Robust Dynamic Energy Use and Climate Change

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Introduction

- Climate Externality and the Macroeconomy:

Economic activity → GHG stock → Global Temperatures → Damages

- Significant fiscal interventions proposed
- Our knowledge is still limited:
  - *GHG* emissions effect on global temperatures
  - Effect of global temperatures on output
- How to deal with this uncertainty?
  - *Model Uncertainty* (as opposed to risk)
  - *Robust control*

Uncertainty

- Econometrician concerned about misspecification
- Make agents in the model share this concern
  - Departure from Rational Expectations (Hansen, 2013)
- Instead, agents optimize given "worst case scenario" model
- Why "maxmin?"
  - Axiomatics (Gilboa and Schmeidler, 1989)
  - Robust Control (Hansen and Sargent, 2008, Whittle, 1981)

What We Do

- Introduce model uncertainty in growth model with energy sector/environmental externality
- Consider "fat-tailed" distributions for damages
- Consider unconventional sources
- Characterize optimal allocation, energy mix, tax, as functions of model uncertainty
- Concern about uncertainty affects optimal use of coal and oil/gas qualitatively and quantitatively
- Optimal robust tax rate depends on level of GHG concentration

The Setup (Golosov et al, 2014)

- Preferences and technology:

$$\max \sum_{t=0}^{\infty} \beta^t u(C_t)$$
$$\text{s.t. } \tilde{K}_{t+1} = K^{\theta} E^{\nu} - C,\ \theta + \nu \leq 1$$
$$\text{GHG evolution}$$

- Golosov, Hassler, Krusell, Tsyvinski (2014): three energy sectors: $E = (\kappa_1 E_1^{\rho} + \kappa_2 E_2^{\rho} + \kappa_3 E_3^{\rho})^{1/\rho}$
  - The oil/gas sector produces oil/gas (E_1) at zero cost; subject to a resource feasibility constraint, $R_0 > 0$
  - The coal and the green energy sector use linear technologies $E_i = A_i N_i$, $i = 2, 3$
  - log utility, 100% capital depreciation (period is 10 years)

GHG Evolution

- Fossil fuel use adds to the atmospheric GHG concentration, S
- Permanent and temporary components of S, P and T, respectively, evolve as follows:

$$P' = P + \phi_L(E_1 + E_2)$$
$$T' = (1 - \phi)T + (1 - \phi_L)\phi_0(E_1 + E_2)$$
$$S' = P' + T'$$

Externality and Uncertainty

- Stochastic process reduces end-of-period capital stock: $K' = e^{-S'\gamma}\tilde{K}'$
- Two-person zero-sum dynamic game: "Malevolent player" chooses worst model specification; social planner best-responds
- Deviation from approximating distribution *penalized* by adding $\alpha\varrho(\hat{\pi}(\gamma), \pi(\gamma))$ to planner's payoff
  - ϱ, distance between approximating distribution, π, and malevolent player's distribution choice, $\hat{\pi}$
  - Higher α adds a larger amount to the planner's payoff $\rightarrow$ Large deviation less likely $\rightarrow$ Lower concern about model uncertainty

Robust Social Optimum

- Approximating distribution of γ: $\pi(\gamma) = \lambda e^{-\lambda\gamma}$
- The malevolent player chooses an alternative distribution $\hat{\pi}(\gamma)$, after observing $(\tilde{K}', S')$

$$V(K,S) = \max_{C,E,\tilde{K}',S'} \min_{\hat{\pi}} \left\{ u(C) + \beta F\left[V(K',S'), \alpha\varrho(\hat{\pi},\pi) \right] \right\}$$
$$\text{s.t. feasibility}$$
$$\text{law of motion for GHG}$$

Equilibrium and Decentralization

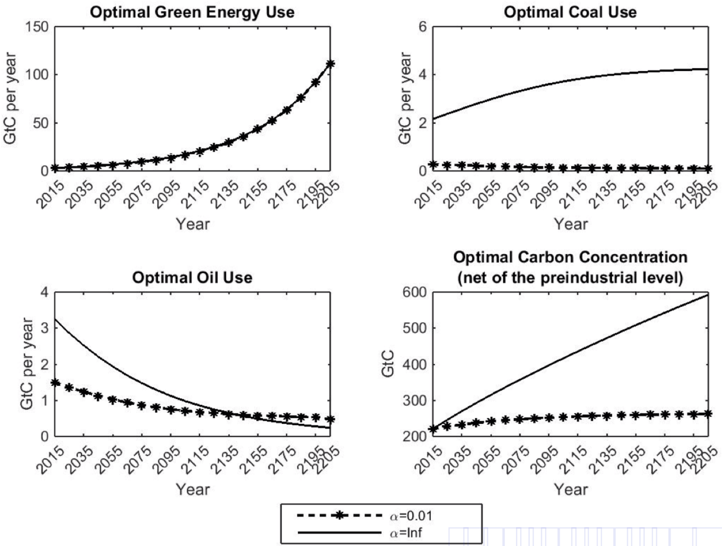
- We characterize the (Markov perfect) equilibrium consumption, energy use, and emissions, as well as the equilibrium distribution regarding damages
- We derive an explicit expression of the marginal externality from emissions
- By imposing the optimal (Pigouvian) tax associated with the externality, and rebating the proceeds as lump-sum payments, the resulting equilibrium allocation is efficient

