**ECON1922 spring 2023**
**University of Oslo**
**WITH ANSWERS**

**EXAM**

# Instructions:

(i) All problems should be solved. Weights are reported in brackets.

(ii) Each exercise indicates how the question should be answered, whether we expect you to explain in words, provide a graphical illustration or use calculus.

(iii) Restrict your answer to what the exercise asks for, non-relevant information is given no credit. Full credit is only given to figures and graphs that are fully explained, correctly illustrated and with notation on the axes.

*This exam consists of 4 main questions.*
*The weight of each question is indicated, and the maximum is 100 points.*

# Question 1. Optimal pollution (40 points)

Consider a country where the population enjoys private consumption, $C$. This consumption is associated with a negative externality: environmental pollution, $E$. Each consumption unit emits one unit of emissions, $C = E$. The damage function $D(E)$ is convex and the benefit function $B(C)$ is concave. The net social benefit ($NB$) of the population can be described by:

$$NB = B(E) - D(E)$$

The functions are illustrated in Figure 1:

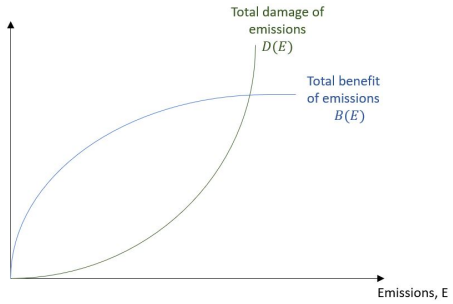


Figure 1: Total damage of emissions and total benefit of emissions.

(a) **(10 points - short answer - words)**
Explain how we can interpret the benefit function, and what is the assumption for making the social benefit of emissions concave?
*Solution key:*
The social benefit of consumption, $B(C)$, can be interpreted as the population's preferences for consumption goods. It has similarities with a standard utility function in consumer theory. In economics, concave utility functions are used to model diminishing marginal utility, which means that the more you consume of a good, the less utility you get from each additional unit. However, in contrast to an individual's utility function this benefit function represents the whole populations aggregated preferences for different volumes of consumption. Since there is a one-to-one relationship between consumption and emissions, we can also interpret this as the social benefit of emissions. When reducing emissions, we miss benefits in terms of lost consumption or production possibilities.

(b) **(10 points - short answer - words and figure)**
Use Figure 1 to indicate the optimal emission level, $E^*$. Explain in words what we mean with the "optimal" level of emission?
*Solution key:*
See figur 2 for the optimal level of emissions.

The optimal level of pollution refers to the *efficient* level of pollution. In other words, "how much pollution is socially acceptable". The word 'optimal' 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.

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. It's up the decision maker, and hence society, to decide how to weight efficiency and fairness when reducing pollution. As economists it is important that we show and explain the distributional impact of optimal and cost-efficient policies.

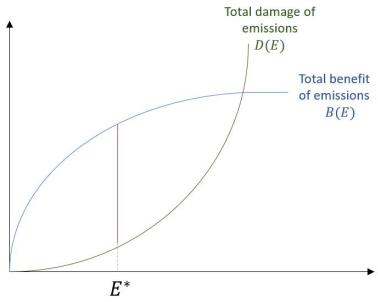


Figure 2: Total damage of emissions and total benefit of emissions.

(c) **(10 points - short answer - words and figure)**
Show how we can draw the figure with marginal values instead of total values, and indicate the Business as Usual (BaU) emission level $E^{BaU}$. Under what circumstances does the population experience this level of emissions, and why is it not optimal?
*Solution key:*
See Figure 3 for the net social benefit of emissions in marginal values. The population will experience the BaU emission level if pollution is not regulated or mitigated.

(d) **(10 points - short answer - words and figure)**
Under what conditions can it be optimal with zero emission pollution? Explain in words and show in a figure.
*Solution key:*
It can be socially optimal with zero pollution, $E^* = 0$, if the marginal damage of the first unit of emissions exceeds the marginal benefit, which can be the case for very toxic pollutants. It will also be optimal with zero pollution if the marginal cost of abatement, the cost of abating the first unit of pollution, is negligible. See Figure 4 for a graphical illustration of this case:

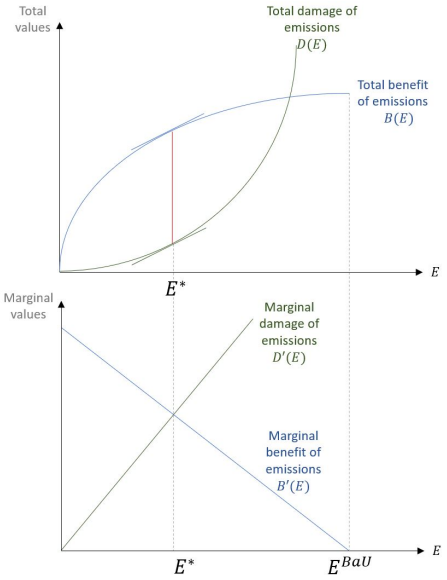


Figure 3: Total damage of emissions and total benefit of emissions.

