Emission Standards and Taxes with Multiple Pollutants

Laura Birg[**] Jan S. Voßwinkel[§]

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Abstract

This paper studies the effect of emission limits and emission taxes on a firm that emits two pollutants. If both pollutants are regulated separately, emission standards are strategic complements while emission taxes are strategic substitutes. Emission standards and emission taxes are equivalent, if the government imposes tailor-made emission standards or taxes on each pollutant separately. If the government is restricted to impose a uniform emission standard or a uniform tax, however, welfare is higher under the emission standard.
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1 Introduction

This paper studies the effect of emission standards and taxes on a firm that emits two pollutants.

Production regularly goes along with the pollution of harmful emissions such as CO_2, CH_4 or SO_2. Governments may influence pollution levels by imposing pollution limits, taxing emissions etc. Typically, a firm does not only emit one pollutant, but multiple pollutants. For instance, electricity generation in a coal fired power plant results in emissions of CO_2 and/or SO_2 (Holland, 2010). The emissions of multiple pollutants may be interdependent, so that reducing emissions of one pollutant may increase or decrease emissions of another pollutant. Generating electricity by using natural gas instead of fuel oil or hard coal reduces emissions of CO_2 and SO_2 simultaneously (Holland, 2010).

[**]Department of Economics, University of Göttingen, Platz der Göttinger Sieben 3, 37073 Göttingen, Germany, laura.birg@wiwi.uni-goettingen.de.
[§]Department of Economics, NGU Nürtingen-Geislingen University, Neckarsteige 6-10, 72622 Nürtingen, Germany, jan.vosswinkel@hfwu.de.

So climate policy that intends to reduce CO_2 emissions reduces SO_2 emissions as a side effect. But using a higher temperature in a natural gas fired power plant also reduces CO_2 emissions, but increases emissions of NO_x ceteris paribus. (Holland, 2010). Irrespective of a technical interdependence of several pollutants, pollutants are linked via the output decision. A reduction in output that is caused by an emission limit for one pollutant also may also reduce emission of other pollutants ceteris paribus. This interaction is important in tailoring policy instruments to reduce emissions and in evaluating the success of policy instruments. For instance an emission standard for one pollutant may transform to a non-binding limit, if emission reductions are caused as a side effect of emission reductions of another pollutant. Also co-benefits have to be considered in the evaluation of instruments that are intended to reduce emissions of one pollutant.

The economic literature has analyzed the different effects of market based instruments, such as emission taxes, and emission limits extensively. Under perfect competition and perfect information, emission taxes and emission quotas are equivalent. Weitzman (1974) shows, however, that if the regulator lacks perfect information of abatement cost, the performance of both kinds of instruments depends on the slope of the marginal benefit of emission reduction compared to the slope of marginal abatement cost. Requate (2005) surveys the dynamic incentives of several environmental policy instruments. The relative performance of market-based instruments and command and control instruments depends on market structure, the commitment strategies of the regulator as well as on assumptions about R&D and technology adoption. However, market-based instruments tend to perform better than command and control policies. Lahiri & Ono (2007) study the effect of a relative emission standard and an emission tax in an oligopoly. When the number of firms is fixed, a stricter relative emission standard is more welfare enhancing than the increase of an emission tax that leads to the same reduction of emission. But a stricter relative emission standard reduces emissions by less than an increase of an emission tax that leads to the increase in welfare. Ambec & Coria (2013) study the effect of emission taxes, emission quotas, and combinations thereof. They assume that abatement costs are private information. Depending on whether pollutants are substitutes or complements and on the marginal abatement cost relative to the marginal damage of pollution, the use of taxes only, quotas only or a mix of taxes and quotas should be introduced.

The focus of the literature on multipollutant firms has been so far on the technical link between various pollutants. Montero (2001) analyzes the effect of integrated markets for tradable emission permits where emission permits for one pollutant may be traded against emission permits for another pollutant. Although this interconnection of permit markets are welfare increasing in many cases, it has never been used in practice. Caplan and Silva (2005) analyze the interplay of a global permit market for a global pollutant (like CO_2) and a local permit market for a local pollutant. Efficient overall pollution reduction requires the consideration of this interplay by global and local regulators. Bollen et al. (2009) present a cost-benefit analysis of various emission reduction strategies that takes damages of global climate change and of local air pollution into account simultaneously. Moslener and Requate (2007) analyze a dynamic problem, when abatement of several pollutants is interrelated. They find that optimal dynamic emission strategies differ when pollutants are substitutes or complements. Ambec and Coria (2013) study the static effect of various policy instruments when abatement efforts for two pollutants are substitutes or complements. Burtraw et al. (2003) and Holland (2010) present an empirical analysis of the effect of greenhouse gas reduction policies on other pollutants.

