effect in poor countries				0.047 (0.065)	0.030 (0.065)	-0.029 (0.072)	0.054 (0.098)

Notes: All specifications use PWT data and include country FE, region \times year FE, and poor \times year FE. Robust standard errors in parentheses, adjusted for clustering at parent-country level. Sample includes all countries with at least 20 years of growth observations. Poor is defined as a dummy for a country having below median PPP gdp per capita in its first year in the data. Hot is defined as a dummy for a country having above median average temperature in the 1950s. Agricultural is defined as a dummy for a country having above median share of GDP in agriculture in 1995. Temperature is in degrees Celsius and precipitation is in units of 100mm per year.

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3: Models with lags

	(1)	(2)	(3)	(4)	(5)
	No lags	1 lag	3 lags	5 lags	10 lags
Temperature × Poor	-1.087** (0.442)	-0.954* (0.559)	-0.932* (0.560)	-0.933* (0.562)	-1.112* (0.586)
L1: Temperature × Poor		-0.351 (0.854)	-0.247 (0.919)	-0.328 (0.909)	-0.216 (0.958)
L2: Temperature × Poor			-0.210 (0.441)	-0.183 (0.459)	-0.120 (0.485)
L3: Temperature × Poor			-0.216 (0.519)	-0.096 (0.559)	-0.231 (0.606)
Temperature × Rich	0.219 (0.210)	0.202 (0.232)	0.243 (0.241)	0.293 (0.238)	0.392 (0.255)
L1: Temperature × Rich		0.047 (0.268)	0.074 (0.251)	0.094 (0.252)	0.093 (0.268)
L2: Temperature × Rich			0.062 (0.190)	0.115 (0.195)	0.043 (0.209)
L3: Temperature × Rich			-0.019 (0.197)	0.120 (0.186)	0.203 (0.198)
Includes precipitation vars.	NO	NO	NO	NO	NO
Observations	6014	6014	5905	5785	5449
R-squared	0.14	0.14	0.15	0.15	0.15
Sum of all temp. coeff. in poor countries	-1.087** (0.442)	-1.304* (0.677)	-1.605** (0.641)	-1.718** (0.720)	-2.006** (0.866)
Sum of all temp. coeff. in rich countries	-0.102 (0.647)	0.219 (0.210)	0.249 (0.268)	0.361 (0.331)	0.184 (0.455)

Notes: All specifications use PWT data and include country FE, region × year FE, and poor × year FE

- Even stronger when instead longer run is estimated (1970-85 vs 1986-2000 are compared).
- Similar results for industrial output, aggregate investment and political stability.
- Tentative conclusion – climate change is a big problem for countries that do not become sufficiently rich.