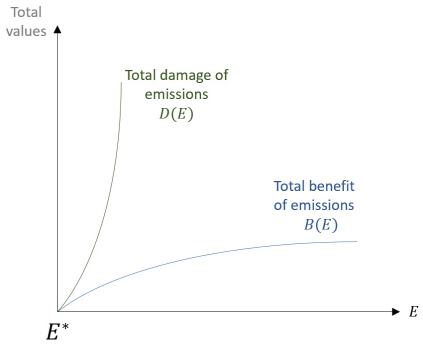


Figure 4: Total damage of emissions and total benefit of emissions.

# Question 2. Climate change policy (30 points)

Consider a country with a new green government that is eager to implement policies to mitigate climate change. However, before they make any policy decisions, they have asked for expert advice from an environmental economist.

(a) **(6 points - short answer - words)**
The policy makers ask you to explain what economists mean by describing climate change as a "public bad" and carbon emissions as "negative externalities". Include the definition of these two market failures.
*Solution key:*
Include the definition of a market failure: In economics the market failures describe parts of the economy that breaks with the conditions in the first welfare theorem. In the presence of market failures, the outcome will not be social optimal. Economists identifies the reasons for climate change and other environmental problems as market failures.

Include the definition of public goods: Public goods are non-excludable and non-rival. The climate is a public good and hence the concentration of carbon in the atmosphere is a public bad, meaning that everyone shares the harm from GHG emissions, and everyone share the benefit of abatement. Public goods will not be sustained in an unregulated market. For global public goods, for example the benefit of costly abatement of greenhouse gas emissions, each country has an incentive to free ride on other countries climate contributions and there will be too little climate mitigation in the aggregate if countries behave as rational actors.

Include the definition of an externality: An externality is a consequence of an economic activity which unintentionally affects other parties without this being reflected in market prices. An example is pollution emissions, smell, noise, or toxic spills. Economic activities associated with negative externalities are too cheap in the unregulated market, and hence the market allows for too much of the damaging activity.

(b) **(6 points - short answer - words)**
The policy makers need to know the difference between economic incentives policies and command-and-control. Give them a brief explanation of the pros and cons of the two types of regulations.
*Solution key:*
The student should come up with some examples of the two policies:

- Command-and-control is a type of environmental regulation that allows policy makers to specifically regulate both the amount and the process of abatement. Examples are output control, location control, technology control, emission standards, emissions licenses that cannot be traded.
- Economic incentive regulations are policies that influence behavior change through altering prices. Examples are taxes, fees, subsidies and tradeable quotas.

In Figure 5 we see the pros and cons from the lecture:

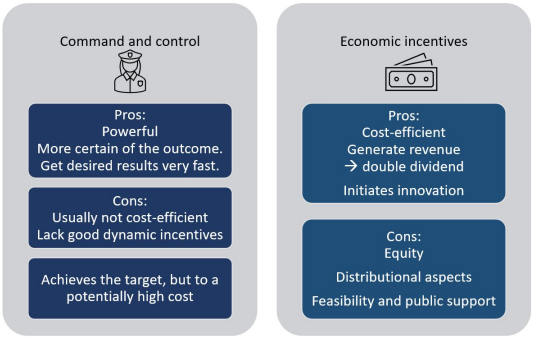


Figure 5: Total damage of emissions and total benefit of emissions.

(c) **(6 points - short answer - words)**
Explain to the policy makers why the global carbon tax should be equal across countries.
*Solution key:*

Carbon and greenhouse gases (GHGs) are uniformly mixing (UM), meaning that their contribution to the atmospheric concentration do not depend on the emission location. An extra tonne of carbon to the atmosphere does the same harm whether it is emitted in Norway or Nepal, hence the optimal price (the Pigou tax) of that tonne 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.

