Optimal Taxes on Fossil Fuel in General Equilibrium

Mikhail Golosov, John Hassler, Per Krusell, and Aleh Tsyvinski

Teja Konduri and Shilpi Kumar

Department of Economics
University of Notre Dame

February 18, 2021

Overview

Introduction

- Global economy-climate DSGE model
- Allows a comparison of the optimal allocation of the tax on carbon to second-best alternatives, such as the market laissez-faire outcome or one with carbon taxes that are less than fully optimal.

Main Results

1. Main Finding: A simple formula for the marginal externality damage of CO_2 emissions which serves as a prescription for the optimal level—from a global perspective of the tax on carbon.
2. It is optimal to use up all the oil. Whereas, coal on the other hand, has large reserves and causes more damage than oil.
3. If the degree of substitutability between different energy sources is high, not taxing coal will imply a large surge in coal use, massive warming, and, hence, significant costs of inaction.

Model Environment

- Multi-sector neo-classical growth model, discrete, infinite time
- Agents:
  - Representative household
  - Final goods producer (denoted by $i = 0$)
  - Intermediate goods producer - produce energy
    - $i = 1, ...I_g - 1$ are dirty and $i = I_g, ...I$ are clean
- Feasibility constraint: $C_t + K_t = Y_t + (1 - \delta)K_t$
- Aggregate production function: $Y_t = F_{0,t}(K_{0,t}, N_{0,t}, \mathrm{E}_{0,t}, S_t)$
- $\mathrm{E}_{0,t} = (E_{0,1,t}, ..., E_{0,I,t})$ is vector of energy input
- Some energy source finite, decumulation $R_{i,t+1} = R_{i,t} - E_{i,t} \geq 0.$
- Production technology for energy source i $E_{i,t} = F_{i,t}(K_{i,t}, N_{i,t}, \mathrm{E}_{i,t}, R_{i,t}) \geq 0.$
- Normalization: one unit E_i produces one unit carbon ("dirty")
- S_t is the amount of carbon in atmosphere

Model Assumptions

1. Assume log utility
2. Damage: carbon $-- >$ temp $-- >$ output

$$F_{0,t}(K_{0,t}, N_{0,t}, \mathbf{E}_{0,t}, S_t) = (1 - D_t(S_t))\tilde{F}_{0,t}(K_{0,t}, N_{0,t}, \mathbf{E}_{0,t}),$$

where $1 - D_t(S_t) = \exp(-\gamma_t(S_t - \bar{S}))$ *and where* $\bar{S}$ *is the pre-industrial atmospheric* CO_2 *concentration.*

$$S_t = \tilde{S}_t\left(\sum_{i=1}^{I_g-1} E_{i,-T}, E^f_{-T+1}, \ldots, E^f_t\right), \quad E^f_s \equiv \sum_{i=1}^{I_g-1} E_{i,s}$$

3. Linear depreciation structure:

$$(5) \qquad S_t - \bar{S} = \sum_{s=0}^{t+T} (1 - d_s) E^f_{t-s},$$

where $d_s \in [0, 1]$ *for all* s.

$$1 - d_s = \varphi_L + (1 - \varphi_L)\varphi_0(1 - \varphi)^s$$

Planner Problem

$$\max_{\{C_t, \mathbf{N}_t, K_{t+1}, \mathbf{K}_t, R_{i,t+1}, \mathbf{E}_t, S_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t)$$

St.

$$R_{i,t+1} = R_{i,t} - E_{i,t} \geq 0.$$

$$E_{i,t} = F_{i,t}(K_{i,t}, N_{i,t}, \mathbf{E}_{i,t}, R_{i,t}) \geq 0.$$

$$\sum_{i=0}^{I} K_{i,t} = K_t, \quad \sum_{i=0}^{I} N_{i,t} = N_t, \quad \text{and} \quad E_{j,t} = \sum_{i=0}^{I} E_{i,j,t}.$$

$$S_t = \tilde{S}_t\left(\sum_{i=1}^{I_g-1} E_{i,-T}, E^f_{-T+1}, \ldots, E^f_t\right), \quad E^f_s \equiv \sum_{i=1}^{I_g-1} E_{i,s}$$

$$C_t + K_{t+1} = F_{0,t}(K_{0,t}, N_{0,t}, \mathbf{E}_{0,t}, S_t) + (1-\delta)K_t$$

FOC for $E_{i,t}$:

$$(8) \qquad \frac{\chi_{i,t}}{\lambda_{0,t}} = \frac{\lambda_{i,t} + \mu_{i,t} + \xi_{i,t}}{\lambda_{0,t}} + \Lambda^s_{i,t}$$

Planner Problem (cont.)

