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ORIGINAL ARTICLE

Efficiency losses from overlapping regulation of EU carbon emissions

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Abstract In order to achieve their climate policy targets EU member states apply various regulatory instruments. We investigate the potential efficiency losses arising from the imposition of emission taxes on sectors that are covered by the EU Emissions Trading Scheme (EU ETS). Our analysis indicates the possibility of substantial excess cost through overlapping regulation. We show that unilateral emission taxes on sectors subject to the EU ETS are environmentally ineffective and increase overall compliance cost of the EU ETS.

Keywords Environmental regulation · Emission taxes · Emissions trading

JEL Classifications D61 · H21 · H22 · Q58

1 Introduction

From 2005 onwards, the EU Emissions Trading Scheme (EU ETS) sets an aggregate CO_2 emission cap for specific energy-intensive installations within the EU. These installations currently cover about 46% of the EU's total CO_2 emissions and belong mainly to five industrial sectors: power, heat and steam generation; oil refineries, iron and steel production; mineral industries (e.g., cement, lime and glass); pulp and paper

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plants (Point Carbon 2006). Each EU member state allocates CO_2 allowances to these installations amounting to an EU-wide cap which can be traded. The allocated volume of allowances represents a share in the overall emission budgets of each EU member state which have been fixed in the EU Burden Sharing Agreement of 1998 (EU 1999). The partitioning of national emission budgets between sectors covered by the EU ETS and the rest of the economy is laid out in the National Allocation Plans which are developed by each member state and approved by the EU Commission (EU 2003a).

In several EU countries, industrial installations under the EU ETS are also affected by national energy tax regimes (Johnstone 2003; Sorrell and Sijm 2003; Andersen et al. 2006).[1] Reflecting basic economic principles, "the use of a mix of policies" in order to pursue a single policy objective "will be at best redundant and at worst counterproductive" (Johnstone 2003): If there is one efficient instrument to implement an environmental target, it makes little sense to introduce an additional one. On the other hand, differentiated or multiple instruments can be justified if there are several policy objectives, such as social or technology-related criteria that may conflict with narrowly defined efficiency considerations (Tinbergen 1952). Second-best regimes reflecting initial tax distortions, market power, external knowledge spillovers, transaction costs, uncertainty, etc. provide another general argument for differentiated regulation. Furthermore, a traditional environmental policy area where (spatial) differentiation of instruments has been advocated on efficiency grounds is pollution control when location of emissions matter. In climate policy design, sector-specific differences in transaction costs have, e.g., been used as an argument for applying different climate policy instruments to different sectors. Likewise, emission location for global pollutants such as CO_2 emissions could become relevant when secondary benefits—e.g., air quality improvements—of jointly reduced pollutants are taken into account (Ekins 1996).

In the EU climate policy debate, there are two popular arguments in favor of additional taxes on residual CO_2 emissions from the ETS sectors. First, proponents of an overlapping regulation argue that an emission tax in the energy-intensive ETS sectors would give an additional incentive for CO_2 emission reductions and thus would help to reach the overall national emission targets as laid down in the EU Burden Sharing Agreement. Second, taxation of emissions is put forward on the point that additional taxes would bring the marginal abatement cost in the EU ETS sectors closer to the efficient level. The latter argument is based on the presumption that—due to a very generous allocation of allowances to the ETS sectors (e.g., Betz et al. 2004)—the marginal abatement cost within ETS sectors are lower than those in the rest of the economy which is subject to complementary regulatory measures in order to comply with the overall national emission budget. The tax is therefore viewed as a second-best instrument to equalize marginal abatement cost across domestic sources and thereby increase the efficiency of national carbon abatement policies.

[1] Whereas selection criteria of EU ETS installations are uniform across all EU member states according to the EU emissions trading directive (EU 2003a), the member states have great latitude whether and how they want to tax their EU ETS installations (see the EU Energy Tax Directive–EU 2003b).

In the present paper, we question the economic rationale of such policy arguments. In Sect. 2, we present a simple theoretical analysis of the environmental and efficiency implications induced by additional taxes on residual CO_2 emissions from EU ETS sectors: Unilateral emission taxes within the EU ETS are environmentally ineffective, subsidize net buyers of allowances and increase overall compliance cost. In Sect. 3, we present numerical simulations based on empirical data for the EU in order to substantiate the policy relevance of our theoretical analysis. In Sect. 4, we conclude.

2 Theoretical analysis

For our stylized analysis of overlapping regulation, we adopt a simple partial equilibrium framework of the EU carbon market. We assume that abatement possibilities of the ETS sectors within each EU member state i are characterized by an aggregate abatement cost function $C_{i,ETS}(e_i)$ (decreasing, convex, differentiable) where e_i denote ETS emissions in region i. The ETS sectors in each member state I receive an emission budget $\overline{E}_{i,ETS}$ according to the National Allocation Plans. Cost-efficiency of emission abatement implies that aggregate abatement cost $\sum_i C_{i,ETS}$ of the EU ETS should be minimized subject to the aggregate EU ETS emission target $\sum_i \overline{E}_{i,ETS}$. This leads to the well-known first-order condition $-C'_{i,ETS}(e^*_{i,ETS}) = p$, i.e., equalized marginal abatement cost at optimal emission levels $e^*_{i,ETS}$ across all EU ETS sectors (where p denotes the value of the marginal emission unit or likewise the emission price). The cost-efficient solution is achieved on decentralized markets through international emissions trading at the endogenous market price p.

Against this benchmark, we can investigate the environmental effects and efficiency implications of additional emission taxes. As a matter of fact, several EU countries have introduced emission-related taxes since the early 90's which may overlap with the ETS (OECD 2001; Andersen et al. 2006).

With respect to environmental effects additional taxes—levied at moderate rates—will not have any impact, disproving the wide-spread argument that "an energy or carbon tax in the energy-intensive ETS sectors would give an additional incentive for CO_2 emission reductions and thus would help to reach the overall emission target laid down in the EU Burden Sharing Agreement" (see Sect. 1): Once the National Allocation Plans are established, the emission budget is fixed for the ETS sectors across all EU member states. Any price-based mechanism *within* the quantity-based emissions trading regime will not alter its environmental effectiveness unless the effective emission tax is high enough (and imposed in a sufficiently large number of countries) to render the emission constraint non-binding.[2]

The efficiency implications of additional emission taxes will depend on whether taxes are levied uniformly across all EU ETS regions or imposed unilaterally. In the case of an EU-wide emission tax imposed uniformly on all ETS sectors, cost efficiency will not be affected since marginal abatement cost are still equalized across all emitters of the ETS sector; the ETS allowance price is simply crowded out by the

[2] The price of emission allowances then falls to zero.

