Emissions floor price options for EU member states

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Summary

We evaluate options for EU member states to take unilateral action to raise carbon prices nationally and within the EU Emissions Trading System.

Abstract

Several EU member states (MS) are exploring options for setting minimum carbon prices nationally. We evaluate different possibilities and their consequences on national and ETS-wide carbon prices, compliance costs, the revenues from emission allowances, emissions, and overall cost-effectiveness. We explore analytically and then numerically three policy options, referred to as "TAX", "KILL" and "BILL". First, a "TAX" policy would implement a national minimum price by adding a tax equal to the difference between the prevailing ETS price and the targeted minimum price. Second, a national auction reserve price would "KILL" allowances by withholding them from auction, raising the ETS price to the national reserve price. Third, a final option would be to require local overcompliance: participating MS would "BILL" their covered entities for extra allowances per ton of emissions (i.e., resident covered entities would have to surrender p_F/p_A allowances for their emissions at the ratio of the desired national floor price over the ETS market price); this policy increases demand for allowances, and thus pushes up the ETS price. Among the options, for a given domestic minimum price, TAX raises the most revenues for the coalition (assuming they are not large net exporters of allowances), at the expense of the rest, since the resulting "waterbed effect" lowers system-wide allowance prices rather than emissions. KILL lowers emissions the most, without sacrificing overall cost-effectiveness, and if a coalition of MS has sufficient shares of the supply while demand for allowances is sufficiently steep the price increase can offset the revenue cost of lost sales for the coalition. BILL requires less sacrifice of revenues by the coalition than KILL, for somewhat less cost-effectiveness. We use an empirically parameterized numerical model based on MS-specific abatement costs and allowance allocations to quantify the distributional and efficiency implications for different MS coalitions and minimum price targets across the different policy options.

Keywords: auction reserve price, emissions trading, carbon, leakage

1. Introduction

Allowance prices in the EU Emissions Trading System (ETS) fell precipitously in 2008 and have remained stubbornly low since. Several factors have been blamed, including the financial crisis and ensuing recession, as well as overlapping targets for renewable energy and energy efficiency that exert a downward pressure on allowance prices (Böhringer and Rosendahl, 2010). Concerned that persistent low prices will not drive the change needed for the clean energy transition (Edenhofer et al. 2017), several EU member states (MS) are exploring options for setting minimum carbon prices nationally. Notably, the United Kingdom (UK) led by introducing a domestic carbon floor for electricity generators in 2013; initially slated to rise, that price is currently capped £18/ton (around €20/ton) through 2020. The Netherlands is currently exploring a floor price mechanism for the electricity sector similar to that in the UK.[1] France floated its own proposal in 2016 that would have set a domestic carbon price floor of €30/ton for domestic power plants. Germany, rather than seek a unilateral approach, considered pressing for a "Europe-wide minimum price" for carbon.[2]

The European Commission has been resistant to the idea of a carbon floor price in the EU ETS. In part, this hesitance comes from concern that a floor price might trigger the special decision rule requiring unanimity in the European Council, which prior to the ETS torpedoed efforts to design an EU-wide carbon tax. Legal scholars argue that introducing an auction reserve price into the EU ETS could be done with the ordinary procedure (see Fischer et al. 2018). Still, the Commission has preferred to rely on quantity-based measures in the form of the Market

[1] https://www.kabinetsformatie2017.nl/binaries/kabinetsformatie/documenten/publicaties/2017/10/10/regeerakkoord-vertrouwen-in-de-toekomst/Regeerakkoord+2017-2021.pdf
[2] http://www.reuters.com/article/europe-carbon-germany-idUSL5N181906

Stability Reserve (Perino and Willner, 2016). As a result, MS that wish to ensure minimum carbon prices are seeking unilateral options.

Three legal aspects of EU law make this possible. First, Article 193 of the Treaty on the Functioning of the European Union (TFEU – EU, 2012) states that EU legislative acts based on the environmental policy shall not prevent the Member States "from maintaining or introducing more stringent protective measures." MS are thus free to impose their own carbon taxes. Second, allowances are classified as financial instruments, meaning MS are free to trade in them, including purchasing and retiring them. Third, MS are allocated specific volumes of the allowances to be auctioned; they may use the common platform to auction them or opt out and appoint their own auction platform. In fact, Germany, Poland and the United Kingdom have all opted out to take charge of their own auctions. Thus, MS may have an opportunity to set their own auction rules, such as including a reserve price, although that possibility hinges on the interpretation of "shall auction" in the EU ETS auction law, and whether that means to offer their allowances for sale or sell them at any clearing price. To summarize: MS can design unilateral measures to raise carbon prices within their jurisdiction and also to retire allowances they control.