(d) **(6 points - short answer - words)**
Explain what could be the effect of implementing a substantial domestic carbon tax, that is higher than the carbon tax in the rest of the world, without a carbon border adjustment mechanism (CBAM)?
*Solution key:*
They key point here is to discuss carbon leakage. In class we have talked about competition between countries at the regulatory level. In an international economy and a globalized world, firms in some sectors (the manufacturing industry for example) are footloose/multinational organizations and they will reallocate in response to policy differences between countries. This can cause pollution havens, where polluting industry locates to the country with lax environmental regulation. In this case, with the green government implementing a substantial domestic carbon tax, it might cause some industry to move abroad - hence the climate effect will be negligible since only emission reduction matter - not the location of the emissions. This argument is the reason for why the EU has implemented policies to protect their firms from competition abroad.

The EU is currently updating the mechanism called CBAM, aimed at hindering carbon leakage. The Carbon Border Adjustment Mechanism (CBAM) is a carbon tariff on carbon intensive products, such as cement and some electricity, imported by the European Union.

(e) **(6 points - critical disucssion - words)**
The policy makers need to decide what value for the discount rate they will use in the government's cost benefit analysis (CBA). Either, they can use a high discount rate of 7%, like the Trump administration, or a lower discount rate of 2.5% like the Obama administration, see figure 6. Explain to the policy makers the implications of the choice of discount rate when doing a CBA of investments in climate mitigation.
*Solution key:*
In class we have discussed how the Trump administration's choice of a higher discount rate altered the size of the social cost of carbon (SCC), making it much smaller than the under the Obama administration. The SCC is used in the US government's cost benefit analysis (CBA) when calculating the true cost of investment projects, where SCC emphasizes the economic costs, or damages, of emitting one additional ton of carbon dioxide into the atmosphere.

There is an important time delay between emissions today and the damage they cause in the fare future (climate change is a stock problem). A higher discount rate implies that we are more impatient and put less weight on future benefits - benefits like avoided climate

damage. This has particularly importance for climate change mitigation projects, since this environmental problem has a *very long* time horizon.

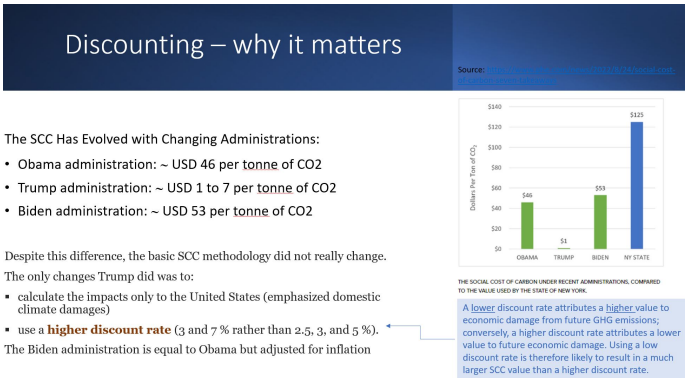


Figure 6: Total damage of emissions and total benefit of emissions.

## Question 3. The Environmental Kuznets Curve (20 points)

In this exercise you will be explaining concepts related to the so called *The Environmental Kuznets Curve* (EKC). The curve is a hypothesized relationship between various indicators of environmental degradation and per capita income, se Figure 7 for an illustration:

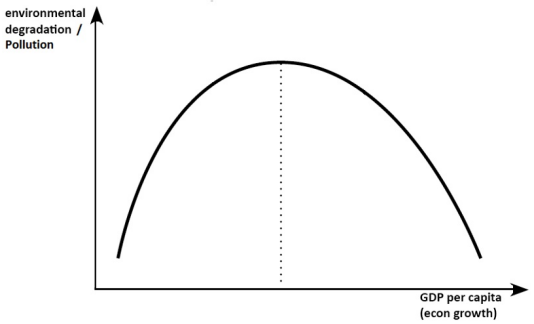


Figure 7: The Environmental Kuznets curve

(a) **(10 points - critical disucssion - words)**
What are the suggested mechanisms that might explain why we have this hump-shape in the relationship between environmental degradation and economic growth.
*Solution key:*
In class we have discussed some possible explanations for how economic growth affects the environment, and there are two conflicting effects: Either increased GDP per capita cause more emissions and environmental harm since a larger economy leaves a larger footprint (scale effect). Or, there economic growth causes changes in preferences, production or technology that reduce the negative environmental impact. We have called these the Income effect, the Composition effect and the Technique effect. See figure 8 for the lecture slide.

The EKC suggest that the scale effect dominated at low levels of economic development, but as countries become richer the other effects will start to dominate.