Marginal Externality damage:

$$\Lambda_{i,t}^{s} = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \frac{\lambda_{0,t+j}}{\lambda_{0,t}} \frac{\partial F_{0,t+j}}{\partial S_{t+j}} \frac{\partial S_{t+j}}{\partial E_{i,t}} = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \frac{U'(C_{t+j})}{U'(C_t)} \frac{\partial F_{0,t+j}}{\partial S_{t+j}} \frac{\partial S_{t+j}}{\partial E_{i,t}}$$

Since $\partial S_{t+j}/\partial E_{i,t} = 0$ for $i = I_g, \ldots, I$ and, by construction,

$$\frac{\partial S_{t+j}}{\partial E_{i,t}} = \frac{\partial S_{t+j}}{\partial E_{i',t}} \quad \text{for} \quad i, i' \in \{1, \ldots, I_g - 1\},$$

PROPOSITION 1: *Suppose Assumptions 1, 2, and 3 are satisfied and the solution to the social planner's problem implies that C_t/Y_t is constant in all states and at all times. Then the marginal externality cost of emissions as a proportion of GDP is given by*

$$\Lambda_t^s = Y_t \left[\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \gamma_{t+j} (1 - d_j) \right]. \tag{11}$$

Limitations: Utility and damage specification

Decentralized Version and Optimal Taxation

$$\Pi_0 \equiv \max_{\{K_{0,t}, N_{0,t}, \mathbf{E}_{0,t}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} q_t \left[F_{0,t}(K_{0,t}, N_{0,t}, \mathbf{E}_{0,t}, S_t) - r_t K_{0,t} - w_t N_{0,t} - \sum_{i=1}^{I} p_{i,t} E_{0,i,t} \right]$$

$$\Pi_i \equiv \max_{\{K_{i,t}, N_{i,t}, E_{i,t}, \mathbf{E}_{i,t}, R_{i,t+1}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} q_t \left[(p_{i,t} - \tau_{i,t}) E_{i,t} - r_t K_{i,t} - w_t N_{i,t} - \sum_{j=1}^{I} p_{j,t} E_{i,j,t} \right]$$

A representative individual maximizes

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t)$$

subject to

$$\mathbb{E}_0 \sum_{t=0}^{\infty} q_t (C_t + K_{t+1}) = \mathbb{E}_0 \sum_{t=0}^{\infty} q_t \big((1 + r_t - \delta) K_t + w_t N_t + T_t \big) + \Pi$$

Decentralized Version and Optimal Taxation

PROPOSITION 2: *Suppose that τ_t is set as in (13) and that the tax proceeds are rebated lump-sum to the representative consumer. Then the competitive equilibrium allocation coincides with the solution to the social planner's problem.*

Optimality of labor input of two types of firm:

$$\hat{\lambda}_{i,t}\frac{\partial F_{i,t}}{\partial N_{i,t}} = w_t = \frac{\partial F_{0,t}}{\partial N_{0,t}}$$

Showing similarity with central planner problem:

Energy firm chooses i : $\hat{\lambda}_{i,t} + \hat{\mu}_{i,t} + \hat{\xi}_{i,t} = p_{i,t} - \tau_{i,t}$

Optimiality (energy input of type i in final sector '0' $\frac{\partial F_{0,t}}{\partial E_{0,i,t}} = p_{i,t}$

Planner optimality and decentralized version $\tau_{i,t} = \Lambda_t^s \equiv \tau_t,$

Limitations: Perfect competition and return on factors

Results - Marginal Externality Damage and Optimal Tax

- Using Nordhaus' calibration of the discount rate (1.5% per year), the optimal tax should approximately be twice that of his. Nordhaus's value is $30, whereas here it is $57 per ton of coal.
- Stern (2007) uses a discount rate of 0.1% and concluded that a tax of $250 per ton of coal is optimal; for that discount rate, the optimal tax in this model is $500 dollars to be the optimal tax.
- If the damages are moderate, with a discount rate of 1.5%, the optimal tax rate is $25.3/ton but $489/ton if they are "catastrophic." For the lower discount rate used by Stern, the corresponding values are $221/ton and a $4,263/ton.