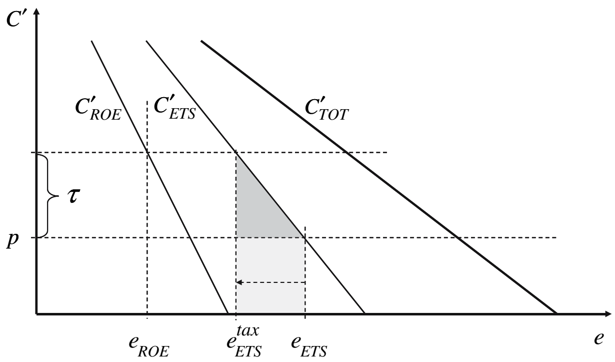

Fig. 1 Unilateral emission tax in the ETS sector

emission tax.[3] On the other hand, if the emission tax is imposed on ETS sectors in only one or a few (but not all) EU countries, inefficiencies will arise as the first-order condition of equalized marginal abatement cost no longer holds. Tax proponents, however, have argued contrariwise claiming that additional taxes in the ETS sectors could cure the problem of allowance over-allocation to ETS sectors and "bring the marginal abatement cost in the EU ETS sectors closer to the efficient level" (see Sect. 1).

Figure 1 illustrates why this argument is misleading. We consider a (small) open economy represented by marginal abatement cost functions for ETS sectors and the rest of the economy (ROE). Mirroring the assumption of allowance over-allocation to ETS sectors, the marginal abatement cost C'_{ROE} in the ROE sectors (associated with emissions e_{ROE}), exceed the allowance price p on the international emissions trading market (notations in Fig. 1 omit the country index i).

Under double-regulation, the ETS sectors face an emission tax τ in addition to the tradable emission allowance regime. The tax increases the incentive to reduce emissions within the taxed region such that the marginal abatement costs of the ETS sectors will equal $p + \tau$. For a small open economy these additional abatement efforts will leave the international allowance price unchanged. The shaded areas in Fig. 1 visualize the tax-induced efficiency effects. On the one hand, reducing emissions from e_{ETS} to e_{ETS}^{tax} will lead to a surplus due to the sale of emission allowances (lighter shaded rectangular area). On the other hand, the additional abatement cost are given by the area under the marginal abatement cost curve (darker shaded triangle plus lighter shaded rectangle). In total, the tax leads to excess cost, represented by the darker shaded triangle.

The EU ETS implements any given EU-wide target for the ETS sectors at minimum cost—independent of whether the country-specific National Allocation Plan implies an over-allocation or not. An additional tax within the trading scheme cannot change the distribution between the ETS and ROE sectors *ex post* nor can it achieve a second-best solution because of the segmentation of the overall EU carbon market into

[3] The first-order condition with an additional uniform carbon tax at an exogenous rate τ then reads as $-C'_{i,ETS}(e^*_{i,ETS}) = p + \tau$.

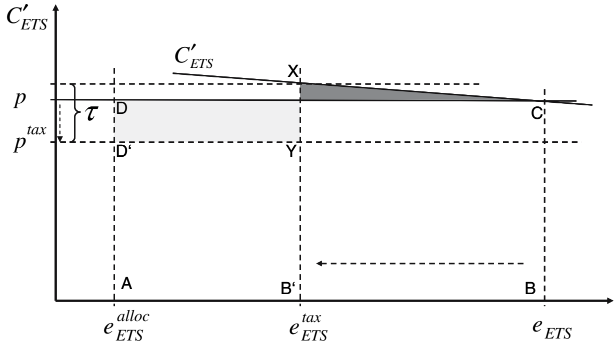

Fig. 2 Potential gains from unilateral emission taxation

ROE and ETS sectors: Unilateral emission taxes will simply drive apart the marginal abatement cost *within* the ETS sectors of the different regions and thereby induce efficiency losses within the EU ETS.[4]

So far we have restricted our efficiency analysis of emission taxes on ETS sectors to the case where the international price of emission allowances remains constant. In an open trading system, however, changes in the allowance demand or supply of a country will affect the international allowance price. Additional taxes on ETS sectors in one country will increase domestic abatement and thus decrease net allowance demand from the international carbon market.[5]

As a consequence, the international allowance price will fall implying secondary gains to allowance-importing countries and secondary losses to allowance-exporting countries.

Under certain—as we will see rather restrictive—conditions a taxing country might achieve a total net gain from the introduction of a domestic emission tax on its ETS sectors: If the country imposing the tax (i) is a net importer of emission allowances (before and after implementing the tax), (ii) has relatively flat marginal abatement cost in the ETS sectors and (iii) can induce a sufficiently large decrease of the international market price for allowances, then the lower (net of tax) price for allowance imports together with the reduced amount of allowances to be imported can more than compensate for the increased abatement efforts. Figure 2 illustrates this reasoning. The ex-ante allowance allocation to the ETS sectors is denoted by e^{alloc}_{ETS}. Prior to the introduction of the carbon tax the emission level e_{ETS} is such that the marginal abatement cost of the ETS sectors equal the allowance price p. The introduction of a carbon tax τ will act as an additional reduction incentive on top of the allowance price, the emissions fall to e^{tax}_{ETS}, and the lower demand for allowances causes the international allowance price to fall to the after-tax level p_{tax}.

4 The excess cost of EU-wide carbon regulation due to the segmentation of the EU carbon market into an EU ETS market and several national carbon markets for the ROE sectors are discussed in detail by Böhringer and Lange (2005) or Böhringer et al. (2005).

5 If the country is a net importer it will decrease its imports; if the country is a net exporter it will increase its exports.