This paper focuses on the connection of two pollutants via the output market. This output effect is present in many cases with multipollutant emissions. The government may not be able to impose different emission standards or emission taxes for each pollutant. We find that emission standards and emission taxes are equivalent, if the government imposes tailor-made emission standards or taxes on each pollutant. If the government is restricted to impose a uniform emission standard or a uniform tax, however, welfare is higher under the emission standard.

The rest of the paper is organized as follows. In the next section, the model is presented and the effects of emission standards and emission taxes are analyzed. Section 3 concludes.

2 The Model

Consider a monopolistic firm that emits two pollutants $i = A, B$ during production. Emissions are proportional to output according to $e_A = \lambda q$ and $e_B = (1 - \lambda) q$. Total emissions are the sum of individual emissions $e = e_A + e_B = q$. One unit of output results in one unit of total emissions, which is a common assumption in the literature. λ and $(1 - \lambda)$ denote emission shares.

The firm can abate emissions of both pollutants by investing in abatement technology z_i. Abatement technologies are independent of each other, so that abatement of A does not alter the emissions of pollutant B. The only link between A and B is via the output level q. The abatement technology is characterized by the cost function

$$c(z_i) = \frac{\gamma_i}{2} z_i^2 \tag{1}$$

We normalize $\gamma_i = 1$. For simplicity, we normalize production cost to zero.

Inverse demand for the good is $p = 1 - q$.

The profit of the firm is then

$$\pi = (1 - q)\, q - \frac{\gamma_i}{2} z_i^2, \tag{2}$$

The emissions cause a damage according to

$$d = e_A^2 + e_B^2. \tag{3}$$

We assume identical but separate marginal damages by both pollutants, i.e. the pollutants do not interact with each other. This is implies it is always more effective to reduce overall emissions than the emissions of one pollutant only to minimize total damage.

2.1 No Regulation

Under no regulation, the monopolist supplies the profit maximizing quantity $\widetilde{q}$ and charges the price $\widetilde{p}$. Since the firm has no incentives to invest in abatement, $\widetilde{z_A} = \widetilde{z_B} = 0$. The emission levels of both pollutants are $\widetilde{e_A}$ and $\widetilde{e_B}$, respectively and total emissions are $\widetilde{e}$. Total welfare $\widetilde{W}$ is the sum of the firms's profit and consumer surplus minus the damage caused by both pollutants.

2.2 Emission Standards

2.2.1 Separate Emission Standards for Both Pollutants

Assume that the government introduces binding emission limits E_A and E_B for pollutants e_A and e_B. The firm now has to reduce the output or has to invest in abatement to reduce the emissions so that $e_A = \lambda q - z_A \leq E_A$ and $e_B = (1 - \lambda)\, q - z_B \leq E_B$.

The equilibrium quantity is $q^{E_A E_B}$, which increases in emission standards. The equilibrium price is $p^{E_A E_B}$, which decreases in emission standards. Abatement effort is $z_A^{E_A E_B} > 0$ and $z_B^{E_A E_B} > 0$.

Total welfare is given as $W^{E_A E_B}$.

Consider now that the government sets the emission standards E_A and E_B to maximize welfare. The emission standards are strategic complements, with a stricter emission standard E_A inducing a stricter emission standard E_B. The welfare-maximizing emission standards are E_A^* and E_B^*. E_A^* increases in λ, while E_B^* decreases in λ. The resulting quantity is $q^{E_A E_B}$, resulting total emissions are $e^{E_A E_B}$. Welfare is $W^{E_A E_B}$ (see Appendix).

2.2.2 Uniform Pollution Standard

Assume that the government restricts emissions of both pollutants by imposing a common pollutant standard E on both pollutants.[1] Emissions of pollutant A are then $e_A = \lambda q - z_A \leq E$, emissions of the other pollutant B are $e_B = (1-\lambda) q - z_B \leq E$.

The equilibrium quantity is q^E.The equilibrium price is p^E. Welfare is given as W^E.

