

Teaching Options for IAMs

Barrage, Greenstone, Metcalf

AEA Continuing Education: Climate Change

January 2020

Teaching Integrated Assessment Models

- ▶ It's one thing to review theory, methodology behind IAMs...
 - ▶ Recommended reference: "A Question of Balance" by William Nordhaus (2008)
 - ▶ Highly accessible "Summary for the Concerned Citizen"
 - ▶ Clear explanations of all model components

...it's another for students to create their own IAMs!

- ▶ Brings theory to life!
- ▶ Allows students to perform their own policy experiments etc.

Teaching Integrated Assessment Models

- ▶ Limited Economics: Simplified DICE in Excel (with, e.g., exogenous GDP projections)
- ▶ Solid Macro: Substitute Ramsey growth model micro-foundation
 - ▶ Utility-based social welfare function
- ▶ Advanced: GAMS– or Matlab-based DICE versions
- ▶ Graduate: Replicate generalized GHKT model

Simplified IAM Model: Key Equations (1/2)

- 1) Given: (gross) GDP projections: $Y_{2000}, Y_{2010}, Y_{2020}, \dots$
- 2) Production causes carbon emissions E_t based on *intensity* σ_t :

$$E_t^{Gross} = \sigma_t \cdot Y_t^{Gross}$$

- 3) Fraction ξ of emissions add to carbon stock S_t :

$$S_t = S_{2000} + \xi \sum_{j=2000}^t E_j$$

- 4) Carbon concentrations lead to temperature change T_t :

$$T_t \approx T_{2000} + \eta \log_2\left(\frac{S_t}{S_{2000}}\right)$$

- 5) Fraction of GDP $D(T_t)$ lost due to climate change T_t :

$$D(T_t) = \phi_1 T_t^{\phi_2}$$

- 6) Economy's interest rate r_t follows Ramsey rule:

$$r_t \approx \rho + \alpha g_t^*$$

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- 4) Carbon concentrations lead to temperature change T_t :

$$T_t = T_{2000} + \eta \log_2\left(\frac{S_t}{S_{1750}}\right)$$

- 5) Fraction of GDP $D(T_t)$ lost due to climate change T_t :

$$D(T_t) = \phi_1 T_t^{\phi_2}$$

- 6) Economy's interest rate r_t follows Ramsey rule:

$$r_t = \rho + \alpha g_t^*$$

⇒ **Sufficient IAM to compute a social cost of carbon!**

Simplified IAM Model: Key Equations (2/2)

⇒ To analyze *optimal* climate policy, further specify:

- 7) Society can reduce carbon emissions by fraction μ_t :

$$E_t^{Net} = (1 - \mu_t) E_t^{Gross}$$

- 8) Total abatement costs TAC_t a fraction of GDP:

$$\frac{TAC_t}{Y_t} = \theta_{1t} (\mu_t)^{\theta_2}$$

- 9) Social planner's problem: Choose abatement to minimize present value sum of climate damages + abatement costs:

$$\min_{\{\mu_t\}_{t=0}^{2250}} \left[\sum_{j=2000}^{2500} \frac{D(T_t) Y_t + TAC_t(\mu_t)}{(1 + r_t)^{(j-2000)}} \right]$$

Simplified IAM

- ▶ Step 2: Provide Students with Excel, Solver practice if desired
- ▶ Step 3: Instructor provides IAM template with select parameters, processes pre-filled in
 - ▶ Step 3.1: Students fill in the rest
 - ▶ Map theory into quantitative model
 - ▶ If desired:
 - ▶ Perform own data collection, research on key parameters
 - ▶ Construct own estimates of, e.g., abatement cost function
- ▶ Step 4: Students run policy experiments, compute SCC!

I21

✕ ✓ f_x

	A	B	C
1	Simple IAM Example		
2			
3	Parameters		
4	Baseline global GDP (trillions of constant 2000 US\$/year), Y_2000	32.21	Source: World Bank
5	Base year (2000) CO2 emissions (billion tons of carbon), E_2000	6.73	Source: World Bank
6	Temperature increase since 1900 (degrees Celsius), T_2000	1	Source: Nordhaus
7	Base year (2000) CO2 concentrations (billion tons of carbon), S_2000	800	Source: Nordhaus
8	Base year (2000) global population (billions)	6.08	Source: World Bank
9	Base year (2000) CO2 emissions intensity (billion tons of carbon/tril. US\$), sigma_2000	0.21	Calculated
10	CO2 emissions intensity growth rate (per year)	-2%	Assumed
11	Fraction of CO2 emissions remaining in atmosphere, xi	0.50	Assumed
12	Climate sensitivity parameter, eta	3.00	Source: Nordhaus
13	Damage function scale parameter, phi1	0.0033	Assumed
14	Damage function curvature parameter, phi2	2.00	Assumed
15	Population growth rate (per year) until 2100	1%	Assumed
16	Population growth rate (per year) after 2100	0%	Assumed
17	Consumption (GDP per capita) growth rate (per year), until 2050 (inclusive), g*	2.75%	Assumed
18	Consumption (GDP per capita) growth rate (per year) after 2050 (i.e., starting in 2060), g*	2.00%	Assumed
19	Utility discount rate (= pure rate of social time preference) per year, rho	1.50%	Assumed
20	Elasticity of marginal utility of consumption, alpha	1.50	Assumed
21	Abatement cost function scale parameter (theta1)	0.1	Assumed
22	Abatement cost function curvature parameter (theta2)	3.3	Assumed
23	Abatement cost scale parameter growth rate (percent per year)	-2.00%	Assumed