Comparison of the before-tax and the after-tax situation provides the efficiency implications for a large open economy: Before, the import expenditures of the country are given by the rectangular area *ABCD*. The increased reduction effort and the lower allowance price of the after-tax regime are associated with abatement cost for the ETS sectors equal to the area *B'BCX*. On the other hand, the import expenditures are reduced, and after-tax expenditures are given by the area *AB'YD'*. Whether the country benefits from the tax is determined by the relative size of the darker and the lighter shaded areas. If the lighter shaded rectangular area exceeds the darker shaded triangular area—as is the case in Fig. 2—then the country benefits from the emission tax imposed on the ETS sectors.

It is a matter of quantitative empirical analysis whether the conditions for such beggar-thy-neighbor-policies from overlapping emission regulation are met by any EU member state. Prima facie, the conditions appear restrictive since countries with flat (marginal) abatement cost functions will export rather than import emission allowances. Moreover, it is questionable whether any of the EU member states has a sufficiently large market share to substantially drive down the allowance price by unilateral action.

It should be noted that our stylized efficiency analysis of additional emission taxes on ETS sectors presumes a lump-sum treatment of additional tax revenues, i.e., we abstract from potential efficiency implications of revenue recycling. Following the extensive literature on green taxation (see, e.g., Goulder 1995, or Bovenberg 1999), it is clear that revenue-neutral recycling of tax revenues to lower initial distortionary taxes could reduce the excess cost of additional emission taxes.

3 Quantitative analysis

We can transform our stylized analytical framework into a numerical partial equilibrium model of the EU ETS carbon market. Marginal abatement cost curves for ETS sectors of EU regions are calibrated to empirical data. Moreover, the effective emission reduction requirements for ETS sectors are based on the implementation of actual National Allocation Plans and official emission inventories. Following a brief description of the model's structure and parameterization, we present simulation results followed by sensitivity analysis.

The quantitative analysis depends both on the parameterization of the (marginal) abatement cost curves together and the climate policy prescriptions which—in our case—reflect the actual implementation of the EU ETS. In the Appendix we provide the computer code[6] as well as the data underlying our simulations such that the interested reader not only can replicate our simulation results but also can revise the parameterization of marginal abatement cost functions or the climate policy prescriptions.

6 The numerical model is implemented using the GAMS programming language (Brooke et al. 1987).

4 Emission market model

Marginal cost of emission abatement may vary considerably across ETS sectors of EU countries due to differences in carbon intensity, initial energy price levels, or carbon substitution possibilities. The derivation of continuous marginal abatement cost curves requires a sufficiently large number of discrete joint observations for marginal abatement cost and the associated emission reductions. These data may be generated by technology-oriented partial equilibrium models of the energy system (such as the POLES model by Criqui and Mima 2001, or the PRIMES model by Capros et al. 1998, or by computable general equilibrium (CGE) models (see, e.g., Eyckmans et al. 2001). Here, we make use of the second option: Marginal abatement cost curves for the ETS and ROE sectors across EU countries are derived from the PACE model—a multi-region, multi-sector CGE model for the EU economy (for a detailed algebraic exposition see Böhringer 2002).[7] PACE is based on most recent consistent accounts of EU member states' production and consumption, bilateral trade and energy flows (as provided by the GTAP6 database—see Dimaranan and McDougall 2006). The energy goods identified in the model include primary carriers (coal, natural gas, crude oil) and secondary energy carriers (refined oil products and electricity). Furthermore, the model features three additional energy-intensive non-energy sectors (iron and steel, paper, pulp and printing, non-ferrous metals) whose installations—in addition to the secondary energy branches (refined oil products and electricity)—are subject to the EU ETS. The remaining manufacturers and services are aggregated to a composite industry that produces a non-energy-intensive macro good, which together with final demand captures the activities (ROE segments) not included in the EU trading system. To generate the reduced form marginal abatement cost curves, a sequence of carbon tax scenarios for each region is performed where uniform carbon taxes (starting from 0 to 200 € per ton of carbon in steps of 1 €) are imposed and the associated emission reductions in ETS as well as ROE sectors are computed. Then a least-square fit by a polynomial of third degree is applied.[8]

5 Policy simulations

For our numerical analysis of overlapping regulation we refer to the implementation of the EU ETS as our policy benchmark. The economic effects of an exclusive cap-and-trade regulation under the EU ETS are then compared to an overlapping regulation where the EU ETS is supplemented with an additional unilateral carbon tax in one of the EU member states.

The benchmark EU ETS regime is characterized by the regional emission allowances to ETS sectors implying specific emission reduction requirements against the business-as-usual (*BaU*) situation. For the latter, we employ official EU projections

[7] Klepper and Peterson (2006) demonstrate that marginal abatement cost functions generated by a computable general equilibrium framework are in general a useful partial equilibrium approximation.

[8] The derived coefficients are provided in Table *mac_coef* of Appendix. The least-square approximation with a polynomial of degree three is sufficiently flexible to provide a very good fit to the actual data (the adjusted R2 of the fit is always higher than .992).

Table 1 EU ETS climate policy data

	BaU emissions of ETS sectors in 2010 (Mt CO_2)[a]	Allocation factor (Mt CO_2)[b]	Emission cutback	Emission cutback of *BaU* emissions in 2010 (%)
Austria	25.9	0.81	4.84	18.7
Belgium	54.5	0.94	3.11	5.7
Czech Republic	73.8	0.83	12.92	17.5
Denmark	25.5	0.82	4.54	17.8
Finland	32.0	0.92	2.53	7.9
France	142.1	0.91	13.22	9.3
Germany	439.8	0.88	54.54	12.4
Greece	68.0	0.81	13.12	19.3
Hungary	32.9	0.89	3.72	11.3
Ireland	20.8	0.75	5.20	25.0
Italy	201.9	0.85	30.49	15.1
Netherlands	84.8	0.89	9.07	10.7
Poland	203.8	0.83	34.03	16.7
Portugal	37.0	0.84	5.96	16.1
Slovakia	28.4	0.93	2.02	7.1
Spain	144.6	0.69	44.39	30.7
Sweden	23.3	0.94	1.40	6.0
United Kingdom	242.2	0.90	24.22	10.0
Baltic States[c]	26.6	0.79	5.71	21.5
Rest of EU[d]	107.1	0.92	8.08	7.5
Total (EU-27)	2015.0	0.86	283.09	14.0

[a] EU (2003c); [b] EU (2007); [c] Estonia, Latvia, Lithuania; [d] Luxembourg, Cyprus, Malta, Slovenia, Bulgaria, Romania

(EU 2003c) on carbon emissions of ETS sectors in 2010—the central year for meeting the EU climate policy targets under the EU Burden Sharing Agreement. In our central case simulations, the allocation of emission allowances to ETS sectors is based on most recent information by the EU Commission for the second EU ETS period 2008–2012 (EU 2007). Table 1 summarizes the EU ETS policy data underlying our simulations.