The welfare maximizing common emission standard is E^*. The uniform emission standard is higher and lower (lower and higher) than the emission standards on pollutant A and B, respectively, when the government sets two standards, if $\lambda >(<) \frac{1}{2}$. The uniform emission standard is higher (lower) than the emission standard on pollutant A only, if $\lambda >(<) \frac{1}{2}$ standard

The resulting quantity is q^E. The quantity under one uniform standard is lower or equal to the quantity under emission standards on both pollutants ($q^E \leq q^{E_A E_B}$). Total emissions are e^E, which are lower or equal than under separate emission standards on both pollutants ($e^E \leq e^{E_A E_B}$).

Total welfare is W^E, which is lower or equal to welfare under emission standards on both pollutants ($W^E \leq W^{E_A E_B}$).

2.3 Emission Taxes

2.3.1 Emission Taxes on Both Pollutants

Assume now that the government imposes a tax rate τ_A on e_A and τ_B on e_B. The profit for the firm is given by $\pi = (1-q) q - \sum_{i=A,B} \tau_i e_i - \sum_{i=A,B} \frac{\gamma_i}{2} z_i^2$. The equilibrium quantity is $q^{\tau_A \tau_B}$. The equilibrium quantity decreases in both taxes. The equilibrium price is $p^{\tau_A \tau_B}$. The equilibrium price increases in both taxes. The optimal abatement effort is $z_A = \tau_A$ and $z_B = \tau_B$. Total emissions are $e^{\tau_A \tau_B}$. Welfare is $W^{\tau_A \tau_B}$.

Consider now that the government sets the emission taxes τ_A and τ_B to maximize welfare. The tax rates $\tau_A (\tau_B)$, $\tau_B (\tau_A)$ are strategic substitutes. The welfare maximizing tax rates are τ_A^* and τ_B^*. τ_A^* (τ_B^*) increases (decreases) in λ.

The equilibrium quantity is $q^{\tau_A \tau_B}$, which is identical to the case of separate emission standards ($q^{\tau_A \tau_B} = q^{E_A E_B}$). The resulting total emissions are $e^{\tau_A \tau_B}$, which are equivalent to the case of emission standards for both pollutants ($e^{\tau_A \tau_B} = e^{E_A E_B}$).

Resulting welfare is $W^{\tau_A \tau_B}$, which is identical to the case of emission standards for both pollutants ($W^{\tau_A \tau_B} = W^{E_A E_B}$).

[1] This case is equivalent to the standard case of emission standard with only one pollutant, but abatement effort is separable.

2.3.2 Uniform Tax

Assume that the government imposes a uniform tax τ on emissions of both pollutants. Profit is then given by $\pi^{\tau} = (1-q)\,q - \sum_{i=A,B} \tau e_i - \sum_{i=A,B} \frac{\gamma_i}{2} z_i^2$.

The equilibrium quantity is q^{τ}. Equilibrium abatement is $z_A^{\tau} = z_B^{\tau} = \tau$. Equilibrium total emissions are e^{τ}. Welfare is W^{τ}.

The welfare maximizing tax rate is τ^*.

The resulting quantity is q^{τ}, which is higher or equal to the quantity under emission taxes on both pollutants ($q^{\tau} \geq q^{\tau_A \tau_B}$).

The quantity is equal or higher than under a uniform emission standard. Total emissions are e^{τ}, which are lower or equal to emissions under emission taxes on both pollutants and higher than emissions under a uniform emission standard ($e^{\tau} < e^{\tau_A \tau_B}$, $e^{\tau} > e^{E}$). Welfare is W^{τ}, which is lower or equal to welfare under a uniform emission standard ($W^{\tau} < W^{E}$).

3 Conclusion

This paper has studied the effect of emission standards and taxes for a firm that emits two pollutants. Emission standards are strategic complements while emission taxes are strategic substitutes.

Emission standards and emission taxes are equivalent, if the government imposes tailor-made emission standards or taxes on each pollutant. If the government is restricted to impose a uniform emission standard or a uniform tax, however, welfare is higher under the emission standard.

