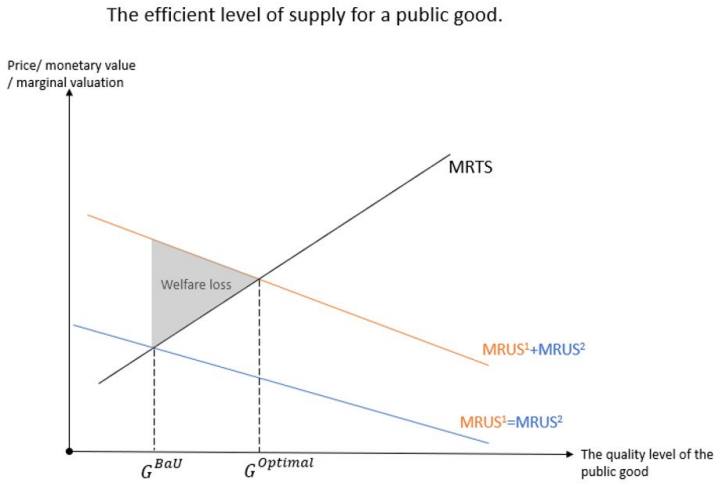
Exam ECON2920 Spring 2022
University of Oslo, Departement of Economics
Tuesday May 31st. 09:00-12:00
Solution sketch

Full credit is given to those that explain and do their own reasoning.

Question 1. Public goods (10 points)

(a) **(5 points - short answer - words and graph)**
What is a 'public good' and what determines the optimal amount of a public good in the social planner solution? How is this different from the solution in the competitive market? Explain and include a graphical illustration.
Solution key:
As a minimum the student should explain what determines a public good: public goods are non-rival and non-excludable, and there are some goods that are partly public goods and partly private/club goods. However, its important that the student explain *why* this is the case and what it implies.

The student need to show that in the market equilibrium the agents do not take into account that they all consume the same unit, hence there will be too little supply of the public good - if they are present in the market at all. In addition, the consumer will have no intcentive to pay for a good that is non-excludable and the firm will have no incentive to supply a good that is non-rivalrous. Because we consume the same unit of the public good - the social optimal amount is the sum of every marginal willingness to pay/the sum of every marginal benefit.



(b) **(5 points - short answer - words)**
Give an example of an environmental public good and a public bad.
Solution key:
The students should give examples of public goods and explain why these example can be thought of public goods. It does not give full credit if the student lists up examples of public gooods: A healthy environment, the atmosphere, clean air etc. Or examples of public bads: Pollution, noise, smell, climatic changes

Question 2. The target (30 points)

Consider a flow pollutant E. The net social benefits from pollution, NB, is defined as pollution benefits minus pollution damages:

$$NB = B(E) - D(E) \tag{1}$$

In our case the damage function is convex, hence $D'(E) > 0$ and $D''(E) > 0$, and the utility function is concave, hence $B'(E) > 0$ and $B''(E) < 0$.

(a) **(5 points - short answer - words)**
Explain what we mean with "pollution benefits" and what is the implication of a concave benefit function?
Solution key:
Pollution benefits are the social opportunity cost of pollution, the welfare improving things we can consume or are able to produce when using pollution as input or output in production. If society does not benefit from any process or product linked to pollution, then it would be social optimal to limit pollution to zero. In reality there is almost always a trade-off between benefits and costs of pollution. When assuming the benefit is concave, it implies that the mariginal value is decreasing in the amount of pollution. A marginal increase among the first units of pollution are more valuable than a marginal increase when there already is a lot of pollution. Concavity is the standard assumption in classic production functions or utility functions.