In our simulations, we subsequently consider overlapping regulation for the six largest EU member states in terms of ETS emission allowances: Germany, U.K., Poland, Italy, Spain, and France. For each of the six EU member states, we impose a unilateral carbon tax on the ETS sectors which increases stepwise from 0 to 10 € per ton of CO_2 emissions.

Figure 3a–f reports the development of the marginal abatement cost for the respective EU member state subject to an additional ETS tax as well as for the remaining EU member states (*Rest of EU*). Whereas marginal abatement cost for the remaining EU member states reflect the international allowance price, the country with overlapping

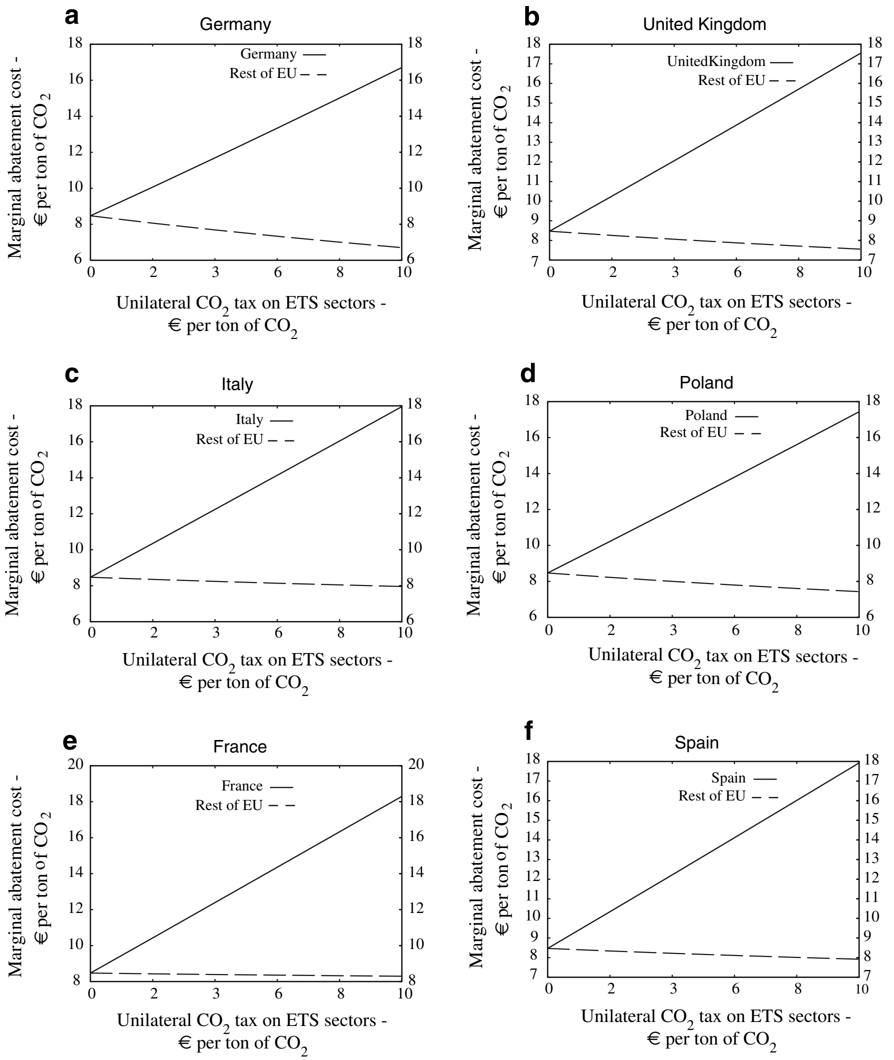

Fig. 3 Marginal abatement cost for unilateral taxation of country (International allowance price (Rest of EU) in € per ton of CO_2 for unilateral taxation at 10€ per ton of CO_2: Germany 6.7, Poland 7.44, United Kingdom 7.55, Spain 7.92, Italy 7.96, and France 8.29)

regulation faces in addition the unilaterally imposed carbon tax. In the benchmark situation, i.e., the EU ETS without unilateral carbon tax, the international allowance price amounts to about 8.5 € per ton of CO_2.

This price warrants compliance with the overall emission reduction requirement of 14% for the EU ETS (as compared to projected *BaU* emissions in 2010). Imposition of a unilateral emission tax exerts a downward pressure on the international allowance price. The tax-induced decrease varies across taxing regions reflecting differences in the CO_2 abatement possibilities. The more a country can abate for a given CO_2 price,

