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Economics 134 Fall 2024 Midterm 2

November 18, 2024

Write your name and UID in the upper right corner of each page.

You have 75 minutes to complete this exam. Show your work.

QUESTION 1 (60 points). Global climate change.

(a) Consider a country, i, with a firm that obtains profits

$$\pi_i(k_i) = 5k_i - \frac{1}{2}k_i^2$$

from emitting $k_i \geq 0$ tons of carbon. Calculate the carbon emissions that will result if the firm maximizes its profits.

Solution: $\pi_i'(k_i^*) = 0$ or $5 - k_i^* = 0$ or $k_i^* = 5$.

(b) Suppose country i's welfare equals its firm's profits from (a), net of its damages from climate change, or

$$W_i(k_i, K) = \pi_i(k_i) - D_i(K),$$

where $D_i(K) = \theta_i K$ is damage to country i, $K \equiv \sum_{i=1}^{N} k_i$ denotes total emissions by all countries, and $\theta_i = 1$ for all i. What level of carbon emissions will country i choose to maximize its welfare?

Solution: $\pi_i'(\tilde{k}_i) - \frac{\partial}{\partial k_i} D_i'(\cdot) = 0$ or $5 - \tilde{k}_i - 1 = 0$ or $\tilde{k}_i = 4$.

(c) Now suppose that there are $N = 5$ countries just like the country in (a)–(b). What level of emissions for each country i will maximize global welfare?

Solution: Maximizing $\sum_{i=1}^{5} \left[\pi_i(k_i) - D_i(\sum_{i=1}^{N} k_i)\right]$ gives the first-order conditions $5 - k_i^{\text{FB}} - 5 = 0$ or $k_i^{\text{FB}} = 0$. The countries should emit zero emissions!

(d) How does moving from (b) to (c) affect the welfare of country i?

Solution: Country i gets 0 under the global first-best of (c). Country i gets $5 \cdot 4 - \frac{1}{2} \cdot 4^2 - \theta_i \sum k_i^* = 20 - 8 - 20 = -8$. So country i's welfare improves by 8 units.

(e) Suppose that countries 2–5 are cooperating to maximize their total welfare. If country 1 chooses its own emissions, k_1, to maximize only its own welfare, what k_1 will it choose? What level of welfare will country 1 obtain in this case?

Solution:

If country 1 chooses k_1 to maximize their payoff, they will pick, as in (b), $\tilde{k}_1 = 4$.

If countries 2–5 maximize their joint surplus, $\sum_{i=2}^{5} \left[5k_i - \frac{1}{2}k_i^2 - \sum_{i=2}^{5} k_i\right]$, then they will each choose $5 - \tilde{k}_i - 4 = 0$ or $\tilde{k}_i = 1$.

Using this, we conclude that country 1 will obtain a payoff of

$$\pi_i(\tilde{k}_1) - D_i\left(\tilde{k}_1 + \sum_{i=2}^{5} \tilde{k}_i\right) = \pi_i(4) - D_i(4 + 4 \cdot 1) = 5 \cdot 4 - \frac{1}{2} \cdot 4^2 - 8 = 20 - 16 = 4.$$

(f) Is country 1 better off in (e) than if it cooperates with countries 2–5 to jointly maximize global surplus? Explain.

Solution:

If country 1 cooperates to jointly maximize global surplus, they will obtain 0 from (c).

From (e), we know they get 4 if they do not cooperate. And $4 > 0$. So, country 1 is better off not cooperating with the rest of the countries!

QUESTION 2 (20 points). Reassessing the social cost of carbon.

Suppose that scientists have determined that emitting an additional ton of carbon today will cause \$2 of environmental damage each year from 2024 to 2224.

(a) Suppose also that the rate of pure time preference is $\rho = 0.1\%$, the elasticity of marginal utility with respect to consumption is $\theta = 3$, and the growth rate of consumption is $g = 0.5\%$. Calculate, or provide a precise numerical formula for, the optimal Pigouvian tax on a ton of carbon today.

Solution: Ramsey's rule implies $r = \rho + \theta g = 0.1\% + 3 \cdot 0.5\% = 1.6\%$.

So damages will be

$$\sum_{t=0}^{200} \frac{1}{(1+0.016)^t} \cdot 2 \approx 121.77$$

dollars per ton of carbon.

(b) Now suppose that $g = 4\%$, but that the other assumptions in (a) remain true. Recalculate the optimal Pigouvian tax.