We evaluate – analytically as well as numerically – three different options for unilateral measures and their consequences on national and ETS system-wide allowance prices, compliance costs, the revenues from emission allowances, emissions, and overall cost-effectiveness. First, a national minimum price can be implemented by a tax equal to the difference between the prevailing ETS price and the minimum price ("TAX"). This policy results in a "waterbed effect," lowering system-wide allowance prices while emissions remain unchanged under the cap, and leads to price disparities within the cap. Still, MS may have a strategic interest in raising their emissions revenues and shifting emissions to other jurisdictions. Second, a national auction reserve price raises systemwide prices by withholding allowances ("KILL"); if a group of MS have sufficient shares of the supply, and demand for allowances is sufficiently steep, the price increase can offset the revenue cost of lost sales for the coalition, while the nonparticipating MS necessarily gain revenue. A final option would be for participating MS to require local covered entities to retire additional allowances for their emissions compliance, so that the effective cost per unit of emissions equals the targeted minimum price ("BILL"). This policy has the effect of increasing demand for allowances, and thus pushing up the ETS price. This price increase is enjoyed by all allowance holders, so revenues in both participating and nonparticipating MS increase in proportion to their holdings, but firms in participating MS face higher emissions costs than those in other jurisdictions.

Among the options, for a given domestic minimum price, TAX raises the most revenues for the coalition (assuming they are not large net exporters of allowances), at the expense of the rest, since the resulting "waterbed effect" lowers systemwide allowance prices rather than emissions. KILL lowers emissions the most, without sacrificing cost effectiveness, and if a group of MS have sufficient shares of the supply, and demand for allowances is sufficiently steep, the price increase can offset the revenue cost of lost sales for the coalition. BILL requires less sacrifice of revenues by the coalition than KILL, for somewhat less cost-effectiveness and emissions reductions.

The remainder of this paper is organized as follows. Section 2 provides a theoretical analysis of the economic impacts across the three unilateral policy options to achieve domestic minimum prices. Section 3 quantifies the distributional and efficiency implications using a numerical model of the ETS carbon market calibrated to empirical data. Section 4 concludes.

2. Theoretical analysis

Consider a simple model of an emissions cap-and-trade scheme. The cap is set at A and allocated among the participating jurisdictions. Subgroup G receives A_G allowances, of which $a_G = \alpha A_G$ are auctioned and the rest $(f_G = (1-\alpha)A_G)$ are grandfathered to firms or installations. Meanwhile, the Rest of Europe (ROE, indexed by R) has $A_R = A - A_G$ allowances in total, auctioned or freely allocated. The market price of allowances is p, and that price prevails in ROE. Jurisdiction G may choose a different domestic price p_G.

Each group has covered entities with a marginal willingness to pay (WTP) for emissions that produces a downward-sloping demand curve for allowances that declines from a choke price of b_i, at which emissions are zero. Total surplus S from emissions is the area under the demand curve above the region's allowance price, p_i: $S_i = \int_{p_i}^{b_i} E(s)ds,$ so $\partial S_i / \partial p_i = -E_i$. Let total domestic private surplus be $TS_i = S_i + PR_i$, the sum of the surplus from emissions plus the private rents, PR, which equal value of their installations' free allocation: $PV_i = pf_i$. Therefore, $\partial TS_i / \partial p_i = -E_i + f_i(\partial p / \partial p_i)$.

Let $z_i = -\partial E_i / \partial p_i$ be the slope parameter of the emissions demand curve. For illustrations, we will let the WTP for emissions by each group be a linear function with slope $1/z_i$: $WTP_i = b_i - E_i / z_i$. Equalizing WTP with the locally prevailing price, we get domestic emissions: $E_i = (b_i - p_i)z_i$. Domestic surplus from emissions (net of allowance costs paid by firms) is $S_i = (b_i - p_i)^2 z_i / 2,$ and $\partial S_i / \partial p_i = -(b_i - p_i)z_i = -E_i$.

In deciding what domestic price p_G if prefers, jurisdiction G takes into account social costs of emissions at a constant marginal damage rate δ; for example, this parameter could be the global social cost of carbon. The government may also place a different weight γ on government revenues relative to costs borne by domestic firms; for example, the marginal cost of raising public funds could lead to $\gamma > 1$, while interest-group lobbying could induce policymakers to care more about economic surplus, implying $\gamma < 1$. A recent study estimates an average marginal cost of public funds (MCPF) for the EU (weighted average) of 1.9 (Barrios et al. 2013).

