Answers to written Re-exam at the Department of Economics winter 2019-20

Economics of the Environment, Natural Resources and Climate Change

Final re-exam

11 February 2020

(3-hour closed book exam)

Answers only in English.

This exam question consists of 4 pages in total

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- leave the examination.
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- Or if you otherwise violate the rules that apply to the exam

Exercise 1. Prices vs. quantities with correlated shocks

The model examined here is basically the same as the model investigated in Lecture Note 11. The only difference is that the covariance between the two stochastic variables is allowed to be different from zero.

Answer to Question 1.1

Figure 1 shows a situation with uncertainty only about the marginal damage cost. The government estimates a marginal damage cost curve, and it uses this curve to set either a pollution tax level, τ^{**}, or a cap for a cap-and-trade system, Q^{**}. The estimated marginal damage cost curve is, however, different from the true marginal damage cost curve such that the optimal emission level Q^* is different from the optimal emission quantity estimated by the government, that is Q^{**}.

Nonetheless, both the pollution tax and the cap-and-trade system leads to the same pollution level, namely Q^{**}. The cap-and-trade system directly ensures this pollution level. For the pollution tax, firms set marginal abatement costs equal to the tax rate: they equalize the marginal (private) cost of abatement with their benefit from pollution abatement which equals τ^{**}, as a unit reduction in their emissions reduces their tax bill by τ^{**}.

Accordingly, it is only changes to the marginal abatement cost curve that may change the emission level of the firms under a pollution tax. Since there is no uncertainty associated with the marginal abatement costs, the government will have full control over the emission level using the price instrument.

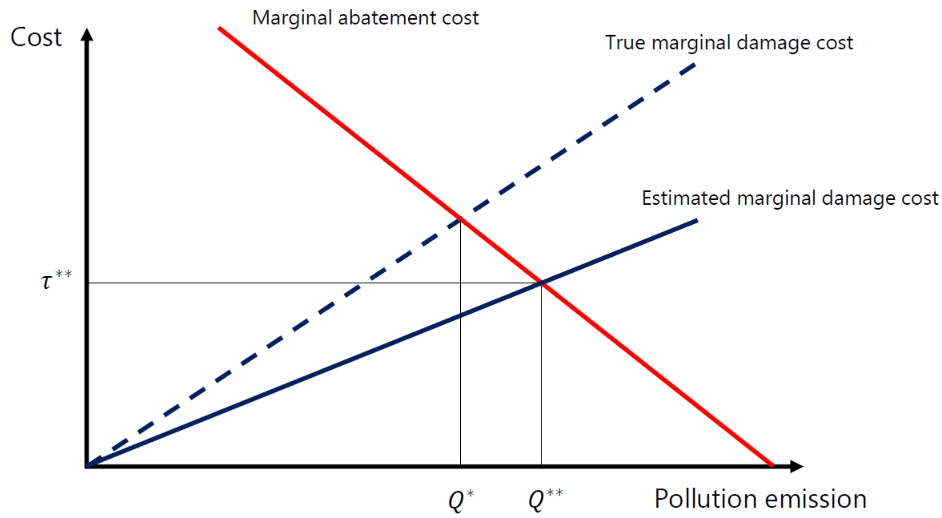

FIGURE 1: Market equilibrium with uncertainty about the marginal damage curve.

Answer to Question 1.2

Minimizing the expected net social cost from pollution emission requires that the expected marginal abatement costs equal the expected marginal damage costs:

$$\mathrm{E}\left[MDC(\tilde{Q})\right] = \mathrm{E}\left[MAC(\tilde{Q})\right].$$

Inserting the expressions for MDC and MAC:

$$\mathrm{E}\left[b\tilde{Q} + \eta\right] = \mathrm{E}\left[c(Q_0 - \tilde{Q}) + \theta\right].$$

Taking expectations yields:

$$b\tilde{Q} = c(Q_0 - \tilde{Q}) \quad \Leftrightarrow \quad \tilde{Q} = \frac{cQ_0}{b+c}.$$

The associated pollution price is found by setting the marginal abatement cost curve for the emission level $\tilde{Q}$ equal to the pollution tax. The intuition is the same as explained in the answer to Question 1.1, namely that the private firms ensure that their marginal abatement costs equal the tax rate in optimum. Accordingly,

$$\tilde{t} = \mathrm{E}\left[MDC(\tilde{Q})\right] = c(Q_0 - \tilde{Q}) = cQ_0 - c\underbrace{\frac{cQ_0}{b+c}}_{\tilde{Q}} = \frac{cbQ_0}{b+c}.$$