Results

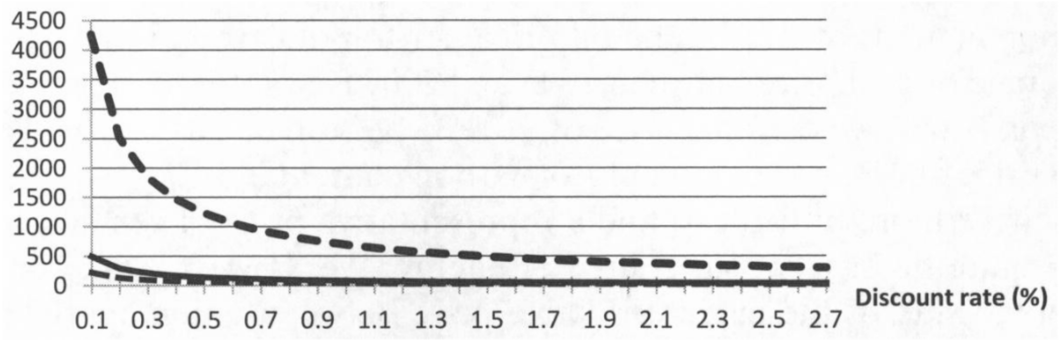

Figure: Optimal tax rates in current dollars per ton of emitted fossil carbon versus yearly subjective discount rate

Results - Implications for Future

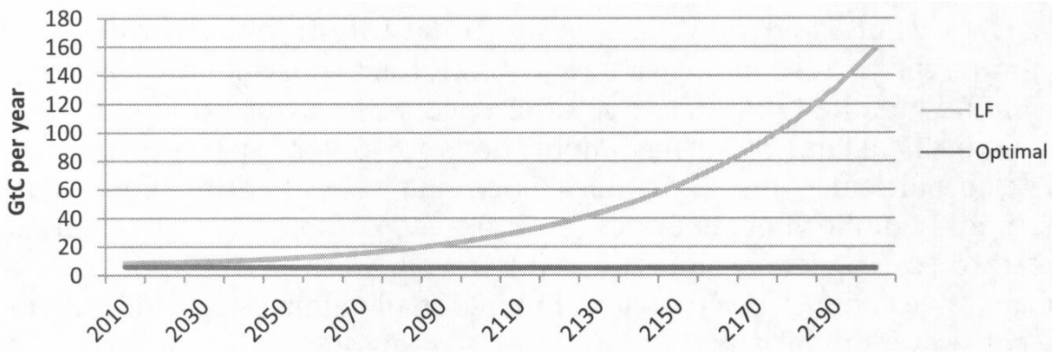

Figure: Fossil fuel use: optimum versus laissez-faire

Coal is the Bad Guy - Middle East FTW!

- Coal grows quickly in the laissez-faire allocation but very slowly if optimal taxes are introduced.
- Effect of tax on coal:
  - Immediate reduction - 46%
  - 100 years from now - laissez-faire coal usage is 7 times more than optimal.
  - 200 years from now - Accumulated optimal outtake will have risen to a little below 900 GtC, and under laissez-faire coal use increases quickly, leading to a scarcity rent unless a backstop appears before.
- The two curves for oil never differ by more than about 6%.
- The optimal and laissez-faire paths for green energy are even more similar, since they are not affected by taxes in any of the regimes (the difference is never 1.1%)

Results

Current coal usage - 4.5GtC (model) v 3.8GtC (actual)