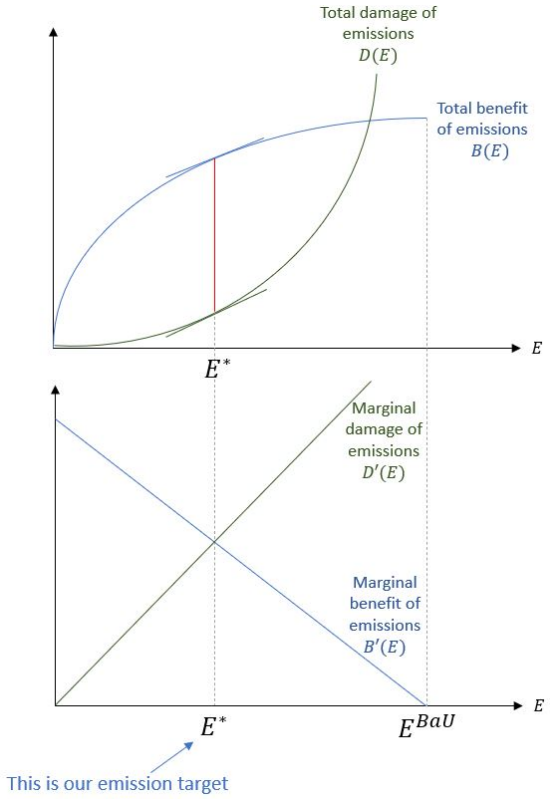
(b) **(5 points - short answer - calculus and figure)**
Show how to solve the maximization problem. Illustrate the net benefits with a figure, and mark the business as usual level (BaU) and the target.
Solution key:
Set up the maximization problem:

$$\max_{E} \quad NB = B(E) - D(E)$$

Take the first derivative and set up the first order condition:

$$B'(E) - D'(E) = 0$$

Hence the marginal values should be equal. We can illustrate this graphically:



(c) **(5 points - short answer - words)**
Explain what we as environmental economists mean by "the optimal level of pollution". When can it be socially optimal with zero pollution?
Solution key:
The optimal level of pollution refers to the *efficient* level of pollution. In other words, "how much pollution is socially acceptable". The word 'opitmal' comes from the concept of Pareto Optimality, when something is pareto optimal no one can improve their welfare without decreasing the welfare of someone else - which means we allocate all available resources; not too little and not too much.

It can be socially optimal with zero pollution if the marginal damage of the first unit of emissions exceeds the marginal benefit, which can be the case for very toxic pollutants. It can also be optimal with zero pollution if the marginal cost of abatement, the cost of abating the first unit of pollution, is negligible.

Since optimality is an efficiency measure, it does not take into account the distribution of costs and benefits. Something that is unfair can still be optimal. In economic analysis we distinguish between arguments based on efficiency and arguments based on fairness, equity and moral, without stating that one measure is more important than the other. Its up the decision maker, and hence society, to decide how to weight efficency and fairness when reducing pollution. As an economist it is important that we show and explain the distributional impact of optimal and cost efficent policies.

(d) **(15 points - long answer - words, calculus and figure)**
Equation (1) defines the trade-off (net benefit) in terms of pollution. Rewrite the net benefit in terms of abatement instead, illustrate in a figure and explain in words how to intepret the curvture of the functions.
Solution key:
The trade-off in terms of abatement can be stated as the benefit of abatement (the benefit of avoiding emission damages) minus the abatement cost (the opportunity cost, the pollution benefits that we miss when reducing emission, in terms of lost consumption or production, together with the cost of performing abatement, installing new equipment or technology):

$$NB = B(A) - C(A) \tag{2}$$

Sometimes we frame the trade-off as minimizing totalt costs, both environmental costs $D(E)$ (emission damages) and abatement costs $C(A)$ (the cost of emission reduction).

Question 3. Regulating a pollutant (30 points)

Suppose the National Environmental Agency calculated the optimal target E^* of the toxic pollutant in Question 2. In this economy there are two main agents that create pollution in their production process, $B(E) = B_1(E_1) + B_2(E_2)$. Firm 1 is the cement industry and Firm 2 is a chemical manufacturer. The regulator needs advice on how to best reduce pollution. Suppose we know the firms' technologies, such that we can draw the following:

