Final Exam - 4910 - Environmental Economics
Spring 2024

If you get stuck, and have questions or if the text/problem below is confusing/unclear, please do the following: Make and state clearly your assumptions (/interpretations of the text), and continue your analysis based on that.

Problem 1 (30%) [Sustainability]
Sustainable development is a concept that was introduced in the 80s and has been subject to economic research in the years after that.

i) (10%) a) How do we define a sustainable development? Explain two different approaches that economists have used to make the measurement of sustainable development operational.

Solution: The World Commission (1987) â the Brundtland report defined the concept in the following way: *A sustainable development is a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.*

We are looking for a definition along these lines that has a similar meaning, not a word-by-word definition.

In economics, sustainable development can be interpreted as ensuring a non-declining standard of living over some time horizon. There are mainly two approaches to interpreting the concept in economics: The utility approach and the capital approach.

The Utility Approach:
The utility of a representative agent should be non-declining over time

$$U'(t) \geq 0 \quad \text{for } t > t_0$$

and utility should not exceed the maximum sustainability level

$$U(t) \leq U_{max\ sust}$$

We do not expect the equations if the student can explain the meaning of the utility approach without equations.

The Capital Approach
This approach does not consider utility but concentrates on society's ability to produce the goods that individuals need. Economic activity depends on the productive base or resources in society which can be defined as stock of capital assets and institutions. The idea is that we should maintain the productive base such that future generations may produce and consume a similar bundle of goods as the present generation does.

ii) (10%) Explain the difference between weak and strong sustainability and critically discuss these two different conceptions of sustainability.

Solution: Weak and strong sustainability are ways to make the capital approach operational. Capital assets may include:

- Manufactured capital; K_M
- Human capital (education and health); K_H
- Natural capital (environment ecosystems and natural resources): K_N
- Social capital (including institutions); K_S
- Foreign debts/assets: K_F

Weak sustainability assumes full substitution between the capital stocks.

$$\frac{dK}{dt} \geq 0 \quad \text{where} \quad K = K_M + K_H + K_N + K_S + K_F \ .$$

Discussion: Substitution between capital stocks has always been a possibility; for instance, humans have used natural resources to reach a given utility level. However, there are limits to how much the capital stocks can be degraded without reducing the living standard. This may typically be for natural capital.

One criticism against this approach may be that we do not need so much of the capital stocks to produce the same amount of goods if there is technological progress. However, technological progress can be included in a capital stock, for instance, knowledge or human capital.

Another argument is if we have a constant productive base, production per capita may fall if the population increases. Thus, we may reinterpret the concept as constant productive base per capita.

Strong sustainability limits substitution as the argument is that not all capital stocks can be replaced by other capital. Examples of capital stocks that cannot easily be replaced may be natural capital and social capital.

$$\frac{dK_N}{dt} \geq 0 \quad \text{and} \quad \frac{dK_S}{dt} \geq 0$$

Discussion: Strong sustainability meets the criticism of weak sustainability as it acknowledges that not all capital stocks can be substituted by other stocks. It is also applied in environmental policy as we set limits to certain changes in natural resources such as the Paris agreement (limit global mean temperature) or the international treaty on biodiversity signed in Montreal in 2022.

iii) (10%) Give some examples of how the concept of weak sustainability has been used.

Solution: Some examples of the application of weak sustainability:

- Green national product: A national income concept that corrects for capital depreciation. Depreciation of all capital stocks needs to be included. This will give a measure of sustainable income. This concept used to be popular in the 90s and the beginning of this century, but the focus is now more on the stocks of natural assets.
- Genuine savings: This concept refers to the change in the productive base by calculating all gross investments minus all depreciation. This is used by the World Bank (named Adjusted Net Savings).

Problem 2 (35%) [Non-market valuation]

i) (10%) Explain the concept of **revealed preferences**. (Hint: What is the key aim of revealed preference methods in the context of environmental goods and services? What is the underlying premise? What are key limitations?)

Solution:

- Background: Markets for environmental goods are often missing or characterized by distortions. Market prices for environmental goods are therefore usually not available, or do not reflect the social marginal willingness to pay for the good. This means that we cannot use market prices directly to quantify the marginal willingness to pay (WTP) for an environmental good. To try to solve this problem, economists often make use of *non-market valuation* to value environmental goods and services. One group of non-market valuation techniques is called revealed preference (RP) methods.
- Key aim: The key aim of RP methods is to quantify the value of environmental goods and services when market prices are absent.
- Key premise: people interact with the environment (e.g., hiking, whale-watching, residential location and air quality)
- Description: RP methods are based on observed behavior in a *related* market, where the premise is that people interact with the environment through the related private market. E.g., residential housing market and air quality. By analyzing the demand for private goods *related* to the environment, such as e.g., house prices, we indirectly learn something about the value of a specific environmental characteristic
- Limitations: Most suitable for estimating use values. RP methods do not capture non-use values such as existence values.