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Appendix

No Regulation

$\widetilde{q} = \frac{1}{2}$

$\widetilde{p} = \frac{1}{2}$

$\widetilde{z_A} = \widetilde{z_B} = 0$

$\widetilde{e_A} = \frac{\lambda}{2}$, $\widetilde{e_B} = \frac{(1-\lambda)}{2}$, $\widetilde{e} = \frac{1}{2}$

$\widetilde{W} = \frac{1+4\lambda(1-\lambda)}{8}$

Emission Standards

Separate Emission Standards for Both Pollutants

$q^{E_A E_B} = \frac{1+\lambda E_A + E_B(1-\lambda)}{-2\lambda+2\lambda^2+3}$

$p^{E_A E_B} = \frac{2\left(-\lambda+\lambda^2+1\right)-\lambda E_A - E_B(1-\lambda)}{-2\lambda+2\lambda^2+3}$

$z_A^{E_A E_B} = \frac{\lambda - E_A\left(\lambda^2-2\lambda+3\right)+\lambda E_B(1-\lambda)}{2\lambda^2-2\lambda+3}$

$z_B^{E_A E_B} = \frac{1-\lambda+\lambda E_A(1-\lambda)-E_B\left(\lambda^2+2\right)}{2\lambda^2-2\lambda+3}$

$W^{E_A E_B} = \frac{2\left(2-\lambda+\lambda^2\right)+4\left(2-\lambda+\lambda^2\right)(\lambda E_A+(1-\lambda)E_B+\lambda E_A E_B(1-\lambda))}{2\left(2\lambda^2-2\lambda+3\right)^2}$

$-\frac{E_A^2\left(10\lambda^4-22\lambda^3+44\lambda^2-36\lambda+27\right)-E_B^2\left(10\lambda^4-18\lambda^3+38\lambda^2-26\lambda+23\right)}{2\left(2\lambda^2-2\lambda+3\right)^2}$

$E_A\left(E_B\right) = \frac{(1+E_B(1-\lambda))\lambda\left(2\lambda^2-2\lambda+4\right)}{\left(10\lambda^4-22\lambda^3+44\lambda^2-36\lambda+27\right)}$

$E_B\left(E_A\right) = \frac{(1-\lambda)\left(2\lambda^2-2\lambda+4\right)(1+\lambda E_A)}{10\lambda^4-18\lambda^3+38\lambda^2-26\lambda+23}$

$E_A^* = \frac{3\lambda\left(2\lambda^2-2\lambda+4\right)}{24\lambda^4-48\lambda^3+102\lambda^2-78\lambda+69}$

$E_B^* = \frac{3(1-\lambda)\left(2\lambda^2-2\lambda+4\right)}{24\lambda^4-48\lambda^3+102\lambda^2-78\lambda+69}$

$q^{E_A E_B *} = \frac{18\lambda^2-18\lambda+27}{24\lambda^4-48\lambda^3+102\lambda^2-78\lambda+69}$

$e^{E_A E_B *} = \frac{6\lambda^2-6\lambda+12}{24\lambda^4-48\lambda^3+102\lambda^2-78\lambda+69}$

$W^{E_A E_B *} = \frac{3\lambda^2-3\lambda+6}{8\lambda^4-16\lambda^3+34\lambda^2-26\lambda+23}$

Uniform Pollution Standard

$q^E = \frac{1+E}{2\lambda^2-2\lambda+3}$

$p^E = \frac{2\lambda^2-2\lambda+2-E}{2\lambda^2-2\lambda+3}$

$z_A^E = \frac{\lambda - E\left(2\lambda^2-3\lambda+3\right)}{2\lambda^2-2\lambda+3}$

$z_B^E = \frac{1-\lambda-E\left(-\lambda+2\lambda^2+2\right)}{2\lambda^2-2\lambda+3}$

$W^E = \frac{2\lambda^2-2\lambda+4+2E\left(2\lambda^2-2\lambda+4\right)-E^2\left(24\lambda^4-48\lambda^3+94\lambda^2-70\lambda+50\right)}{2\left(2\lambda^2-2\lambda+3\right)^2}$
$E^* = \frac{2\lambda^2-2\lambda+4}{24\lambda^4-48\lambda^3+94\lambda^2-70\lambda+50}$
$q^{E^*} = \frac{12\lambda^2-12\lambda+18}{24\lambda^4-48\lambda^3+94\lambda^2-70\lambda+50}$
$e^{E^*} = \frac{4\lambda^2-4\lambda+8}{24\lambda^4-48\lambda^3+94\lambda^2-70\lambda+50}$
$W^{E^*} = \frac{3\lambda^2-3\lambda+6}{12\lambda^4-24\lambda^3+47\lambda^2-35\lambda+25} = 3\frac{\lambda^2-\lambda+2}{12\lambda^4-24\lambda^3+47\lambda^2-35\lambda+25}$ is true