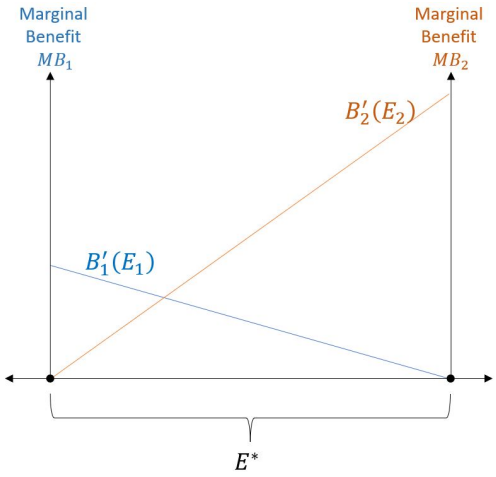


Figure 1: Optimal level of emissions and the two marginal benefits

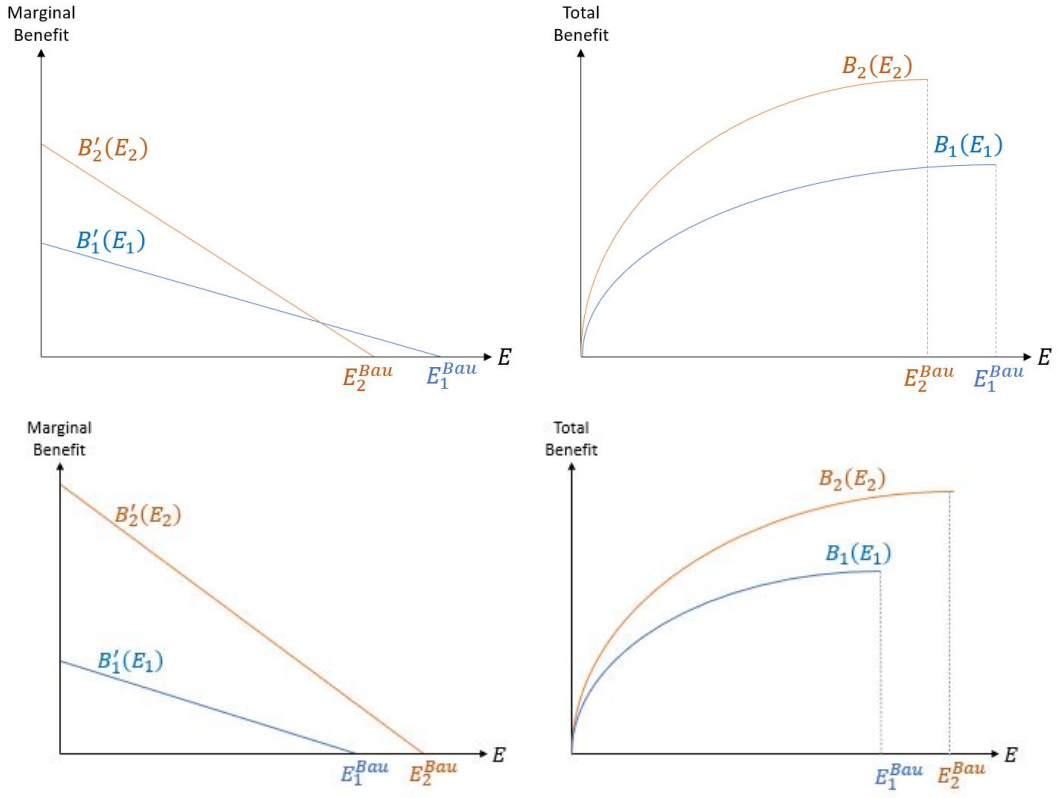


Figure 2: Note that we cannot be sure which firm that emits more in BaU, there is too little info in the exercise to support the placement of E_1^{Bau} and B_2^{BaU} in this figure - we only know that firm 2, with the steepest MB of emissions, necessarily has a steeper curvature in total benefits/production. Hence firm 2 can produce more output than firm 1 for the same level of emissions

(a) **(5 points - short answer - words and figure)**

In Figure 1, the marginal benefit is steeper for Firm 2 than for Firm 1. What does this imply? Can you give an example of when this might be the case?