Domestic welfare in *G* equals the total domestic private surplus *TS*, plus weighted auction revenues *TR*, less perceived damages from systemwide emissions:

$$W_G = TS_G + \gamma TR_G - \delta\left(E_G + \beta E_R\right)$$

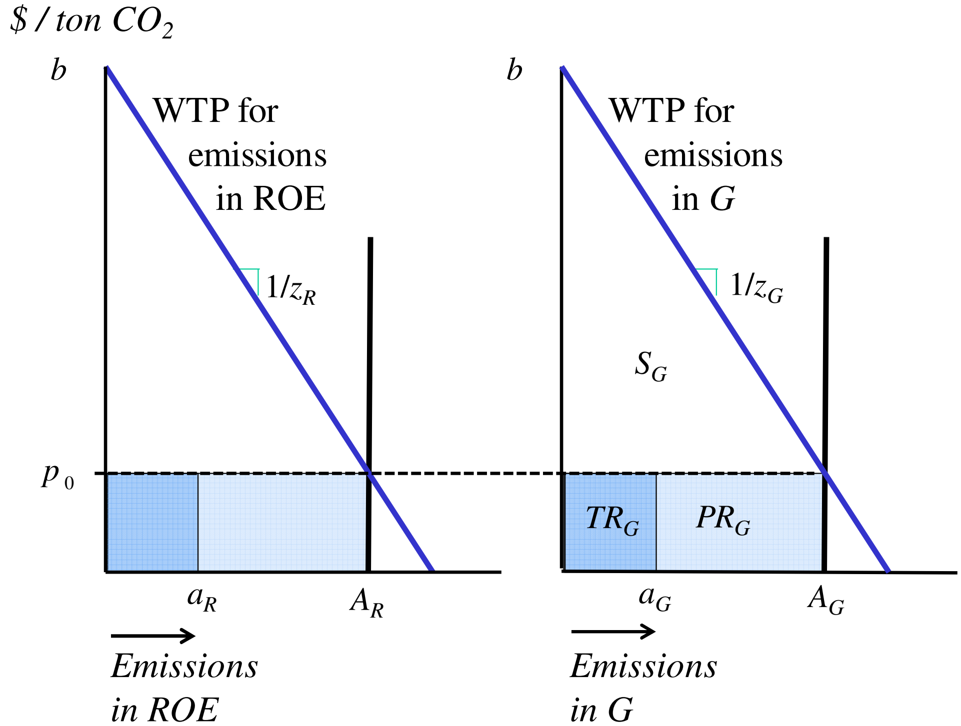
In the absence of additional unilateral policy, both jurisdictions face the same price, p_0. Using our functional form assumptions, that price is $p_0 = \overline{b} - \dfrac{A}{z_G + z_R}$, where

$$\overline{b} = b_G \frac{z_G}{z_G + z_R} + b_R \frac{z_R}{z_G + z_R}.$$

The subsequent analysis will focus on the perspective of group *G*; only the variables that require distinction from ROE will be subscripted. (I.e., the parameters α, γ, δ, β, etc. are in practice country- and region-specific, but the foreign values do not enter into the acting group's welfare function, so we drop the indexing).

Figure 1 depicts the emissions market equilibrium in our simple two-region model for the reference scenario, with no unilateral interference in the system. The surplus from emissions is the triangular area, and the rent from allowances is shaded. The darkly shaded area is the value of auctioned allowances, while the lightly shaded area is the private allowance value. For convenience in the figures, we assume symmetric regions, and that each region is allocated its equilibrium share of emissions under the cap, but this need not hold in the general analysis.