Calibration

Table : Calibration Summary

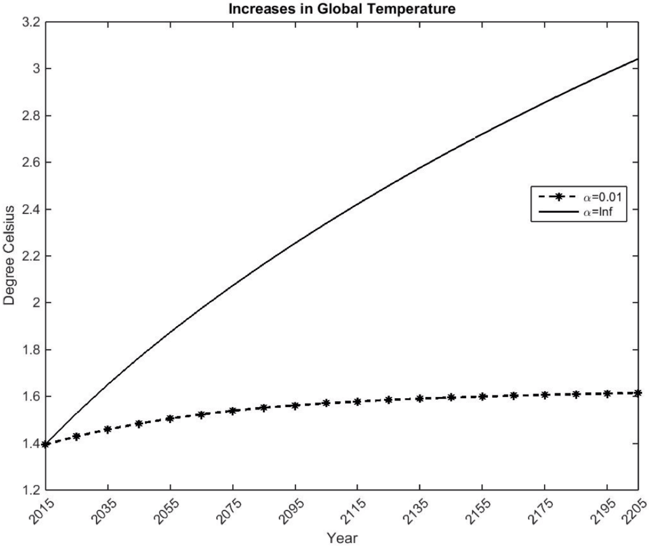
θ	ν	β	R_0
0.3	0.04	0.985^{10}	253.8
κ_1	κ_2	ρ	$1+g$
0.5008	0.08916	-0.058	1.02^{10}
P_0	T_0	$A_{2,0}$	$A_{3,0}$
103	699	7,693	1,311
ϕ	ϕ_L	ϕ_0	λ^{-1}
0.0228	0.2	0.393	2.38×10^{-5}

Optimal Energy Path (Excluding Unconventional)

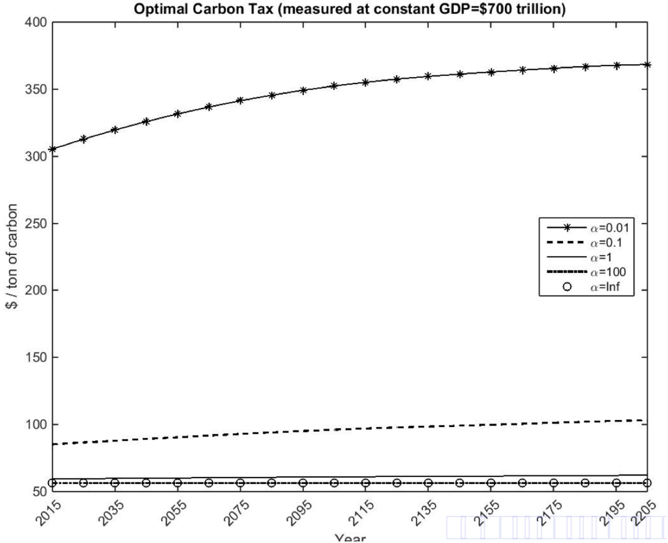


Temperatures

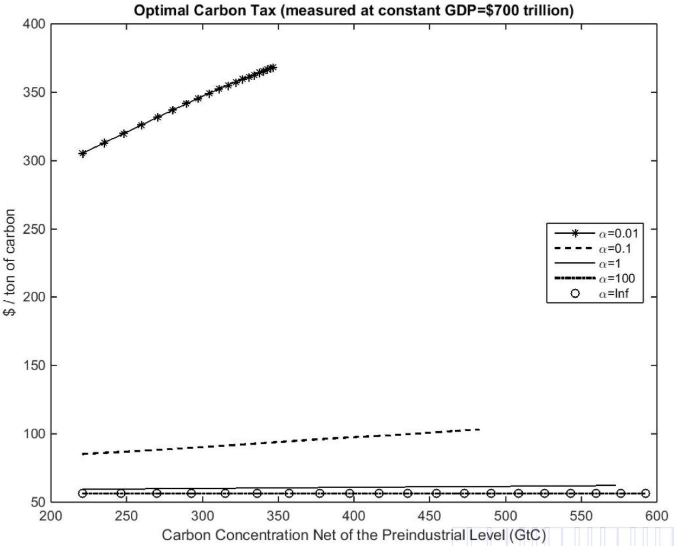
- Map carbon concentrations to temperatures: $T(S_t) = 3\ln(\frac{S_t}{\overline{S}})/\ln(2)$
  - $\overline{S}$, preindustrial carbon concentration
- Average current temperature *1.4 degrees* above preindustrial level
- Carbon concentration over next 200 years implies temperature increase of:
  - More than *1.6 degrees Celsius* in non-robust path
  - About *0.2 degrees Celsius* in the robust path