Solution key:

For the firms the marginal benefit (MB) of emissions can be thought of as the production function, i.e. how much the firms can produce given their technology when using emissions as input to production. The production function is concave, such that the marginal product of an extra increase in inputs is falling in the amount of inputs, here emissions. The steepness tells us about the curvature of the production function. The steeper the MB, the more valuable is that unit of emissions compared to the other firm. The firm with the steepest MB has a larger marginal product for a given amount of emissions, meaning that it has a different technology making it possible to produce more on the margin. The firm with the steep MB is the high-cost-abater.

Note: This can be a challenging exercise. The students are used to see this figure with

upward sloping MAC-curves, measuring abatement on the x-axis. Most will probably talk about cost of abatement, but the point here is to address benefits of emissions. It is also a challenge to understand that these are firm-specific benefits and not the society's benefit of emissions. The key is to notice that this figure is from the firms' perspective, and we measure emissions along the x-axis and the benefit curves are downward sloping.

(b) **(5 points - short answer - words)**
The regulator suggests an "equal for all"-policy that sets an emission cap per firm $i = 1, 2$, given by $\bar{m}_i = E^*/2$. What type of policy is this? Briefly discuss the pros and cons of this regulation (use the figure above in your arguments).
Solution key:

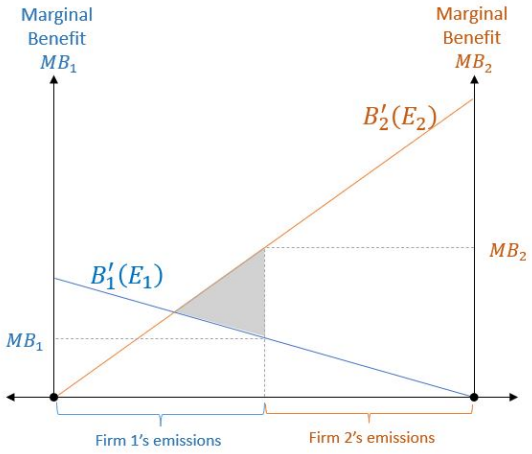


Figure 3: Solution to Question 3b

This policy is a command-and-control policy. Yes, we reach the target of E^*, but to an unnecessarily high cost. Each firm is allowed to use half of the total amount of optimal emissions, but since Firm 2's marginal benefit of that last emission unit is higher than Firm 1's MB there is room for Pareo Improvements - meaning this is not Pareto Optimal. In other words, this policy is not cost efficient, we are not reaching the target to least cost. We can increase overall benefits if we reallocate som emissions from Firm 1 to Firm 2, and the firm would do this reallocation on their own if we allowed them to trade emission quotas. The efficiency loss is given by the grey triangle in Figure 3.

(c) **(5 points - short answer - words and figure)**
The regulator suggests forbidding pollution from the chemical manufacturer. Meanwhile, the cement industry is allowed to pollute the amount E^*. What is the welfare

loss from this policy choice? Briefly discuss the pros and cons (use the figure above).
Solution key:

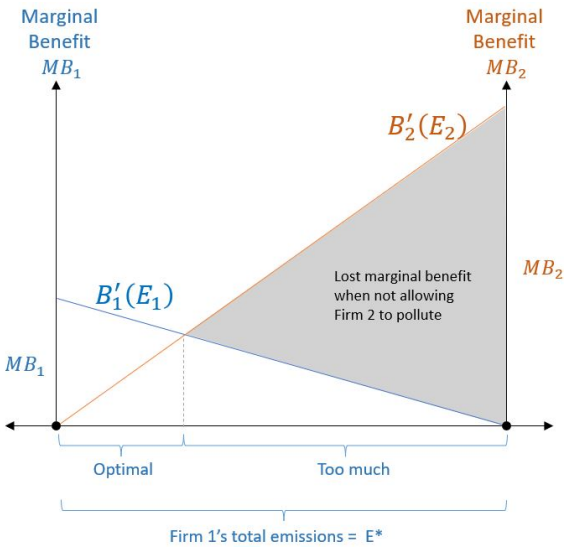
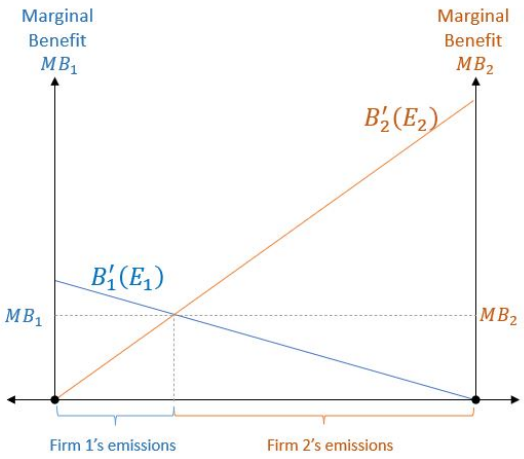