Answer to Question 1.3

Under a tax policy, the actual emission level ensures that given the shock realizations, the marginal abatement cost equals the pollution tax rate:

$$\tilde{t} = MAC(Q_{tax}).$$

Inserting the relevant expressions:

$$\underbrace{\frac{cbQ_0}{b+c}}_{\tilde{t}} = \underbrace{c(Q_0 - Q_{tax}) + \theta}_{MAC(Q_{tax})} \quad \Leftrightarrow \quad Q_{tax} = \tilde{Q} + \frac{\theta}{c}.$$

Under a tax policy the actual emission level only differs from the emission level that minimizes the expected net social cost of pollution if there is a shock to the marginal abatement cost curve different from its mean value of zero. The intuition is closely related to that of Question 1.1. As firms set their marginal abatement costs equal to the tax rate, it is only shocks to the marginal abatement cost curve that affect the emission level. That is why θ appears in the expression, while η is absent.

If θ is positive, then marginal abatement costs are higher than expected for any level of emissions. As the marginal abatement costs are declining in the emission level, the firms emit more pollution to drive the marginal abatement cost down to the fixed pollution price (tax rate). The opposite intuition holds for θ less than zero. This explains why Q_{tax} is increasing in θ.

Answer to Question 1.4

The optimal emission level, Q^*, ensures that given the stochastic shock realizations, the marginal abatement cost equals the marginal damage cost:

$$\underbrace{bQ^* + \eta}_{MDC(Q^*)} = \underbrace{c(Q_0 - Q^*) + \theta}_{MAC(Q^*)} \quad \Leftrightarrow \quad Q^* = \tilde{Q} + \frac{1}{b+c}(\theta - \eta).$$

The expression shows that if the shocks equal their expected value, the emission level that minimizes the expected net social cost of pollution equals the optimal pollution level.

Additionally, the expression shows that the optimal emission level is increasing in θ and decreasing in η. Intuitively, positive realizations of θ imply that the marginal abatement costs are higher than expected. As marginal abatement costs and marginal damage costs are equalized in optimum, a positive realization of θ will, all other things equal, reduce the optimal abatement effort, implying a higher optimal emission level. The same line of arguments can be employed to explain why negative realizations of θ result in lower optimal emission levels.

Positive realizations of η imply that marginal damage costs are higher than expected. This will, all other things equal, increase the optimal abatement effort, resulting in a lower emission level. The same intuition explains why negative realizations of η result in higher optimal emission levels.

Answer to Question 1.5

The social loss function simply states the net social welfare loss from an emission level Q compared to the optimal emission level Q^*. Consider the case $Q > Q^*$. In this case, pollution damage costs are too high and pollution abatement efforts are too low. The welfare loss equals the increase in total pollution damage costs minus the total decrease in pollution abatement costs. The increase in total pollution damage costs compared to the optimal emission level can be obtained by integrating the marginal damage costs over the interval Q^* to Q. Likewise, the decrease in total abatement costs is obtained by integrating the marginal abatement costs over the interval Q^* to Q. Hence,

$$SL = \underbrace{\int_{Q^*}^{Q} MDC(q)\,\mathrm{d}q}_{\text{Increase in damage costs}} - \underbrace{\int_{Q^*}^{Q} MAC(q)\,\mathrm{d}q}_{\text{Decrease in abatement costs}} \quad .$$

The question can also be answered graphically. Figure 2 illustrates a situation where emissions are nonoptimally high. The area A plus B is the additional social loss obtained from pollution damages when moving from the optimal emission level Q^* to the emission level Q. However, the pollution abatements costs are also reduced. This results in a welfare gain captured by the area B. The net social loss is therefore: (A+B)-B=A. The area A+B can be calculated by integrating the MDC curve from Q^* to Q, while the area B can be calculated by integrating the MAC curve from Q^* to Q. Hence the formula for the social loss basically calculates these two areas and subtracts the latter from the former.

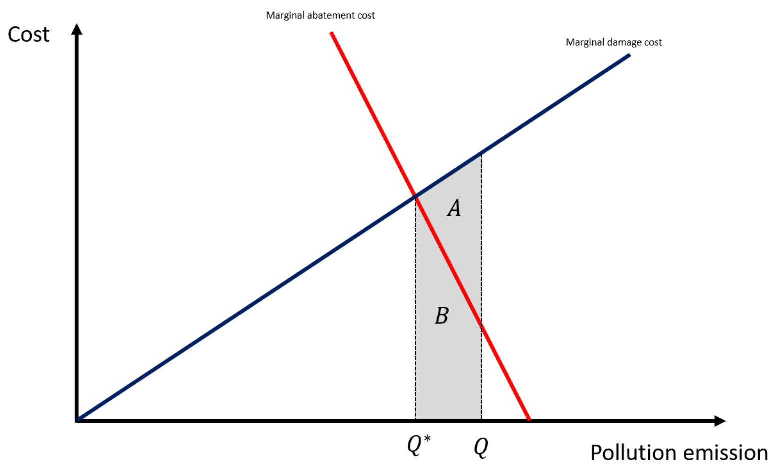

FIGURE 2: Social loss in a price-quantity diagram.