Figure 1: Two-region ETS without unilateral intervention



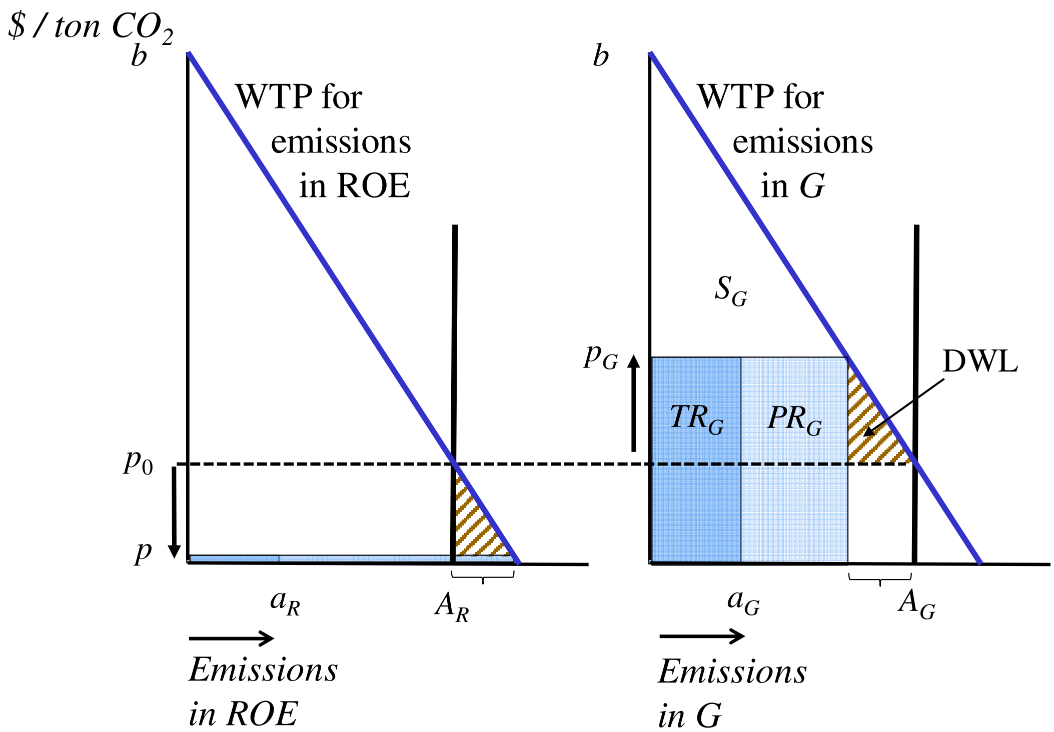
2.1. TAX: Floor price for resident covered entities

One option is to set a domestic floor price. A minimum price could be implemented by taxing the emissions of resident entities covered by the ETS. The UK Carbon Price Support (CPS) mechanism follows this model: the carbon price floor is made up of the price of CO2 from the EU ETS and the CPS rate per tCO2 to make up the difference for the UK-only additional tCO2 emitted in the power sector.

This option creates stronger signals for low-carbon investments domestically, but has well-known inefficiencies. One is that it causes marginal abatement costs to diverge across MS. The other is known as the "waterbed effect": Reducing local demand for allowances does not change the total number of allowances under the cap; rather it drives down the value of tradable allowance and allows the other MS to emit more under the cap (see, e.g., Fischer and Preonas

2010). The combination of higher domestic prices and lower ETS prices would also effectively shift some revenues from the rest of Europe to the MS or subgroup.

Figure 2: ETS market equilibrium with unilateral carbon tax in *G*



Formally, from the cap constraint $A = E_G + E_R$, we totally differentiate, $dp_G \partial E_G / \partial p_G + dp \partial E_R / \partial p = 0$, to find how the coalition's floor price influences the prevailing market price for allowances:

$$\frac{dp}{dp_G} = -\frac{\partial E_G / \partial p_G}{\partial E_R / \partial p} = -\frac{z_G}{z_R} < 0$$

In other words, the market price falls according to the ratio of the slopes of the emissions demand curves.

With our functional forms, $A = (b_G - p_G)z_G + (b_{ROE} - p)z_{ROE}$, we see that the market price for allowances depends on the floor price set for the group via their resulting emissions

$$p = b_R - \frac{A - E_G}{z_R}$$

Thus, $\partial p / \partial p_G = \partial E / \partial p_G / z_R = -z_G / z_R < 0$.

Domestic revenues are the sum of the auction revenues at the market price plus the carbon tax premium paid by local firms:

$$TR_G = p_G E_G + p(a_G - E_G)$$

Taking the derivative with respect to p_G and simplifying, we see that total coalition revenues increase with the unilateral floor price if

$$MR = E_G + (p_G - p)\frac{\partial E_G}{\partial p_G} - \frac{\partial p}{\partial p_G}(E_G - a_G) > 0$$

The first term is positive (excluding the possibility of negative emissions). Note that the second term is negative but close to zero initially. The third term is positive if *G* auctions fewer allowances than it emits: driving down the market price ensures rents are transferred home. Thus, the smaller the coalition's share of allowances, the larger the range in which implementing a domestic floor price will increase revenues. I.e., revenues will increase until the domestic price reaches $p_G^{T\max} = \overline{b} - \left(A + \alpha_G A_G + (b_R - b_G) z_R\right) / \left(2(z_G + z_{ROE})\right) > p_0$.

Note that total domestic private surplus necessarily decreases with the tax, since not only is economic surplus from emissions lower, but also the value of the industry allowance allocation falls. $\partial TS_G / \partial p_G = -E_G / 2 - f_G(z_G / z_R) < 0$.