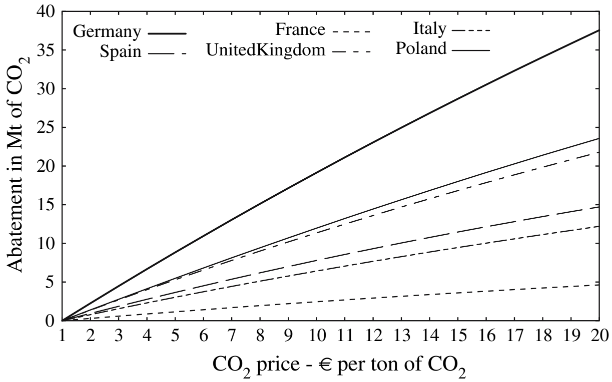

Fig. 4 Marginal abatement cost curve across major EU ETS regions

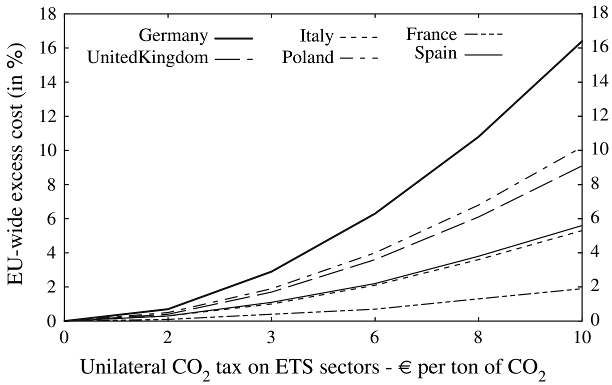

Fig. 5 EU-wide excess cost of unilateral CO_2 taxes on ETS sectors

the bigger is ceteris paribus the downward pressure of an additional unilateral emission tax on the international allowance price. Figure 4 sketches marginal abatement cost curves for ETS sectors across the six major regions in the EU ETS market: Germany has rather cheap abatement options (e.g., due to fossil-fuel based electricity production) whereas emission abatement in France is expensive (e.g., due to nuclear based electricity production). The ranking of the marginal abatement cost curves in Fig. 4 thus determines the tax-induced price effects reported in Fig. 3: The decrease of the international allowance price is strongest for unilateral taxation in Germany, while it hardly falls for unilateral taxation in France.

In line with our stylized theoretical analysis, overlapping regulation through unilateral CO_2 taxation induces overall EU-wide excess cost for the EU ETS. Figure 5 illustrates these excess cost in percent of the compliance cost for the efficient EU-ETS regime. We see that the excess cost may become substantial. Again, the ranking in excess cost across taxing EU member states reflects the order of the marginal abatement cost curves.

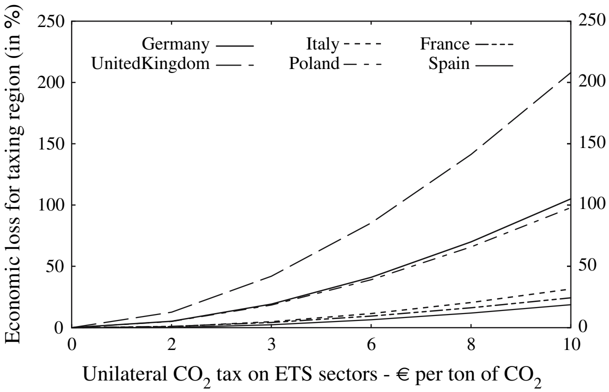

Fig. 6 Excess cost for region with unilateral CO_2 tax on ETS sectors

While the EU-wide efficiency implications of unilateral taxation are unambiguous, individual EU member states may benefit or lose from unilateral carbon taxes imposed on ETS sectors of individual member states. The basic reasoning behind the regional effects are linked to the initial trade patterns: Since the international allowance price decreases, regions that are net exporters of emission allowances can be expected to lose as the allowance price decreases, whereas allowance importers can be expected to win. As has been discussed in Sect. 2, the tax-induced drop in the international allowance price may—in theory—even be large enough to compensate the unilaterally taxing region for additional abatement expenditure. Based on our empirical parameterization, however, the three conditions for a country to benefit from its unilateral tax are obviously not fulfilled: Figure 6 clearly indicates that none of the six major EU ETS regions is able to achieve a net profit from unilateral CO_2 taxation.

6 Sensitivity analysis

In order to test the sensitivity of our results with respect to the stringency of the EU ETS emission constraint, we have calculated the excess cost of overlapping regulation depending on the allocation factor. The latter determines the allowance allocation to the ETS sectors and, thus, the stringency of the emission reduction target. In the central case simulation, the average EU allocation factor amounts to 0.86 (see last row in Table 1). In the sensitivity analysis, we scale country-specific allocation factors (as of Table 1) uniformly to cover a range of average EU allocation factors between 0.96 and 0.80. Figure 7 reports the EU-wide excess cost of unilateral taxation in Germany as a function of both the emission tax rate and the allocation factor (Figures for the other central regions provide the same insights). We see that overall excess cost of the unilateral carbon tax decreases with the stringency of the emission cap for the EU ETS. As emission caps become more restrictive, the international allowance price (marginal cost) and the overall (inframarginal) compliance cost of the no-tax EU ETS regime go up. The imposition of unilateral emission taxes then induces smaller excess cost (measured in percent of the compliance cost for the efficient no-tax trading system): As

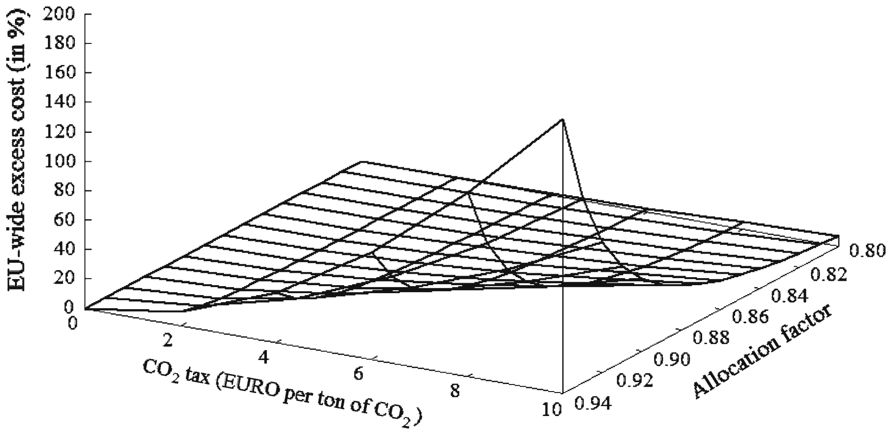

Fig. 7 Excess cost of unilateral CO_2 tax in Germany w.r.t. environmental stringency