Figure 4: Solution to Question 3c

This policy is a command-and-control policy. Yes, we reach the target of E^*, but to an unnecessarily high cost. By forbidding emissions from Firm 2 the regulator is giving all the emission to the one firm that has lower marginal benefit of those emission units (lowest abatement cost). The netto efficency loss is = the marginal benefit we could have realized by allowing Firm 2 to pollute, minus the marginal benefit we get from letting Firm 1 pollute an total amount equal to E^*. This gives a huge efficency loss illustrated with a grey triangle in Figure 4.

(d) **(15 points - long answer - words and figure)**
Explain to the regulator how a quota market with tradable permits works, using the figure above. What determines the price of quotas (permits) in this market? Can the government establish a cost-effective quota market without knowing the firms' technology (and thus knowing their actual abatement cost)?
Solution key:
In a tradeable quota market the firms needs a permit/quotas when emitting one unit of emissions. If they are not willing to pay for a permit, they need to abate instead - hence firms weight the cost of abating to the emission permit price. The only information necessary for establishing a quota market is the the cap, number of emission permits, which should be equal to the optimal target E^*. The regulator/government can either hand out (granfathering) or auction out the permits at the scheme's be-

ginnning. In order to determine the target, as we do in Question 2, the regulator needs to know the aggregate net benefit (welfare) of emissions at a society level - that includes both the consumers' and producers' benefit of emissions. If permits are tradable, the initial allocation of emission permits does not matter for whether we reach the target to least cost. The firms will trade permits based on each firms' individual technology. The firms will mutually benefit from trade in permits as long as one firm is willing to pay more than what the other firm is willing to accept. They will trade until the marignal willingnes to pay for a permit is equal. Hence, the price of a permit in a cap-and-trade-scheme revelas how much the industry values a unit of emissions on the margin. The permit price in an efficient permit market equals the Pigouvian tax. The price level depends on how many permits there are (scarcity) and the industry's valuation/benefit of emissions. Since Firm 2 will buy more permits than Firm 1, and the trade is open information, the regulator then also learns that Firm 2 is the high-cost-abater in this industry.



Question 4. Global climate change (30 points)

In this exercise we will discuss climate change and emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs).

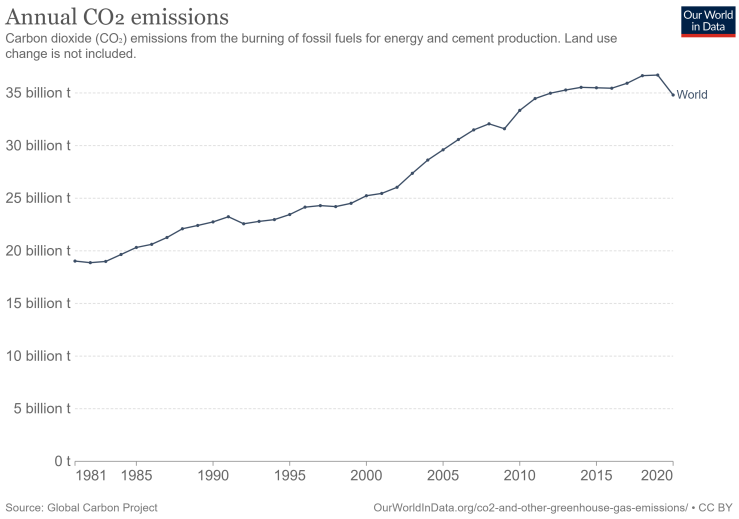


Figure 5: Global CO_2 emissions from fossil fuels, 1981-2020.