Answer to Question 1.6

The expected value of Δ is given by:

$$\begin{aligned}
\mathrm{E}[\Delta] &= \mathrm{E}\left[\left(\frac{b-c}{2}\right)\left(\frac{\theta}{c}\right)^2 + \left((b+c)\,\tilde{Q} + \eta - cQ_0\right)\left(\frac{\theta}{c}\right)\right] \\
&= \mathrm{E}\left[\left(\frac{b-c}{2}\right)\left(\frac{\theta}{c}\right)^2\right] + \mathrm{E}\left[\left((b+c)\,\tilde{Q} + \eta - cQ_0\right)\left(\frac{\theta}{c}\right)\right] \\
&= \left(\frac{b-c}{2c^2}\right)\mathrm{E}\left[\theta^2\right] + \left(\frac{b+c}{c}\tilde{Q}\right)\mathrm{E}\left[\theta\right] + \left(\frac{1}{c}\right)\mathrm{E}\left[\theta\eta\right] - Q_0\,\mathrm{E}\left[\theta\right] \\
&= \left(\frac{b-c}{2c^2}\right)\sigma_\theta^2 + \frac{\gamma}{c}.
\end{aligned}$$

where it is used that $\mathrm{E}\left[\theta\right] = 0$ and $\mathrm{E}\left[\theta\eta\right] = \gamma$.

The expected value of Δ is the expected social loss of the tax policy minus the expected social loss of the cap-and-trade policy. Hence if the expected value of Δ is positive, then the expected social loss of the tax policy is larger than that of the cap-and-trade policy, and thus, the cap-and-trade policy is preferred. Likewise, if the expected value of Δ is negative, the expected value of the tax policy is smaller than that of the cap-and-trade policy. Hence the tax policy is preferred. Consequently, one can analyse the important factors of the problem by analysing the expected value of Δ.

Answer to Question 1.7

In this case:

$$\mathrm{E}[\Delta] = \left(\frac{b-c}{2c^2}\right)\sigma_\theta^2.$$

It follows that:

- $\mathrm{E}[\Delta] > 0$ if $b > c$, implying that the cap-and-trade policy is preferred.
- $\mathrm{E}[\Delta] < 0$ if $b < c$, implying that the tax policy is preferred.

The optimal policy choice boils down to a question about the relative sloops of the marginal abatement cost curve, c, and the marginal damage cost curve, b.

If the marginal damage function is relatively steep (see figure 3), even large shocks to the abatement cost curve affects the optimal emission level little. A cap-and-trade system - that fixes the emission level - will therefore make a (relatively) small error. A tax system will make a (relatively) large error, as even small deviations in the emission level causes large emission price changes. Hence even small shocks will make the best-guess tax much different from the optimal tax.

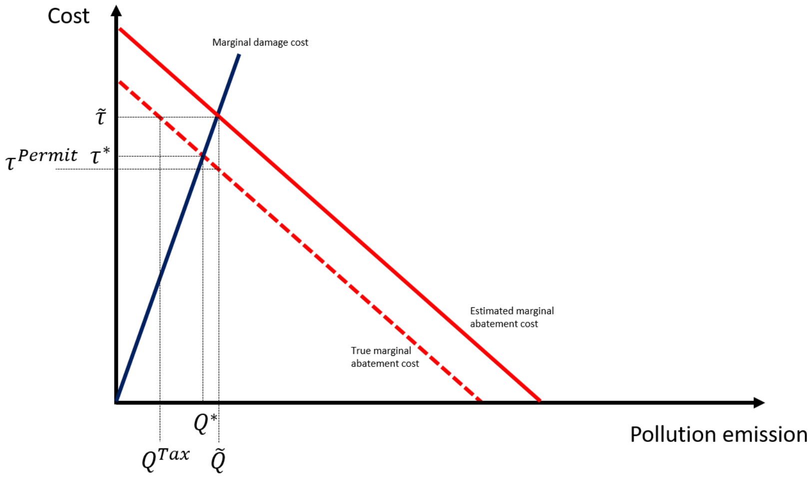

FIGURE 3: Relatively steep MDC curve.