B17

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✕

✓

fx

2.75%



A

B

C

D

20	Elasticity of marginal utility of consumption, alpha	1.50	Assumed	
21	Abatement cost function scale parameter (theta1)	0.1	Assumed	
22	Abatement cost function curvature parameter (theta2)	3.3	Assumed	
23	Abatement cost scale parameter growth rate (percent per year)	-2.00%	Assumed	
24				
25				
26	Economy	2000	2010	2020
27	GDP (gross) (trillions of constant 2000 US\$/year)			
28	Population (billions, beginning of year)			
29	GDP/Population (thousands US\$/year)			
30	Interest rate (percent per year)			
31				
32	Emissions			
33	CO2 Emissions Intensity [(billion metric tons of carbon/year) / (trillion 2000 US\$/year)]			
34	CO2 Emissions (gross) (billion metric tons of carbon/year)			
35	Net of abatement μ CO2 Emissions (billion metric tons of carbon/year)			
36	Atmospheric CO2 Concentration (billion tons of carbon, end of decade)			
37	Equilibrium Temperature Change (°C) since 1900			
38				

25			
26	Economy	2000	2010
27	GDP (gross) (trillions of constant 2000 US\$/year)	=B4	=C28*C29
28	Population (billions, beginning of year)	=B8	=B28*(1+\$B\$17)
29	GDP/Population (thousands US\$/year)	=B27/B28	=B29*(1+\$B\$17)
30	Interest rate (percent per year)	=\$B\$19+\$B\$20*\$B\$17	=\$B\$19+\$B\$20*\$B\$17
31			
32	Emissions		
33	CO2 Emissions Intensity [(bil. MT carbon/year) / (tril. 2000 US\$/year)]	=B9	=B33*(1+\$B\$17)
34	CO2 Emissions (gross) (billion metric tons of carbon/year)	=B5	=C33*C27
35	Net of abatement μ CO2 Emissions (billion metric tons of carbon/year)	=(1-B39)*B34	=C34*(1-\$B\$17)
36	Atmospheric CO2 Concentration (billion tons of carbon, end of decade)	=B7+\$B\$11*B35*10	=B36+\$B\$11*B35*10
37	Equilibrium Temperature Change (°C)	=\$B\$6+\$B\$12*(LOG(B36/\$B\$7)/LOG(2))	=\$B\$6+\$B\$12*(LOG(B36/\$B\$7)/LOG(2))
38	Abatement		
39	μ (percentage of emissions reduction)	0	0
40			

3	Abatement		
9	μ (percentage of emissions reduction)	0.10	
0			
1	Damages		
2	Damages/GDP (percent per year)	0.0044	
3	Damages (trillions of constant 2000 US\$/year)	0.143227064	0.2780
4	PV of damages (trillions of constant 2000 US\$/decade)	1.432270635	1.6088
5	PVT [Sum of NPV of Damages] (tril. 2000 US\$)	72.1607606	
5			
7	Abatement		
3	Total abatement costs / GDP (percent per period)	0.00	
9	Total abatement costs (tril. 2000 US\$/decade)	0.02	
0	PV of total abatement costs (tril. 2000 US\$/decade)	0.02	
1	PVT [Sum of NPV of Total Abatement Costs] (tril. 2000 US\$)	0.06	
2			
3	Policy Objective		
4	Sum of [PVT Damages + PVT Abatement Costs] (tril. 2000 US\$)	72.22	
5			
5	Implied Optimal Carbon Price (US\$/metric ton of carbon)	7.92	
7	(= Marginal abatement cost)		

Abatement

μ (percentage of emissions reduction)	0.10
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Damages

Damages/GDP (percent per year)	0.0044
Damages (trillions of constant 2000 US\$/year)	0.143227064
PV of damages (trillions of constant 2000 US\$/decade)	1.432270635
PVT [Sum of NPV of Damages] (tril. 2000 US\$)	72.1607606

Abatement

Total abatement costs / GDP (percent per period)	0.00
Total abatement costs (tril. 2000 US\$/decade)	0.02
PV of total abatement costs (tril. 2000 US\$/decade)	0.02
PVT [Sum of NPV of Total Abatement Costs] (tril. 2000 US\$)	0.06