Emission Taxes

Emission Taxes on Both Pollutants

$q^{\tau_A\tau_B} = \frac{(1-\lambda\tau_A-(1-\lambda)\tau_B)}{2}$
$p^{\tau_A\tau_B} = \frac{(1+\lambda\tau_A+(1-\lambda)\tau_B)}{2}$
$z_A = \tau_A$, $z_B = \tau_B$
$e^{\tau_A\tau_B} = \frac{1-\tau_B(3-\lambda)-\tau_A(\lambda+2)}{2}$
$W^{\tau_A\tau_B} = \frac{4\lambda-4\lambda^2+1+2\left(\lambda\tau_A\left(-4\lambda+4\lambda^2+3\right)+\tau_B(1-\lambda)\left(4\lambda^2-4\lambda+3\right)-\lambda\tau_A\tau_B(1-\lambda)\left(-4\lambda+4\lambda^2+7\right)\right)}{8}$
$-\frac{\tau_A^2\left(4\lambda^4-4\lambda^3+7\lambda^2+4\right)-\tau_B^2\left(4\lambda^4-12\lambda^3+19\lambda^2-18\lambda+11\right)}{8} + \tau_A\left(\lambda\frac{(1-\lambda\tau_A-(1-\lambda)\tau_B)}{2} - \tau_A\right)$
$+\tau_B\left((1-\lambda)\frac{(1-\lambda\tau_A-(1-\lambda)\tau_B)}{2} - \tau_B\right)$
$\tau_A(\tau_B) = \frac{1}{11\lambda^2-4\lambda^3+4\lambda^4+12}\left(5\lambda - 4\lambda^2 + 4\lambda^3 - 11\lambda\tau_B + 15\lambda^2\tau_B - 8\lambda^3\tau_B + 4\lambda^4\tau_B\right)$
$\tau_B(\tau_A) = -\frac{1}{-26\lambda+23\lambda^2-12\lambda^3+4\lambda^4+23}\left(9\lambda - 8\lambda^2 + 4\lambda^3 + 11\lambda\tau_A - 15\lambda^2\tau_A + 8\lambda^3\tau_A - 4\lambda^4\tau_A - 5\right)$
$\tau_A^* = \frac{5\lambda-4\lambda^2+4\lambda^3}{-26\lambda+34\lambda^2-16\lambda^3+8\lambda^4+23}$
$\tau_B^* = -\frac{9\lambda-8\lambda^2+4\lambda^3-5}{-26\lambda+34\lambda^2-16\lambda^3+8\lambda^4+23}$
$q^{\tau_A\tau_B*} = \frac{6\lambda^2-6\lambda+9}{34\lambda^2-26\lambda-16\lambda^3+8\lambda^4+23}$
$e^{\tau_A\tau_B*} = \frac{3\lambda^2-10\lambda-4\lambda^3-4\lambda^4}{68\lambda^2-52\lambda-32\lambda^3+16\lambda^4+46} + \frac{32\lambda-33\lambda^2+20\lambda^3-4\lambda^4-15}{68\lambda^2-52\lambda-32\lambda^3+16\lambda^4+46} + \frac{1}{2}$
$W^{\tau_A\tau_B*} = 3\frac{\lambda^2-\lambda+2}{8\lambda^4-16\lambda^3+34\lambda^2-26\lambda+23}$

3.0.3 Uniform Tax

$q^\tau = \frac{1-\tau}{2}$
$p^\tau = \frac{\tau+1}{2}$
$z_A^\tau = \tau$, $z_B^\tau = \tau$
$e^\tau = \frac{1-5\tau}{2}$
$W^\tau = \frac{\left(4\lambda-4\lambda^2+1\right)+2\tau\left(4\lambda^2-4\lambda+3\right)-\tau^2\left(4\lambda^2-4\lambda+15\right)}{8} + \tau\left(\lambda\frac{1-\tau}{2} - \tau + (1-\lambda)\frac{1-\tau}{2} - \tau\right)$
$\tau^* = \frac{-\lambda+\lambda^2+\frac{5}{4}}{-\lambda+\lambda^2+\frac{35}{4}}$
$q^\tau = \frac{4\lambda-4\lambda^2-5}{8\lambda^2-8\lambda+70} + \frac{1}{2}$
$e^\tau = \frac{20\lambda-20\lambda^2-25}{8\lambda^2-8\lambda+70} + \frac{1}{2}$

$W^\tau = \frac{-24\lambda^2+24\lambda+15}{8\lambda^2-8\lambda+70}$