If the marginal damage function is relatively flat (see figure 4), even large shocks to the abatement cost curve affects the optimal emission price little, while they have a substantial impact on optimal emission levels. A tax system - that fixes the price level - will therefore make a (relatively) small error compared to a cap-and-trade system, where the emission level is kept fixed.

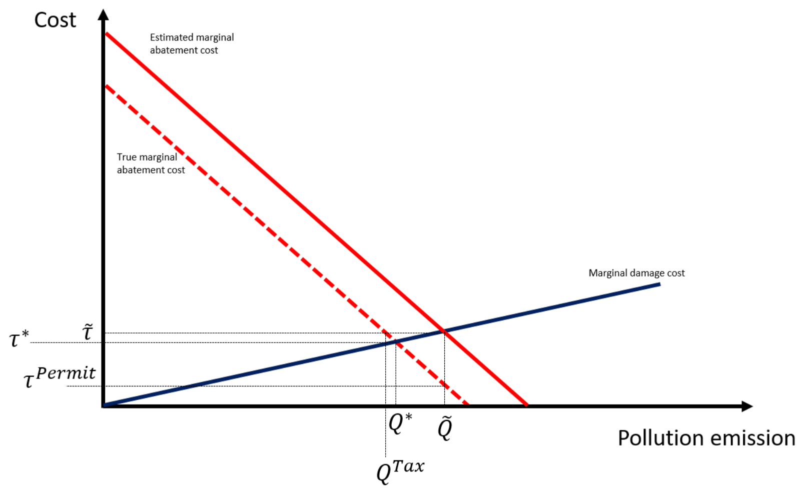

FIGURE 4: Relatively flat MDC curve.

The expected value of Δ does not depend on η or the variance of η. The intuition follows from the answer to Question 1.1. Seen in isolation, the emission level is unaffected by a shock to the MDC curve for both instruments. As a consequence, shocks to marginal damage costs have no influence on the choice between the two instruments.

Answer to Question 1.8

In both cases:

$$E[\Delta] = \left(\frac{b-c}{2c^2}\right)\sigma_\theta^2 + \frac{\gamma}{c}.$$

It follows that:

- $E[\Delta] > 0$ if $\left(\frac{b-c}{2c^2}\right)\sigma_\theta^2 + \frac{\gamma}{c} > 0$, implying that the cap-and-trade policy is preferred.
- $E[\Delta] < 0$ if $\left(\frac{b-c}{2c^2}\right)\sigma_\theta^2 + \frac{\gamma}{c} < 0$, implying that the tax policy is preferred.

These expressions show that compared to a situation where $\gamma = 0$, the case $\gamma > 0$ favours a cap-and-trade system, whilst the case $\gamma < 0$ favours a pollution tax. If, for instance, $\gamma > 0$ then it may be the case that a cap-and-trade system is preferred even if $b < c$.

Intuitively, a positive value of γ implies that if there is a positive realization of θ, then it is more likely that the realization of η is positive as well and vice versa. A positive realization of θ increases the optimal emission level (compared to the emission level that minimizes the expected net social cost from pollution), as pollution abatement becomes more costly. In contrast, a positive realization of η reduces the optimal pollution level, as the damages from pollution becomes more severe. These two effects counteract each other, resulting in a relatively small total effect on the optimal emission level, Q^*, compared to the emission level aimed for by both policies, $\tilde{Q}$. This explains why a positive covariance between the shocks favours a cap-and-trade system that fixes the quantity. When it comes to a pollution tax that fixes the price of pollution emission, the positive covariance works in the opposite direction. Both shocks increase the optimal price of pollution emission. Thus, the positive covariance amplifies the error made by a fixed pollution price policy, making the pollution tax policy relatively less attractive. The situation is illustrated in figure 5.

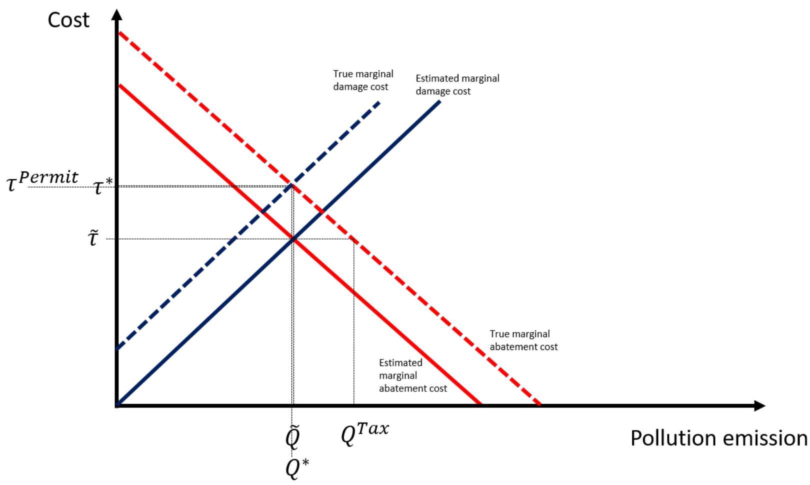

FIGURE 5: Positive realizations of both θ and η.