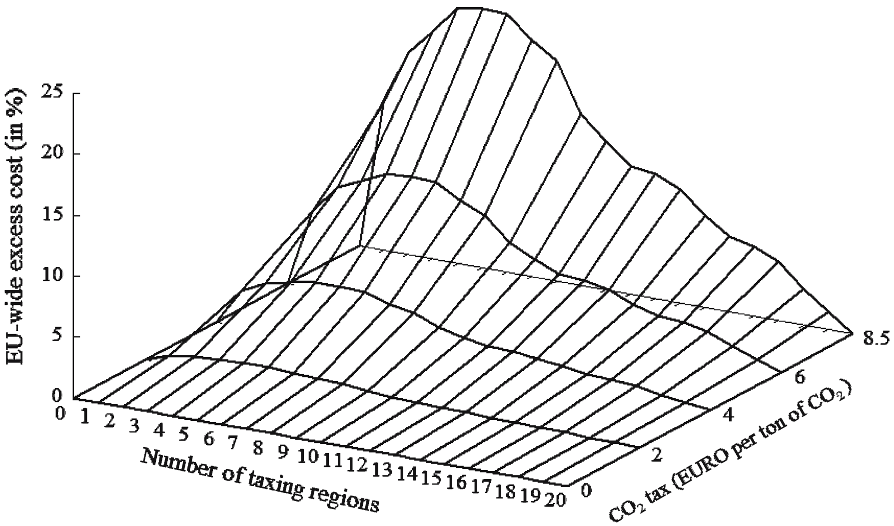

Fig. 8 Excess cost of multilateral taxation in EU member states

the tax wedge between the international allowance price and the marginal abatement cost for ETS sectors in the taxing region becomes less pronounced in relative terms also the absolute excess cost of taxation become smaller relative to the compliance cost for the an efficient regulation.

Figure 8 provides insights how excess cost of additional emission taxes depend on the number of taxing regions. The labels on the x-axis of Fig. 8 indicate the number of EU countries that simultaneously impose a unilateral emission tax (at a uniform rate). As to the order of countries entering the tax regime along the x-axis, we start with the largest ETS region in terms of allocated emission allowances (i.e., “1” corresponds to Germany), followed by the second largest (i.e., “2” corresponds to a tax coalition formed by Germany and the United Kingdom), and so on. By definition, excess cost are zero if the number of taxing regions is zero or if the tax rate across regions is zero.

Reflecting our theoretical analysis, excess cost are also zero if all countries (here: “20”) apply the same tax rate. For any fixed number of regions (larger than “0” and smaller than “20”) the excess cost increase towards higher emission taxes. If we increase subsequently the number of taxing regions for a given tax rate the excess cost first go up, peak, and then fall as we exceed a critical coverage. Note that emission taxes in Fig. 8 only range up to 8.5 € per ton of CO_2, which is the allowance price for the exclusive cap-and-trade regulation without additional emission taxes. If all ETS regions were to apply an emission tax at 8.5 € per ton of CO_2, the international allowance price would be fully crowded out.[9]

7 Conclusion

In this paper, we have addressed the question whether carbon emissions of the EU ETS sectors should be additionally regulated by unilateral emission taxes.

Based on stylized theoretical analysis, we have pointed out that—in general—unilateral emission taxes within the EU ETS are environmentally ineffective and increase overall compliance cost of the EU ETS. Since the allocation of emission allowances has been fixed ex ante through the National Allocation Plans, any additional emission tax will not affect environmental effectiveness of the quantity-based EU ETS. The one exception refers to a situation where emission taxes are levied in a sufficiently large number of EU member states at a rate which crowds out the international allowance price. When applied within the EU ETS, unilateral carbon taxes increase the EU-wide cost of implementing the overall ETS emission constraint. In general, a unilateral carbon tax also induces an excess burden for the country that introduces the tax since the additional abatement expenditures exceed the additional revenues from allowance sales, or from reduced spending for allowance purchases, respectively. Only for very restrictive conditions might a taxing country gain at the expense of overall cost effectiveness: The respective country must have a large share in the emission allowance market, dispose of rather cheap abatement options in the ETS sectors, and at the same time must be a net importer of emission allowances.

We have substantiated our theoretical analysis with empirical simulations for the EU ETS. Our quantitative results confirm that the excess cost of overlapping regulation can be substantial.

To conclude, energy or carbon taxes within the part of the EU economy which is regulated by the EU ETS should be handled with great care and justified by other reasons than fulfilling the obligations under the EU Burden Sharing Agreement in a cost-efficient manner.

Acknowledgements The authors would like to thank two anonymous referees and Michael Crew for helpful comments.

[9] For EU-wide uniform emission taxes beyond 8.5 € per ton of CO_2 the induced emission reduction would exceed the aggregate ETS reduction commitment provide by the National Allocation Plans.