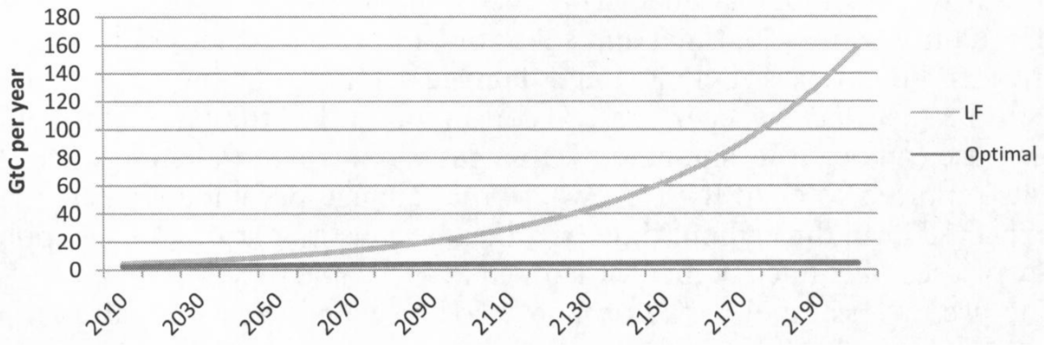

Figure: Coal use: optimum versus laissez-faire

Results

Current oil usage - 3.6GtC (model) v 3.4GtC (actual, 2008)

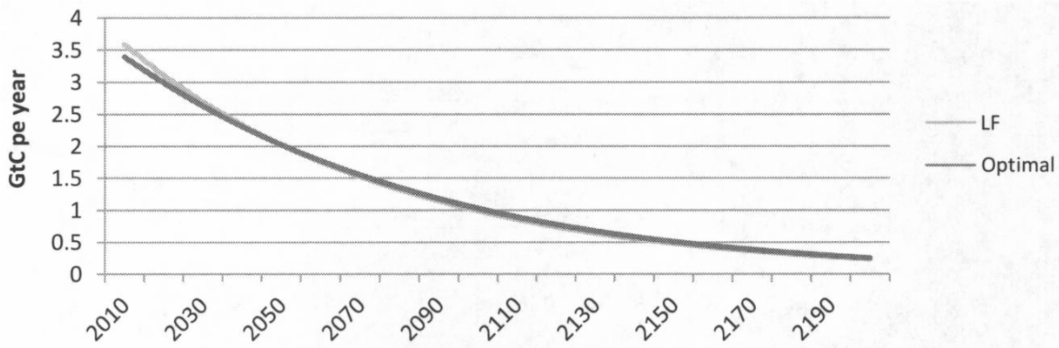

Figure: Oil use: optimum versus laissez-faire

Tax reduces the damage caused

years from now	laissez-faire	optimal tax
100	2.2%	1.1%
200	10%	1.5%

Table: Damages caused (as % of GDP)

Results

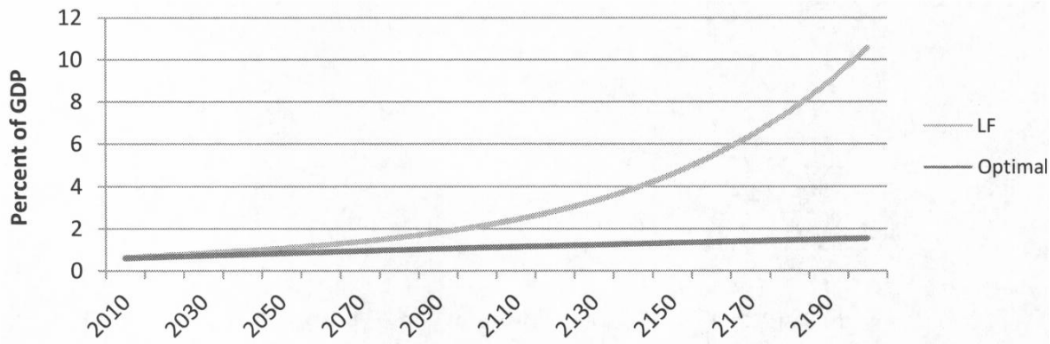

Figure: Total damages as % of GDP: optimum versus laissez-faire

Taxes can make Marshall Islands survive!

years from now	laissez-faire	optimal tax
100	4.4°C	2.6°C
200	10°C	3°C

Note: These temperature increases are measured relative to the pre-industrial climate; relative to the model's prediction for the current temperature, the increases are about 1.5°C less as aerosols in the atmosphere lead to a cooling effect which is not captured in the model.