Exercise 2: The Environmental Kuznets Curve

Answer to Question 2.1

Figure 6 illustrates an Environmental Kuznets curve (EKC from here). The idea is that pollution emissions per capita (or aggregate pollution emissions) increase with income for low levels of income, while emissions per capita (or aggregate pollution emissions) decrease for high levels of income. As income usually increases over time, the EKC hypothesis suggests that emissions peak at some point in time.

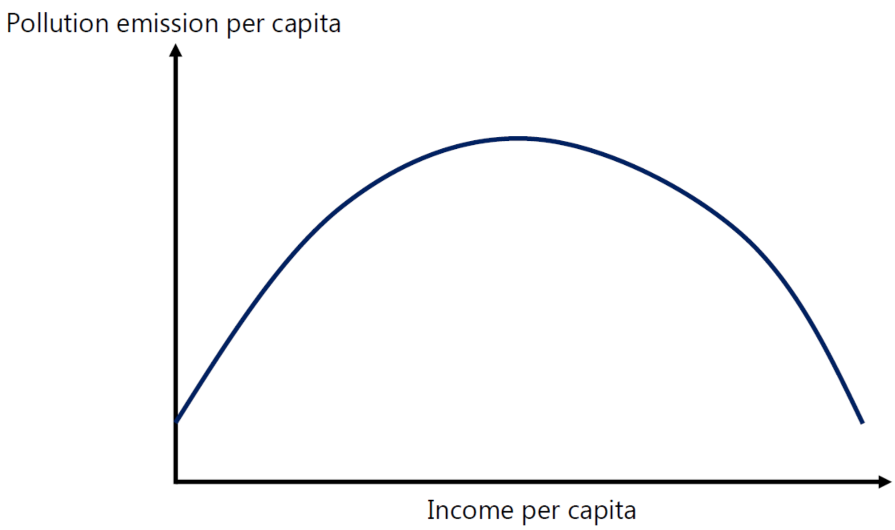

FIGURE 6: Environmental Kuznets curve

Answer to Question 2.2

In the Green Solow model population and income growth increase pollution emissions, while increases in the pollution abatement technology reduce pollution emission. Specifically, the growth rate of pollution emission equals the growth rate of income plus the population growth rate minus the growth rate of the pollution abatement technology. The growth rates of the pollution abatement technology and population are assumed constant. If is therefore changes in the growth rate of income that generate a peak in pollution emission (under certain parameter assumptions).

At low stages of development, the capital level is relatively low implying a high marginal productivity of capital. Capital accumulation will, therefore, have a large growth effect at low stages of development. Over time, the capital stock becomes larger, resulting in a declining marginal productivity of capital and thereby a declining income growth rate. The income growth rate converges to the (constant) growth rate of the productivity variable.

The relatively fast growth rate of income at low stages of development results in an initial increase in emissions. Over time, income growth slows down which slows down emission growth. At some point, income is growing slow enough for increases in the pollution abatement technology to dominate the effects of both income and population growth, implying that emissions start to decline, generating an EKC.

Answer to Question 2.3

Plausible mechanisms that may generate an EKC include:

- Endogenous policy changes: as income grows the population may priorities more pollution abatement, and thus, they may vote for politicians that are willing to ensure that this demand is met. Hence the environmental policy is likely to be tightened over time as income grows, which reduces the emission intensity of production. If the environmental policy is tightened sufficiently fast over time this may generate an EKC. This mechanism is discussed in Stokey (1998).

- Changes in trade patterns: the same mechanism as in the above item, except that a tighter regulation in the home economy induces a change in trade patterns such emission intensive industries are moved abroad.

- Directed technical change: the same mechanism as in the above two items, except that a tighter regulation results in a faster development of pollution abatement technologies as the market for such technologies expand. This mechanism is discussed in Kruse-Andersen (2016).

- Structural change: a transition from agriculture to manufacturing at low stages of development may initially increase pollution emission, while a transition from manufacturing to services may reduce emissions at higher levels of income. Stefanski (2013) emphasizes a similar mechanism.

References

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N. L. Stokey. Are There Limits to Growth? *International Economic Review*, 39(1):1–31, 1998.