Since total emissions are fixed $(E_R = A - E_G)$, the damage component of the welfare function is fixed unless marginal damages for *G* are different for different regions ($\beta \neq 1$).

$$W_G = S_G + pf_G + \gamma(pa_G + p_G E_G) - \delta_G \left(E_G + \beta E_R\right)$$

Maximizing group welfare with respect to its choice of domestic price, we get

$$\frac{\partial W_G}{\partial p_G} = (\gamma-1)E_G + \frac{\partial p}{\partial p_G}\left(A_G + (\gamma-1)a_G\right) + \frac{\partial E_G}{\partial p_G}\left(\gamma p_G - \delta(1-\beta)\right)$$

from which we see three potential incentives to change the domestic price from the market price, despite the waterbed effect (recalling $\partial E_i / \partial p_i = -z_i$):

$$p_G = \underbrace{\frac{\delta(1-\beta)}{\gamma}}_{\substack{\text{Marginal value of}\\ \text{shifting emissions}}} + \underbrace{\frac{(\gamma-1)/\gamma}{z_G} E_G}_{\substack{\text{Marginal excess}\\ \text{value of revenue}}} - \underbrace{\left(\frac{A_G + (\gamma-1)a_G}{\gamma z_R}\right)}_{\text{Lost allowance rents}}$$

Under the cap, the prevailing market price reflects the value of emissions abatement. The next term is positive if $\beta < 1,$ that is, if abatement is more valuable at home than in ROE. The second bracketed term is positive if $\gamma > 1,$ that is, if the government cares more about revenues than surplus. The last term is negative, since the fall in the market price drives down both public and private allowance values.

Using our linear emissions demand functions and solving in terms of the parameters,

$$p_G^{Tax} = b_G - \frac{\gamma(1+\alpha)A + (1-\alpha)A_G - \delta(1-\beta)z_R - (b_R - b_G)\gamma z_R}{2\gamma(z_G + z_R) - z_R}$$

2.2. KILL: Reserve price in local auctions

The second option would avoid the waterbed effect by reducing the supply of allowances. Group *G* can decide to withhold (or “kill”) *k* permits from auction, or equivalently cancel the permits if the corresponding reserve price p_G is not met.

Under this option, both regions take the same allowance price, p_G. Group *G* can equivalently (in the absence of uncertainty) choose the price or choose how many allowances to cancel. In equilibrium, under the adjusted cap constraint, $E_G + E_R = A - k$. Thus, if the group wants to raise the allowance price to p_G, it will need to cancel $k(p_G) = A - E_G(p_G) + E_R(p_G)$

allowances. Using our linear functional forms, $k = A - (\bar{b} - p_G)(z_{ROE} + z_G)$, and we see the maximum feasible market price the group can sustain is that which involves cancelling their entire allocation from auction is equal to $p_G^{K\max} = p_0 + a_G / (z_{ROE} + z_G)$.