30 years ago 154 countries signed the first climate treaty, the UN Framework Convention on Climate Change, where they agreed to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system" (UNFCCC, 1992). Figure 5 shows that CO_2 emissions have continued to rise since then.

(a) **(5 points - short answer - words)**
Explain what it means that countries are "sovereign states". What are the implications for international environmental agreements?
Solution key:
Countries are sovereign states as they by definition have supreme legitimate authority over their territory, meaning they decide their own laws. This implies that there is no supra-national institution that can implement international regulation and force countries to comply with global policies, since no outside entity other than the national government can decide the country's policies. Global regulation and cross-country policies need to be ratified in international agreements. (Like the European Economic Area (EEA)-treaty (EØS-avtalen), that has large implications for the Norwegian policies. Norwegian policymakers decided to join EEA in 1994, and Norway is free to withdraw whenever. However, as long as we are in the agreement it is legally binding. If we choose to violate the laws in the EEA we need to withdraw from whole the agreement - and all these years the benefit of beeing part of the EEA

has been larger than the cost, even though this is an ongoing political debate in Norway).

Since no country can be forced to enter an international agreement, cross-country cooperation needs to be voluntary. If countries act as rational agents (and it is up to discussion whether this is a good assumption) a country would never enter an agreement voluntary that implies more costs than private benefits.

(b) **(5 points - short answer - words)**
Why should the global carbon tax be equal across countries?
Solution key:
Carbon and greenhouse gases (GHGs) are uniformly mixing, meaning that their contribution to the atmospheric concentration do not depend on the emission location. An extra tonn of carbon to the atmosphere do the same harm whether it is emitted in Norway or Nepal, hence the optimal price (the Pigou tax) of that tonn of carbon should be equal in all countries that emit GHGs.

Note: In the lecture we have discussed carbon leakage, and some students may mention that a uniform carbon tax levels the floor and eliminate any incentives that cause carbon leakage.

(c) **(5 points - short answer - words)**
What is the difference between stock and flow pollution and why do we need to take this distinction into account when discussing solutions to the climate problem? What type of pollution is illustrated in Figure 5?
Solution key:
The harm from flow pollution stops immediately when we stop emitting (like the noise from a machine). The harm from stock pollution depends on previous emitted pollution - and the harm continue even though we stopped the flow. Climate change and plastic waste in the oceans are examples of stock pollution. If we stop dumping plastic in the oceans today, we still need to face the problem of previously emitted plastic.

Time is introduced to the analysis when dealing with stock pollution problem, because there is a wedge between the time of the emissions and the time of the damage. The climatic damages we experience today are due to emissions emitted in the past. The CO_2 emissions we emit today will cause climatic damage in the future.

To limit the harm from climate change we need to both stop the flow of GHGs but also invest in technology to reduce the carbon already accumulated in the atmosphere. The regualtory instruments we discuss in class are foremost targeted to flow emissions.

We need other types of regualtory instruments to reduce the stock. Often this involves cleansing, clean-up or other types of removal-technology.

In figure 5 we see the emission flow, the added billion tonns of CO_2 added to the stock each year. The stock, on the other hand, is the atmospheric concentration of CO_2 - se figure 6:

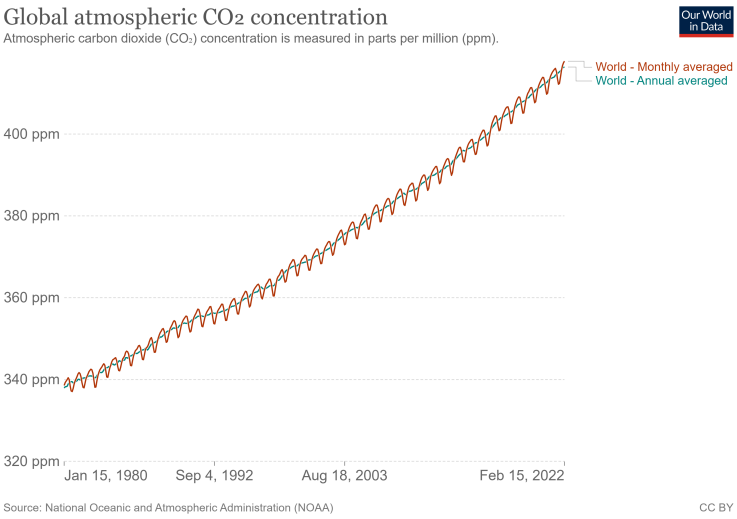


Figure 6: CO_2 accumulation in the atmosphere, 1981-2020.