ii) Assume that you are interested in quantifying the marginal willingness to pay (WTP) for clean air. You compile a dataset of individual house prices for a single year, and combine this information with ambient levels of PM_{10} from nearby monitoring stations in the same year. You run the following cross-sectional OLS regression:

$$ln\ y_i = \alpha + \beta PM10_i + \varepsilon_i\ , \tag{1}$$

where $ln\ y_i$ is the natural logarithm of individual house price and $PM10$ is the annual mean concentration of particulate matter in micro gram per cubic meter of air (ug/m3). You estimate a β coefficient of -0.009** that is statistically significant at a 5 % level.

a) (5%) Interpret β. In other words: what does -0.009 mean? (1 sentence is sufficient.)

b) (10%) Discuss potential reasons for why β may not be interpreted as a *causal* effect of air pollution on house prices.

c) (10%) Discuss potential empirical strategies you could employ to try to get closer to an unbiased causal effect. You can assume that it is possible to compile additional data. You can use (policy) examples from the literature in your discussion.

Solution:

- a) A 1 unit decrease in PM_{10} is associated with a 0.9% increase in house prices.
- b) Endogentiy issues: exposure to air pollution is not random and is likely correlated with a lot of other factors such as income, proximity to traffic and industrial sites, quality of schools, etc. β therefore reflects a correlation and not a causal effect as the coefficient might capture a whole range of household characteristics and neighborhood amenities.
- c) Potential strategies:
  - Covariates: Include covariats to try to mitigate omitted variable bias. E.g., characteristics of the house (m2, number of bathrooms) and characteristics of the neighborhood.
  - Panel FE: Expand the dataset to a panel dataset. Include fixed effects to difference out e.g., time trends and time-invariant area/neighborhood/house characteristics. Trade-off: too detailed FE could remove the variation in air pollution that we are interested in.
  - IV: Try to find an instrument that isolates exogenous variation in PM10. Literature: wind direction, inversion episodes, policy changes such as the clean air act. Obs: exclusion restriction need to hold, e.g., policy change should only affect house prices via its effect on PM10 levels.

Problem 3 (35%) [Emission Regulation]
A policymaker decides to regulate the emissions of a polluting industry after estimating the social damages D from emissions E and the industry's abatement cost curve $C(E)$:

$$D(E) = 2E$$
$$C(E) = 4E - E^2$$

We represent the industry by a representative firm. The problem is a flow pollution problem, so the policymaker can tackle it period by period.

i) (5%) Calculate the *marginal* abatement cost curve and the marginal damage curve. Assuming that the policymaker's estimates are correct, state the optimal carbon price and quantity.

Solution: The marginal damage and abatement cost curves are

$$MD(E) = 2$$
$$MC(E) = 4 - 2E$$

Leading to the equibrium emission level $E = 1$ and emissions price $p = 2$.

ii) (10%) Assume that the true industry abatement cost curve and the true marginal industry abatement cost curves are everywhere higher than the one estimated by the policymaker (and on which he or she bases the policy target). Is the deadweight loss higher under a tax or under a (classical) cap and trade system?

Solution: The deadweight loss (or social cost of the regulation) is higher under a cap and trade system. The optimal tax (of $p = 2$) matches the social damages at all emission levels and, thus, always implements the social optimum independently of the true abatement cost curve.

iii) (10%) Assume the policymaker is bound to use a cap and trade system. Could you think of a way to alter the classical cap and trade system to reduce the deadweight loss?

Background note on applied policy: The assumption might be a consequence of the following asymmetry for regulations in the EU. A price instrument requires unanimity among the member countries, whereas a quantity instrument can be decided by a majority vote.

Solution: A smart cap can reduce and even eliminate the deadweight loss. Here, the emission allowance per traded certificate is a function of the market price for certificates. We denote the total number of certificates by Q (won't be needed), the allowance of emissions per certificate by q, and the price of certificates (not emissions) by p. Then, if a firm is allowed to emit

$$q(p) = \frac{1}{2}p$$

units of emissions per certificate, the deadweight loss is zero.

Details: The smart cap equates the costs of one emission unit to a firm $\frac{p}{q}$ with the marginal damages:

$$\frac{p}{q} = MD(Qq).$$

Here, marginal damages are constant and we find

$$\frac{p}{q} = 2 \;\Rightarrow\; q(p) = \frac{1}{2}p \;.$$

The function $q(p)$ is the conversion function of certificates into emission units and has to be announced by the policymaker upfront.

iv) (10%) Let's return to the assumption that the policymaker's estimate of the abatement cost curve is correct. Yet, the policymaker's estimate of the damage cost curve is off and the true damage curve is

$$D(E) = 2E + E^2 \;.$$

Is the deadweight loss higher under a tax or under a (classical) cap and trade system?

Solution: The deadweight loss is the same under both instruments because the equilibrium will be identical under both instruments. Either regulation implies the market equilibrium calculated in the first question. It is the one targeted by the policymaker, who is mistaken about the true social damages. Therefore, also the deadweight loss is identical under both policy instruments.