Group revenue is

$$TR_G^{Kill} = p_G(a_G - k) = p_G\left(a_G - A + E_G + E_R\right)$$

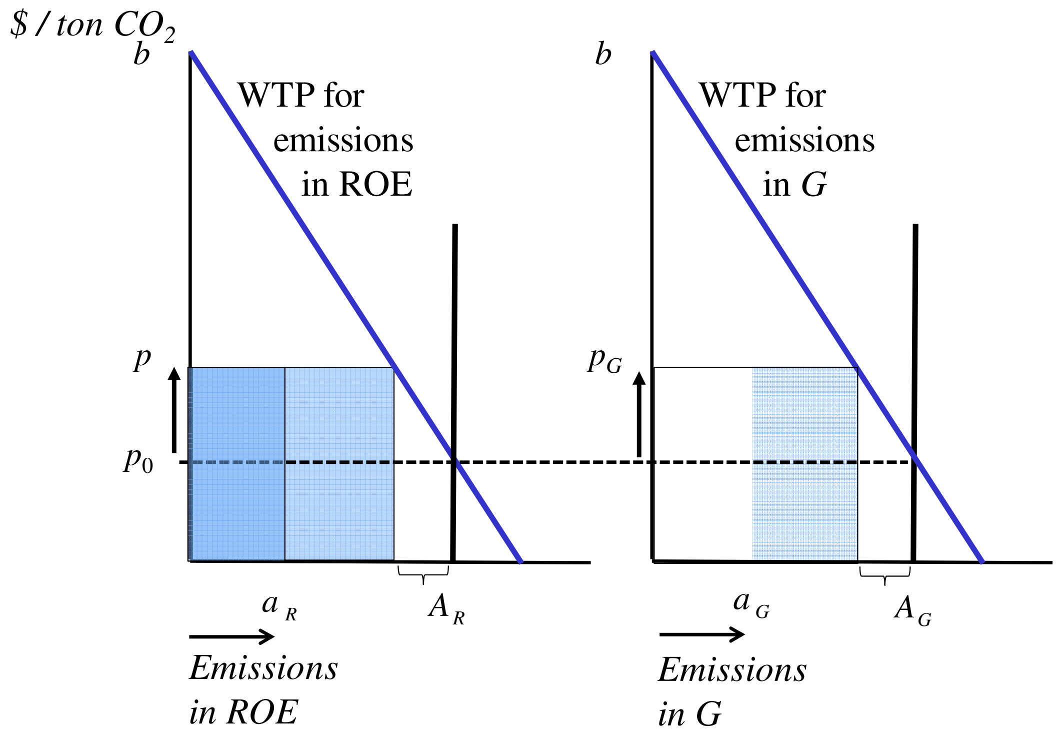
which implies that

$$\frac{\partial TR_G^{Kill}}{\partial p_G} = (a_G - k) + p_G\left(\frac{\partial E_G}{\partial p_G} + \frac{\partial E_R}{\partial p}\right)$$

This equation reveals that KILL can only raise revenues up to a point, well below the point where the auction allocation is exhausted, since the second term is negative. In other words, group *G*'s revenue change may be positive or negative, depending on whether it will lose more on the allowances not sold than it will gain on the remaining allowances it sells. ROE, on the other hand, always sees its revenue increase with a reserve price.

The revenue-maximizing price floor target is $p_G^{Krev} = (a_G - k) / \left(z_G + z_R\right)$, which is declining in the allowances available to withhold. Using our functional forms, we solve for this price and find the revenue-maximizing price is half of the maximum price: $p_G^{Krev} = p_G^{K\max} / 2$. The corresponding allowances withheld, however, are less than half of those available for auction: $k^{Krev} = (a_G - \left(b_G z_G + b_G z_R - A\right)) / 2$. The revenue maximizing floor price need not be above p_0.

Figure 3: ETS market with unilateral reserve price in *G*



Welfare for the group in this case is

$$W_G = S_G + p_G f_G + \gamma p_G \left(a_G - A + E_G + E_R\right) - \delta\left(E_G + \beta E_R\right)$$

Maximizing with respect to the reserve price,

$$\frac{\partial W_G}{\partial p_G} = \underbrace{f_G - E_G}_{\text{incremental private rent net of costs}} + \underbrace{\gamma\left(E_G + E_{ROE} - A + a_G + \frac{\partial E_G}{\partial p_G} p_G + \frac{\partial E_R}{\partial p} p_G\right)}_{\text{marginal revenue}} - \underbrace{\delta\left(\frac{\partial E_G}{\partial p_G} + \beta \frac{\partial E_R}{\partial p}\right)}_{\text{marginal damages}}$$

Setting equal to zero and solving for the strategically optimal reserve price,

$$p_G = \underbrace{\frac{\delta}{\gamma}\left(\frac{z_G + \beta z_{ROE}}{z_G + z_{ROE}}\right)}_{\text{marginal damage to coalition}} + \underbrace{\frac{(\gamma - 1)}{\gamma}\left(\frac{E_G - f_G}{z_G + z_R}\right)}_{\text{importance of revenues versus net compliance costs}} + \underbrace{\frac{E_R - A_R}{z_G + z_R}}_{\text{terms of trade (net exports to ROE)}}$$

The first term is the perceived (relative to revenue) marginal damages of emissions. Second, if the MCPF exceeds one—and the domestic firms have a net permit liability—there is some added incentive to raise the price and thus revenue. Third, terms-of-trade effects also matter: G would like to further raise the reserve price to the extent that it will export allowances to ROE. Or, as before, to the extent that it imports allowances from ROE (which becomes more likely the more allowances it needs to cancel to maintain the price), it would like to depress the common allowance price.

Using our functional form expressions, the coalition's optimal price becomes

$$p_G^{Kill} = \frac{\delta(z_G + \beta z_R) + \gamma\left(b_G z_G + b_R z_R - (A - \alpha A_G)\right) - (b_G z_G - (1-\alpha) A_G)}{2\gamma(z_G + z_R) - z_G}$$

2.3. BILL: Supplemental compliance requirement

Another option would be to require local covered entities to retire more allowances for their compliance; i.e., if the desired domestic floor price is p_G, but market prices are p, resident covered entities would have to surrender $\phi = p_G / p$ allowances for their emissions.[3] Compliance ratios do have some precedent: requiring compliance at a ratio other than 1:1 was part of the Clean Air Interstate Rule in the US.

A supplemental compliance requirement has the effect of *increasing* demand for allowances, and thus pushing up the ETS price. This price increase is enjoyed by all allowance holders, so governments in both regions benefit in proportion to their holdings. The compliance requirement is equivalent to the coalition imposing a tax differential and earmarking the revenues to purchase and retire allowances.