(d) **(15 points - long answer - words/calculus/figure)**
Climate change is a global problem. What is the mechanism that prevents countries from achieving full cooperation? Explain why the Nash equilibrium of a climate treaty game never will be social optimal. Use either words, calculus or a figure to explain.
Solution key:
The climate is a public good and hence the concentration of carbon in the atmosphere is a public bad, meaning that everyone share the harm from GHG emissions and everyone share the benefit of abatement.

Since the benefit of costly abatement is a public good, each country has an incentive to free ride on other countries contributions. The outcome of a game is called the Nash equilibrium or the Non-cooperative solution. In the non-cooperative equilibrium no one will contribute enough to limit the problem, even though limiting the problem would be social optimal for all. This is called the free rider problem. The game structure where the dominant strategy is to not cooperate is called a prisoner's dilemma game. In these settings it is difficult to achieve the full-cooperative outcome since we cannot force sovereign states to cooperate – it needs to be voluntary.

Some students might draw the Prisoners' Dilemma game with several countries:

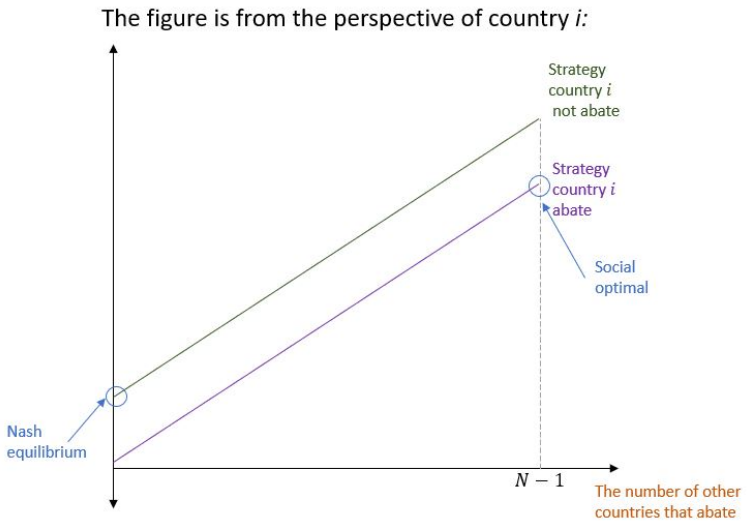


Figure 7: Prisoners' Dilemma game with several countries

Some students might draw the figure of a public good and the non-cooperative and the full-cooperative abatement level:

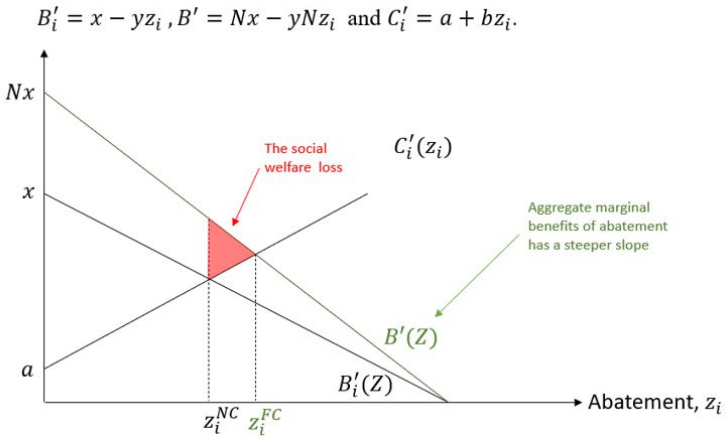


Figure 8: Non-cooperative and Full-coopertive outcome