Increases in Global Temperature
Degree Celsius
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
Year
2015
2035
2055
2075
2095
2115
2135
2155
2175
2195
2205
α=0.01
α=Inf

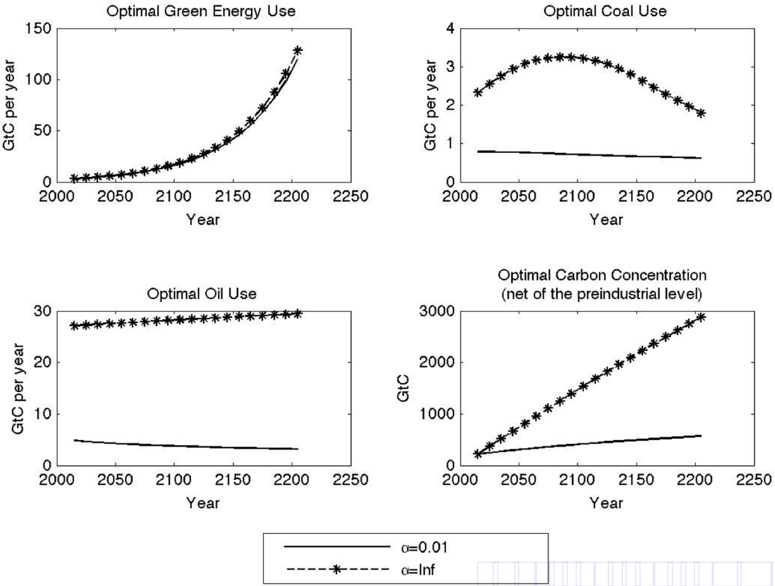
Optimal Tax as a Function of Model Uncertainty



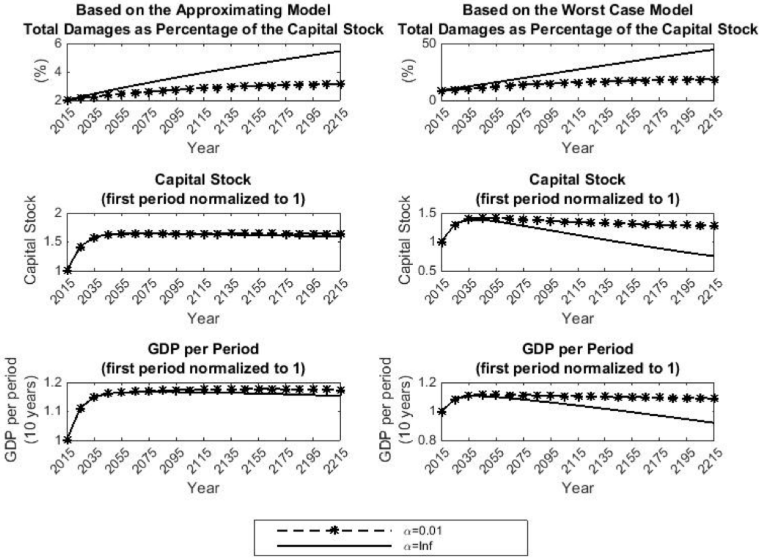
Optimal Tax as a Function of Emissions Stock



Optimal Energy Path (Including Unconventional)



Capital and Output



Summary: Concern about Model Uncertainty

- Optimal carbon tax can restore efficiency and *GHG* concentration matters for optimal tax
  - Example of policy in that spirit (Michael Greenstone): adjust mining leases to reflect full climate damage from corresponding fuels
    - Market forces would lead to fossil fuels having the highest value (net of climate impact) being exploited first
    - Dirtiest fuels might well stay in the ground
- Smoother consumption of oil/gas
- Significant reduction in coal consumption
- Lots to do:
  - Technological progress in renewables *and* in fossil fuel extraction