For the cap to clear with the additional compliance requirement in g, we need $(p_G / p)E_G + E_R = A.$ Thus,

[3] Karp and Traeger (2017) propose a variation of a system-wide "smart cap" to address uncertainty; here we consider a regional version to address system-wide overallocation.

$$p = p_G E_G / (A - E_R)$$

Totally differentiating, we get $dp = dp_G \frac{E_G}{(A-E_R)} + dp_G \frac{\partial E_G}{\partial p_G} \frac{p_G}{(A-E_R)} - dp \frac{\partial E_R}{\partial p} \frac{p_G E_G}{(A-E_R)^2}$, so in its general form,

$$\frac{dp}{dp_G} = \frac{E_G + p_G \frac{\partial E_G}{\partial p_G}}{(A-E_R) + p_G \frac{\partial E_R}{\partial p} \frac{E_G}{(A-E_R)}}$$

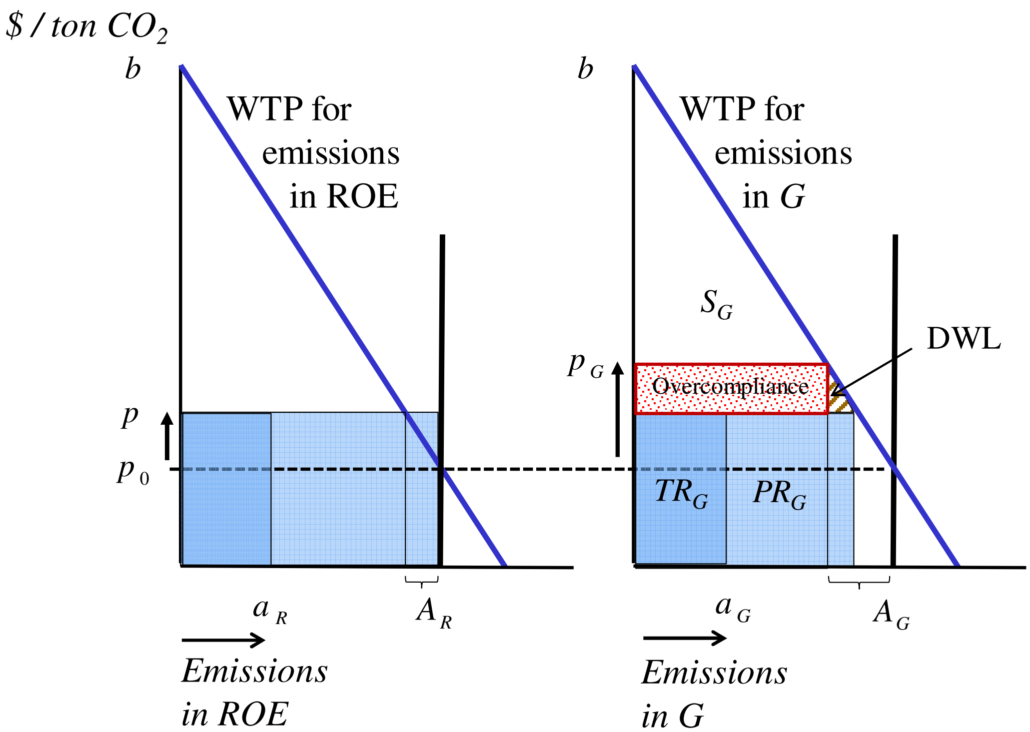
We assume that p_0 is low enough so that $dp / dp_G > 0$ at least initially. (It is simple to see that if we evaluate this expression at the point where the cap is just nonbinding, so $p_G = p_0 = 0$, the $dp / dp_G > 0$ necessarily.) More specifically, we assume $p_0 << \min\left[E_G^0 / z_G, E_G^0 / z_R\right]$, since at $p_G = p_0$, $A - E_R = E_G$. With linear WTP, this means $p_0 << b_G / 2 \cdot \min\left[1, z_G / z_R\right]$. In other words, the overcompliance requirement raises equilibrium allowance prices as long as the effective price in *G* does not exceed half of its choke price. (Above that price, the emissions base in the subgroup is shrinking faster than the additional compliance requirement increases, resulting in a net loosening of the cap.)

Using our functional forms, $p = \frac{b_R z_R - A + \sqrt{(A - b_R z_R)^2 + 4 p_G E_G z_R}}{2 z_R}$ and

$$\frac{\partial p}{\partial p_G} = \frac{(b_G - 2 p_G) z_G}{\sqrt{(A - b_R z_R)^2 + 4 p_G E_G z_R}}.$$

Figure 4 illustrates the effect on the ETS market of the overcompliance requirement. Coalition revenues are $p a_G$. Both the subgroup government, its private allowance holders, and ROE unambiguously gain auction revenues, since the price is higher and they can sell all of their allowances (see the shaded rectangles). However, this comes at higher costs for *G*'s industry, as it must make additional payments, as seen in the red boxes. In addition, this option entails an efficiency cost, due to the divergence in marginal abatement costs.