Solution: The new discount rate is $r = 0.1\% + 3 \cdot 4\% = 12.1\%$. So damages will be

$$\sum_{t=0}^{200} \frac{1}{(1+0.121)^t} \cdot 2 \approx 18.53$$

dollars per ton of carbon.

(c) Of the real discount rates considered in (a) and (b), which is closer to the discount rate used by the EPA in its 2022 updated social cost of carbon?

Solution: The discount rate in (a). The discount rate in (b) of 13% is much higher than any considered by the EPA.

QUESTION 3 (40 points). Air pollution.

Suppose that there are $N = 100$ polluting firms in California. Assume that the firms are identical and each obtain profits $\pi_i(q_i) = pq_i - \frac{1}{2}c_i q_i^2$ from emitting q_i tons of pollution, with $p = 10$ and $c_i = 1$ for all i.

Suppose that the total pollution, $Q \equiv \sum_{i=1}^{100} q_i$, causes environmental damage $D(Q) = \frac{1}{200}Q^2$.

(a) How much pollution will California face if firms maximize profits, without any policy intervention?

Solution: $\frac{\partial}{\partial q}\pi_i(q) = 10 - q_i^* = 0$ or $q_i^* = 10$, so in total, $\sum_{i=1}^{100} q_i^* = 1000$.

(b) What is the first-best level of pollution for each firm?

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Solution: $\frac{\partial}{\partial q_i}\left[\sum_{i=1}^{100} pq_i - \frac{1}{2}c_i q_i^2 - D(\sum_{i=1}^{100} q_i)\right] = p - c_i q_i - \frac{1}{200}\cdot\sum_{i=1}^{100} q_i = 0$, and with $p = 10$, $c_i = 1$, and symmetry, we obtain

$$10 - q_i^{\text{FB}} - \frac{1}{200}\cdot 2 \cdot \underbrace{100 q_i^{\text{FB}}}_{\sum_{i=1}^{100} q_i^{\text{FB}}} = 10 - 2q_i^{\text{FB}} = 0$$

or $q_i^{\text{FB}} = 5$.

(c) Will a command-and-control mandate that prohibits any firm from producing more than $\overline{q} = 5$ tons of pollution deliver the efficient outcome? Explain.

Solution: Yes. The firms are identical, so there is no need to differentiate the policy across them. And, by the result of (b), $\overline{q} = 5$ will lead all firms to produce $q_i^{\text{FB}} = 5$.

(d) One of the 100 firms has developed a new technology, so that they now produce with a profit function where $c_i = \frac{1}{10}$. The rest of the firms still have the old technology (so $c_j = 1$ for all $j \neq i$). Explain how this will change your answer to (c), if at all.

Solution: Now command-and-control is second-best (A1 and A2 are satisfied from Lecture 11). It does not deliver the efficient outcome, which would dictate that we would like the newly more-efficient firm i to produce more than the rest of the firms.

QUESTION 4 (24 points). True or false.

(a) As discussed in lecture, the use of a higher real discount rate is an important reason for the increase in the U.S. federal government's social cost of carbon from the 2014 Obama-era guidance to the 2022 EPA update.

Solution: False. The 2022 EPA update used lower discount rates. And, regardless, a higher discount rate will lower the social cost of carbon.

(b) Nordhaus' 2008 cost-benefit analysis argued that doing nothing about climate change would be preferable to implementing the Stern Review's recommended climate policy.

Solution: True. When Nordhaus calculates the net benefits of the Stern Review policy, he finds that the costs outweigh the benefits. Note that Nordhaus's own climate policy has positive net benefits and, according to his calculations, would have been preferable to doing nothing.

(c) As discussed in lecture, equilibrium prices of annual permits to pollute NO_x in the first four years of the RECLAIM market were close to zero. This was because the government issued many more permits than the total pollution generated.

Solution: True.

(d) Unfortunately, since 1990, scientists have made limited progress reducing uncertainty over the parameter that determines the sensitivity of average global temperature to carbon dioxide.

Solution: True.

(e) Because historical temperature deviations correspond to fluctuations in weather, not the climate, empirical studies that relate historical temperature deviations to economic outcomes cannot directly answer what the true economic costs of future climate change will be.

Solution: True.

(f) One argument for the command-and-control policies discussed in lecture is that they can improve welfare relative to the free market.

Solution: True.