Appendix: Computer program for numerical analysis

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the EU
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GAMS source code to replicate central results of manuscript:
  Efficiency Losses from Overlapping Regulation of EU Carbon Emissions
Christoph Böhringer, Henrike Koschel, and Ulf Moslener
University of Oldenburg, Oldenburg
Centre for European Economic Research (ZEW), Mannheim
Correspondence: boehringer@uni-oldenburg.de
Oldenburg — May 2007
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          BAL Baltic States,
          BEL Belgium,
          CZE Czech Republic,
          DEU Germany,
          DNK Denmark,
          ESP Spain,
          FIN Finland,
          FRA France,
          GBR United Kingdom,
          GRC Greece,
          HUN Hungary,
          IRL Ireland,
          ITA Italy,
          NLD Netherlands,
          POL Poland,
          PRT Portugal,
          SVK Slovakia,
          SWE Sweden,
          XEU Rest of EU
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SET     allr All EU member states
        /AUT, BEL, DEU, DNK, ESP, FIN, FRA, GBR, GRC, IRL, ITA, LUX,
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        HUN.HUN,
        POL.POL, CYP.XEU, CZE.CZE, MLT.XEU, SVK.SVK, SVN.XEU, EST.BAL,
        LVA.BAL,
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TABLE data(*,*)     Carbon emission inventories for EU Member States
(in Mt of C)
* Data sources:
* European Energy and Transport - Trends to 2030, European Commission,
  Brussels
* http://europa.eu.int/comm/dgs/energy_transport/figures/trends_2030/
  index_en.htm
* EU (2007). National Allocation Plans: Second Phase (2008-2012),
  European Commission,
* http://ec.europa.eu/environment/climat/2nd_phase_ep.htm
* Key:
* C_ETS_10: Projected total carbon emissions of ETS sectors in 2005 by
  region
*-----------------------------------------------------------------------
* Lambda:   Fulfillment factor for ETS sectors by region as ratio of
  allocated
*            emission allowances over business-as-usual emissions
      C_ETS_10   Lambda
AUT   25.9       0.813
BEL   54.5       0.943
DEU   439.8      0.876
DNK   25.5       0.822
ESP   144.6      0.693
FIN   32.0       0.921
FRA   142.1      0.907
GBR   242.2      0.900
GRC   68.0       0.807
IRL   20.8       0.750
ITA   201.9      0.849
LUX   3.3        0.839
NLD   84.8       0.893
PRT   37.0       0.839
SWE   23.3       0.940
HUN   32.9       0.887
POL   203.8      0.833
CYP   4.5        0.881
CZE   73.8       0.825
MLT   2.1        0.997
SVK   28.4       0.929
SVN   7.2        0.777
EST   11.2       0.644
LVA   4.6        0.736
LTU   10.8       0.953
BGR   32.9       0.940
ROM   57.1       0.940;
SCALAR CO2inC Conversion factor from carbon to carbon dioxide;
CO2inC = 12/44;
*     Assign data to aggregate model regions:
*     Emission reduction requirements are based on projected
*     emission data for 2010 which is used as the reference
*     year for compliance within the model simulations.
PARAMETER   carbonstat(*,*)            Emission data by model region,
            ffactor(r)         ETS fulfillment factor by model region;
carbonstat(r,"ETS") = SUM(allr$mapit(allr,r),
                      data(allr,"C_ETS_10")*CO2inC);
ffactor(r)$SUM(allr$mapit(allr,r), data(allr,"C_ETS_10")) =
      SUM(allr$mapit(allr,r), data(allr,"Lambda")
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            *data(allr,"C_ETS_10"))
            /SUM(allr$mapit(allr,r), data(allr,"C_ETS_10"));
DISPLAY carbonstat, ffactor;
TABLE   mac_coef(r,*) Exogenous coefficients for MAC function
approximation
*       (here: polynomial of third degree)
* Units:   Euro per ton of carbon
* Source:   Own calculations based on European CGE model
*          (Böhringer 2002: Applied Economics, 34, 523-533)
*           Economic data for CGE model is based on 2001 GTAP6 data
*          (Dimaranan and McDougall 2006, Purdue University)
*           available at: http://www.gtap.agecon.purdue.edu/
          a1            a2            a3
AUT    31.792798    11.404881    7.6574059
BEL    12.525735    1.3631822    0.83551358
DNK    16.815408    2.2750154    2.2515957
FIN    28.630794    5.0711964    1.0307786
fra    12.195939    1.5427418    0.5759482
DEU    1.6106427    0.0192323    0.00044646
GBR    2.6584576    0.06894563   0.00365619
GRC    13.948536    -0.53775863  0.15444644
IRL    23.029636    6.8247019    7.8718684
ITA    4.5824262    0.2904227    0.01431379
NLD    6.9398464    0.47487886   0.05661485
PRT    85.224805    20.01391     28.23715
ESP    3.8660081    0.12586864   0.02242585
SWE    56.792634    45.884037    54.739798
BAL    28.538172    -9.3137061   8.1172545
XEU    2.7068989    0.04599646   0.00385902
CZE    3.8816768    -0.01813968  0.03491031
HUN    13.588239    1.6882308    1.5992551
POL    2.6225261    0.02984338   0.0034039
SVK    19.856852    2.8059284    4.8509275;
*      Compute effective reduction targets w.r.t 1990 and 2010
PARAMETER target(r) Reduction targets in Mt of carbon;
target(r) = carbonstat(r,"ETS") - ffactor(r) * carbonstat(r,"ETS");
DISPLAY target;
*      Assignment of MAC curve coefficients
*      Approximations of MACs: MAC = a1*e + a2*e**2 + a3*e**3
PARAMETER a1, a2, a3;
a1(r) =mac_coef(r,"a1");
a2(r) =mac_coef(r,"a2");
a3(r) =mac_coef(r,"a3");
*      Specification of carbon tax regime for selected regions (tax_r)
SET
  tsc      Tax scenarios /T0, T2, T4, T6, T8, T10/,
  tax_r(r)    Regions with additional carbon tax in ETS sectors;
PARAMETER
  taxlevel(tsc)      Carbon tax rate by scenario (in Euro per ton of
CO2)
              /T0 0, T2 2, T4 4, T6 6, T8 8, T10 10/,
  tax(*)       Carbon tax;
*        Definition of multi-regional emission market model
FREE VARIABLE
        tcost       Aggregate cost of carbon mitigation;
POSITIVE VARIABLE
        d(r)        Abatement by ETS sectors in region r
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EQUATIONS
        totalcost   Total compliance cost for model regions
        ceiling           Total emission ceiling for model regions;
totalcost.. tcost =e= SUM(r, (1/2)*a1(r)*d(r)**2 + (1/3)*a2(r)*d(r)**3
                     + (1/4)*a3(r)*d(r)**4) - SUM(r, tax(r)*d(r));
ceiling..   SUM(r, d(r)) =g= SUM(r, target(r));
MODEL nlp_model     Emission market model in NLP formulations
              / totalcost, ceiling/;
*     Scenario runs and reporting
PARAMETER
      cost     Summary - total compliance costs (in millions of Euros)
      mac      Summary - marginal abatement costs (in Euros per ton of
CO2)
      trade    Permit imports (in Mt of CO2)
      Fig_3    Marginal abatement cost in Euro per ton of CO2
      Fig_4    EU-wide excess cost of unilateral CO2 tax(in %)
      Table_1  Benchmark emission data;
Table_1(r,"emissions_2010")       = 1/CO2inC*carbonstat(r,"ETS");
Table_1("EU-27","emissions_2010") = SUM(r,1/CO2inC*carbon-
stat(r,"ETS"));
Table_1(r, "ffactor2010")         = ffactor(r);
Table_1("EU-27","ffactor2010")    = SUM(r, ffactor(r)*carbon-
stat(r,"ETS"))
                                /SUM(r, carbonstat(r,"ETS"));
Table_1(r, "cutback_total")       = 1/CO2inC*target(r);
Table_1("EU-27","cutback_total")  = SUM(r, 1/CO2inC*target(r));
Table_1(r, "cutback_percent")     = ROUND(100*target(r)/carbon-
stat(r,"ETS"), 1);
Table_1("EU-27","cutback_percent") = ROUND(100*SUM(r, target(r))
                                /SUM(r,carbonstat(r,"ETS")), 1);
DISPLAY Table_1;
*     Region(s) with additional carbon taxes (Here: Germany (deu)))
*     Other regions can be assigned with "$setglobal region ..."
*     Multiple runs over differen regions may be operated through
*     a external batch routine
$setglobal region deu
tax_r("%region%") = YES;
$if %region%==deu $setglobal rlabel Germany
$if %region%==gbr $setglobal rlabel UnitedKingdom
$if %region%==pol $setglobal rlabel Poland
$if %region%==ita $setglobal rlabel Italy
$if %region%==esp $setglobal rlabel Spain
$if %region%==fra $setglobal rlabel France
LOOP(tsc,
tax(r)$tax_r(r) = taxlevel(tsc)/CO2inC;
DISPLAY tax;
SOLVE nlp_model USING NLP MINIMIZING tcost;
cost("EU", tsc)     = EPS + SUM(r, ROUND( ( (1/2)*a1(r)*d.l(r)**2
                         + (1/3)*a2(r)*d.l(r)**3
                         + (1/4)*a3(r)*d.l(r)**4), 3));
cost(r, tsc) = EPS + ROUND((( (1/2)*a1(r)*d.l(r)**2
                         + (1/3)*a2(r)*d.l(r)**3
                         + (1/4)*a3(r)*d.l(r)**4)
                         + (target(r) - d.l(r))*ceiling.m), 3);
trade(r,tsc) = EPS + 1/CO2inC*(target(r) - d.l(r));
mac(tsc)     = EPS + ROUND(CO2inC*ceiling.m, 3);
);
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$setglobal batch yes
*     Marginal abatement cost in ETS sectors:
Fig_3(tsc,"Rest of EU") = EPS + ROUND(mac(tsc), 1);
Fig_3(tsc,"%rlabel%")    = EPS + ROUND(mac(tsc) + taxlevel(tsc),1);
*     EU-wide excess cost (in % of no-Tax case):
Fig_4(tsc,"EU-ETS") = EPS + ROUND(100*(cost("EU",tsc)/cost("EU","T0")
- 1),1);
Display Fig_3, Fig_4
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References