Policy Objective

Sum of [PVT Damages + PVT Abatement Costs] (tril. 2000 US\$)	72.22
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Implied Optimal Carbon Price (US\$/metric ton of carbon) (= Marginal abatement cost)	7.92
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Solver Parameters

Set Objective: \$B\$4

To: ☐ Max ☒ Min ☐ Value Of: 0

By Changing Variable Cells:

\$B\$39:\$AZ\$39

Subject to the Constraints:

\$B\$39:\$AZ\$39 <= 1

\$B\$39:\$AZ\$39 >= 0

☒ Make Unconstrained Variables Non-Negative

Select a Solving Method: GRG Nonlinear

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the Evolutionary engine for Solver problems that are non-smooth.

Help

Solve

IAM (2)

IAM

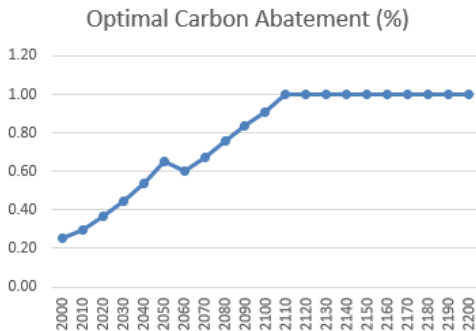
AbtCostCalibration



Policy Experiments

1. Optimal Climate Policy

- ▶ Solve for optimal abatement rates
- ▶ Back out optimal carbon taxes → Marginal abatement costs



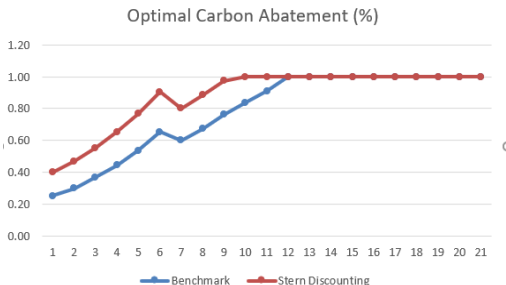
Policy Experiments

1. Optimal Climate Policy

- ▶ Solve for optimal abatement rates
- ▶ Back out optimal carbon taxes → Marginal abatement costs

2. Key Issues / Sensitivity Analysis

- ▶ Discounting: Prescriptive (ethical) "Stern" ($\rho = 0.001$) vs. Descriptive (market-based) "Nordhaus" approach
- ▶ Climate Sensitivity: IPCC low ($\eta = 1.5$) or high ($\eta = 4.5$)?
- ▶ Climate Damages, Technological change, etc.



Policy Experiments

3. Global Climate Agreements: Cost-Effective Policy

- ▶ Solve for least-cost policy to meet global climate targets
- ▶ Add constraint that $T_t \leq 2^\circ\text{C} \ \forall t \rightarrow$ Paris Accord

4. Social Costs of Sub-Optimal Climate Policy

- ▶ Compare PVT Damages + Abatement costs in optimal scenario
- vs. Laissez-Faire ($\mu_t = 0 \ \forall t$)
- vs. delayed climate policy (start optimization in 2030)
- vs. aggressive policy (Green New Deal $\rightarrow \mu_t = 0 \ \forall t \geq 2030$)

5. Compute business-as-usual Social Cost of Carbon

- ▶ Duplicate laissez-faire IAM sheet
- ▶ Add +1 unit of carbon emissions (= +1 bil. MT) in 2000
- ▶ Calculate difference in PVT of Damages with/without marginal emissions increase
- ▶ Adjust units $\rightarrow$ SCC in \$/ton Carbon

Advanced Students: Ramsey Growth Model

- ▶ Replace exogenous GDP Y_t with production function, e.g.:

$$Y_t^{Gross} = A_t(K_t)^\alpha(L_t)^{1-\alpha}$$

- ▶ Introduce representative household with preferences, e.g.:

$$U_0 \equiv \sum_{t=0}^{\infty} \beta^t \cdot u(c_t)$$

where $c_t \equiv \frac{C_t}{L_t}$ is per capita consumption

- ▶ Household investment I_t optimally determined
 - ▶ Solve household problem separately, or in planner's problem
- ▶ Capital accumulation:

$$K_{t+1} = K_t(1 - \delta) + I_t$$

- ▶ Social welfare function:

$$SWF = \sum_{t=0}^{\infty} \beta^t \cdot N_t u(c_t)$$

Further References

- ▶ All materials referenced in slides available online
- ▶ Excel, GAMS versions of full DICE Model available online
[<https://sites.google.com/site/williamdnordhaus/dice-rice>]
- ▶ Matlab version of generalized GHKT Model available online
- ▶
[<https://www.econometricsociety.org/publications/econometrica/issue-supplemental-materials/2014/01/>]