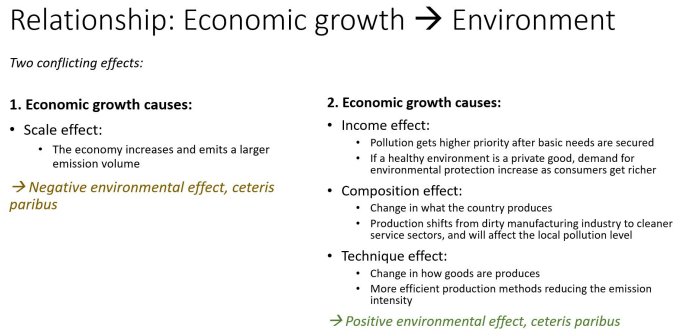


Figure 8: The Environmental Kuznets curve

(b) **(10 points - critical disucssion - words)**
On the y-axis in Figure 7 we measure the level of "environmental degradation/pollution", but

its not clear from the hypothesis of the Environmental Kuznets Curve what this measure. Discuss some arguments for why the relationship in the Kuznets curve is more likely to hold for local than for global pollution.

*Solution key:*

In contrast to GDP per capita, which is a well-established measure, it is more complicated to agree on a measure for environmental quality. There is a wide range of environmental problems, some are more present in the local environmental as others are fare away (in the upper atmosphere or in the deep ocean). In this question I hope the student can show independent and critical discussion of the EKC hypothesis. I want them to discuss how EKC is more likely to hold for local environmental problems like the pollution of rivers, recreational areas, and air quality. We can think of demand for a clean environment as demand for a normal good, as we become richer, we want a cleaner environment (the income effect) and are willing to spend more money one mitigation policies and abatement investment. However, it might be that the dirty activity is just moved to areas with a poorer community, that cannot afford expensive environmental regulation.

## Question 4. Total emissions (10 points)

The *Kaya identity* is a useful equation for quantifying the total emissions of carbon dioxide ($CO_2$). The identity breaks down $CO_2$ emissions (left side of the equation) into key driving elements (right side of the equation):

$$Total\ CO_2\ emissions = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy} \tag{1}$$

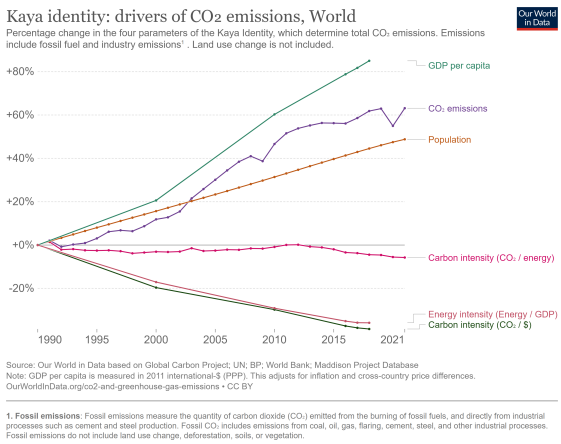


Figure 9: Drivers of $CO_2$ emissions, world. Percentage change relative to the year 1990. Source: Our World in Data

In figure 9 we see a visualization of the Kaya indentity for the World from 1990 until 2021. Help us to correctly read the figure by answering the questions below:

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

Explain how we should interpret Figure 9, what do we measure on the y-axis?

*Solution key:*

The figure depicts yearly changes in the driving elements of the Kaya identity, relative to the initial year 1990 in the time span of the last 30 years. Hence, an 80% increase in the world's GDP per capita in 2020 tells us that the global population is on average 80 percent richer than it was in 1990. We see that there has been increasing population growth, but the increase in the economic growth is even larger.

(b) **(5 points - short answer - words)**

What does it mean when "Energy intensity" is downward sloping, and "Carbon intensity" is almost flat, and below zero?

*Solution key:*

This exercise is considered difficult, and the point is to test the students' ability to read and convey facts from graphs.

Energy intensity is a measure of total energy consumption (terra watt hours) in the world divided by GDP (money). The measure indicates how much of the world's economic budget is used on energy. The higher the intensity the more we spend on energy. When Energy intensity decrease it means that each year energy intensity is less than it was in 1990. Either because we use less energy, or because the economy grows faster than the growth in energy use.

Carbon intensity is a measure of total carbon consumption (tonne of CO2) in the world divided by energy use (terra watt hours). The measure indicates how much of the world's energy budget is carbon based. When the curve is flat and below zero, it implies that the carbon intensity is decreasing each year at a constant speed. We use an increasing amount of CO2 each year, but since total energy use is increasing more the carbon intensity has a negative change relative to 1990.