Results

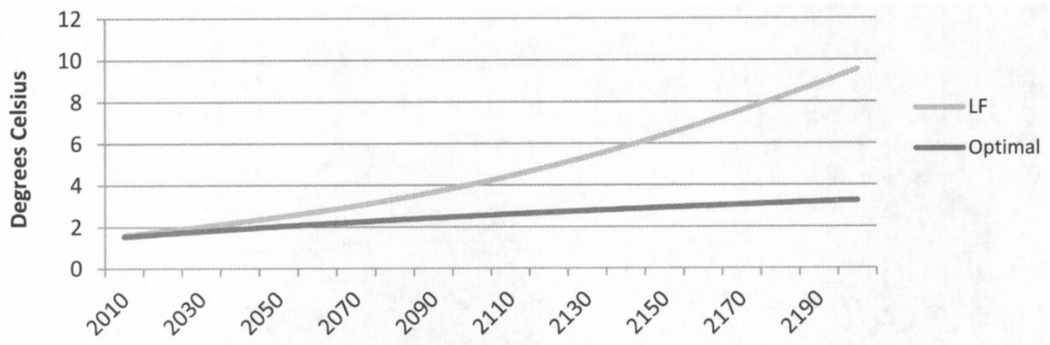

Figure: Increases in global temperature: optimum versus laissez-faire

Taxes increase GDP in the long run

- Negligible short run losses in the optimal allocation
- Less coal usage $\Rightarrow$ Less labor in coal energy production
- Oil consumption not affected.

years from now	GDP net of damages
100	2.5%
200	15%

Table: Difference between optimal and laissez-faire

Results

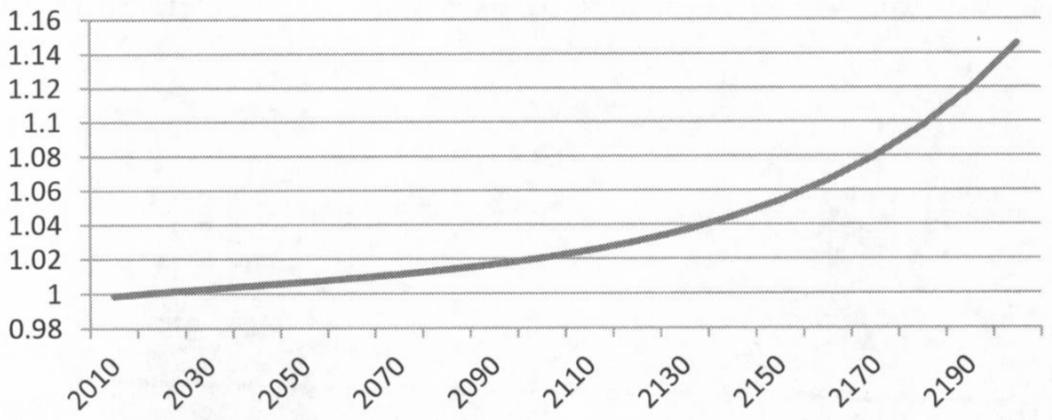

Figure: Net output: optimum versus laissez-faire

Comparison with DICE and RICE

- Optimal tax rate in Nordhaus (2007) - $27 for 2005 that should rise to $42 in 2015 (subjective discount rate of 1.5% per year). This paper - $56.
- Accounting for the differences in utility functions, the adjusted optimal tax is $32
- Differences -
  1. Different ways of dealing with uncertainty - Nordhaus optimizes under certainty - matching with Nordhaus, optimal tax doubles
  2. Different ways of modeling the carbon cycle - This paper assumes 50% of Carbon gets absorbed in 10 years - matching both models would increase optimal tax by a factor of 1.5
  3. Different Climate Model - Nordhaus assumes that oceans create a drag in the temperature - matching by adjusting depriciation structure optimal tax would be $37.6
- Both papers don't model "tipping points"

Conclusion

- DSGE model with a climate externality.
- Derives a simple formula for the SCC that depends only on four factors:
  1. the size of the global economy
  2. discounting
  3. the damage elasticity,
  4. carbon depreciation in the atmosphere.

  the last three factors are likely to be variables rather than constants
- Damage elasticity is extremely complicated to calculate
- Does not capture geographical and institutional variation

Questions?