Andersen, M. S., Evenvoldsen, M. K., & Ryelund, A. V. (2006). Decoupling of CO_2 emissions from energy-intensive industries. *TemaNord, 58*.

Betz, R., Eichhammer, W., & Schleich, J. (2004). Designing national allocation plans for EU emissions trading—a first analysis of the outcome. *Energy and Environment, 15*(3), 375–423.

Böhringer, C. (2002). Industry-level emission trading between power producers in the EU. *Applied Economics, 34*(4), 523–533.

Böhringer, C., & Lange, A. (2005). Mission impossible!?—on the harmonization of national allocation plans under the EU emissions trading directive. *Journal of Regulatory Economics, 27*(1), 51–71.

Böhringer, C., Hoffmann, T., Lange, A., Löschel, A., & Moslener, U. (2005). Assessing emission allocation in Europe: An interactive simulation approach. *The Energy Journal, 26*(4), 1–22.

Bovenberg, A. L. (1999). Green tax reforms and the double dividend: An updated reader's guide. *International Tax and Public Finance, 6*(3), 421–443.

Brooke, A., Kendrick, D., & Meeraus, A. (1987). *GAMS: A user's guide*. South San Francisco: Scientific Press.

Capros, P., Mantzos, L., Kolokotsas, D., Ioannou, N., Georgakopoulos, T., Filippopoulitis, A., & Antoniou, Y. (1998). The PRIMES Energy System Model–Reference Manual. National Technical University of Athens. Document as peer reviewed by the European Commission, Directorate General for Research.

Criqui, P., & Mima, S. (2001). The European greenhouse gas tradable emission permit system: Some policy issues identified with the POLES-ASPEN Model. *ENER Bulletin, 23*, 51–55.

Dimaranan, B. V., & McDougall, R. A. (2006). *Global trade, assistance, and production: The GTAP 6 data base*. Center for Global Trade Analysis, Purdue University.

Ekins, P. (1996). The secondary benefits of CO_2 abatement: How much emission reduction do they really justify? *Ecological Economics 16*(1), 13–24.

EU (1999). EU Council of Ministers, Commission Communication, Preparing for Implementation of the Kyoto Protocol, COM (1999), Annex 1. Available at: http://europa.eu.int/comm/environment/docum/99230_en.pdf.

EU (2003a). Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003, Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC. *Official Journal of the European Union L 275/32*, Brussels.

EU (2003b). Council Directive 2003/96/EC of 27 October 2003, Restructuring the Community Framework for the Taxation of Energy Products and Electricity. *Official Journal of the European Union L 283/51*, Brussels.

EU (2003c). European Energy and Transport Trends to 2030, European Commission, Brussels.

EU (2007). National Allocation Plans: Second Phase (2008–2012), European Commission, http://ec.europa.eu/environment/climat/2nd_phase_ep.htm.

Eyckmans, J., van Regemorter, D., & van Steenberghe, V. (2001). Is Kyoto fatally flawed?—an analysis with MacGEM. Working Paper Series–Faculty of Economics, No. 2001–18, Catholic University of Leuven, Leuven.

Goulder, L. H. (1995). Environmental taxation and the double dividend: A reader's guide. *International Tax and Public Finance, 2*, 157–183.

Johnstone, N. (2003). The use of tradable permits in combination with other environmental policy instruments. Report ENV/EPOC/WPNEP(2002)28/Final, OECD, Paris.

Klepper, G., & Peterson, S. (2006). On the robustness of marginal abatement cost curves: The influence of world energy prices. *Resource and Energy Economics, 28*(1), 1–23.

OECD (2001). Environmentally related taxes in OECD countries—issues and strategies, OECD, Paris.

Point Carbon (2006). Carbon 2006. H. Hasselknippe & K. RØine (Eds.).
Sorrell, S., & Sijm, J. (2003). Carbon trading in the policy mix. *Oxford Review of Economic Policy, 19*(3), 420–437.
Tinbergen, J. (1952). *On the theory of economic policy*. Amsterdam: North-Holland.