Figure 4: ETS market with unilateral overcompliance requirement in *G*



Coalition welfare with supplemental compliance is (recalling that $f_G = A_G - a_G$):

$$W_G = S_G + pA_G + (\gamma - 1)pa_G - \delta\big((b_G - p_G)z_G + \beta(b_R - p)z_R\big)$$

Maximizing subgroup welfare with respect to the domestic price (meaning a compliance ratio of p_G / p),

$$\frac{\partial W_G}{\partial p_G} = \underbrace{-E_G}_{\substack{\text{incremental}\\\text{domestic}\\\text{cost}}} + \underbrace{\frac{\partial p}{\partial p_G}\big(A_G + (\gamma - 1)a_G\big)}_{\substack{\text{incremental}\\\text{rents}}} + \underbrace{\delta\left(z_G + \frac{\partial p}{\partial p_G}\beta z_R)\right)}_{\text{incremental abatement}}$$

In this case, solving for the optimal p_G must be done numerically.

2.4. Comparing options

From the preceding analysis, we can compare the incentives of unilateral interventions. Table 1 summarizes the effects on the primary components of welfare. All options of course raise CO_2 prices and lower domestic emissions within the coalition. The terms of trade effects depend on the response of allowance prices in ROE and whether the coalition is a net exporter of allowances. Lower emissions are always better, but shifting emissions can also have welfare impacts if $\beta \neq 1$. The revenue impacts for the coalition are ambiguous for KILL, but otherwise (within bounds) are unambiguous.

Table 1: Summary of impacts for alternative unilateral pricing options

	CO_2 price / Compliance cost		**Emissions**		**Revenues**	
	Coalition	ROE	Coalition	ROE	Coalition	ROE
TAX	↑	↓	↓	↑	↑ (*)	↓
KILL	↑	↑	↓	↓	↓↑	↑
BILL (**)	↑	↑	↓	↓	↑	↑
* Up to $p_G = p_G^{T\max}$ ** Up to $p_G = b_G / 2$						

We can make some clear rankings for some of the outcomes:

Proposition 1: *For the same domestic carbon price, meaning coalition emissions are held constant across the options, then* $p^{Kill} > p^{Bill} > p_0 > p^{Tax}$ *and* $E_{ROE}^{Kill} < E_{ROE}^{Bill} < E_{ROE}^{0} < E_{ROE}^{Tax}$.

Proof: The emissions result falls out of the noncoalition carbon prices, and total emissions rankings will thus be the same. By the assumption, all coalition firms face the price

p_G. Under KILL, p_G also applies to noncoalition firms; under BILL, noncoalition firms face a lower price than the coalition, but higher than without the intervention $(p^0 < p < p_G)$; meanwhile, the TAX policy drives down allowance prices $(p < p^0)$.

It follows that to achieve the same net emissions, the coalition must seek a higher domestic allowance price with BILL than with KILL, since ROE will be doing less $(p^{Bill} < p_G^{Kill} < p_G^{Bill})$. The TAX option cannot achieve lower emissions unless the ETS price is driven to zero, so ROE does no abatement while coalition firms do more than the total abatement implied by the cap. □

Proposition 2: *For the same domestic carbon price, if the coalition's emissions exceed its auction allocation, then* $TR_G^{Tax} > TR_G^{Bill} > TR_G^{Kill}$.

Proof: If $E_G - a_G \geq 0$, then $TR_G^{tax} = p_G a_G + (p_G - p)(E_G - a_G) \geq p_G a_G > \frac{p_G}{\phi} a_G = TR_G^{bill}$. Furthermore, $TR_G^{bill} > TR_G^{kill}$ if $(a_G - k) < a_G / \phi$ or $(\phi - 1)a_G < \phi k$, which we see is true since $(\phi - 1)a_G < (\phi - 1)E_G^{Bill} < k < \phi k$. The first step results from the auction allocation assumption; the second step reflects that the number of allowances withdrawn from overcompliance is less than those withdrawn under the unilateral carbon price, following emissions in Proposition 1; the third step notes that $\phi > 1$. □

That the coalition's auction allocation is not greater than its emissions is a sufficient but not necessary condition for this ranking to hold. Of course, which policy the coalition will prefer depends on how they weight the different outcomes.

3. Numerical analysis

3.1. Model

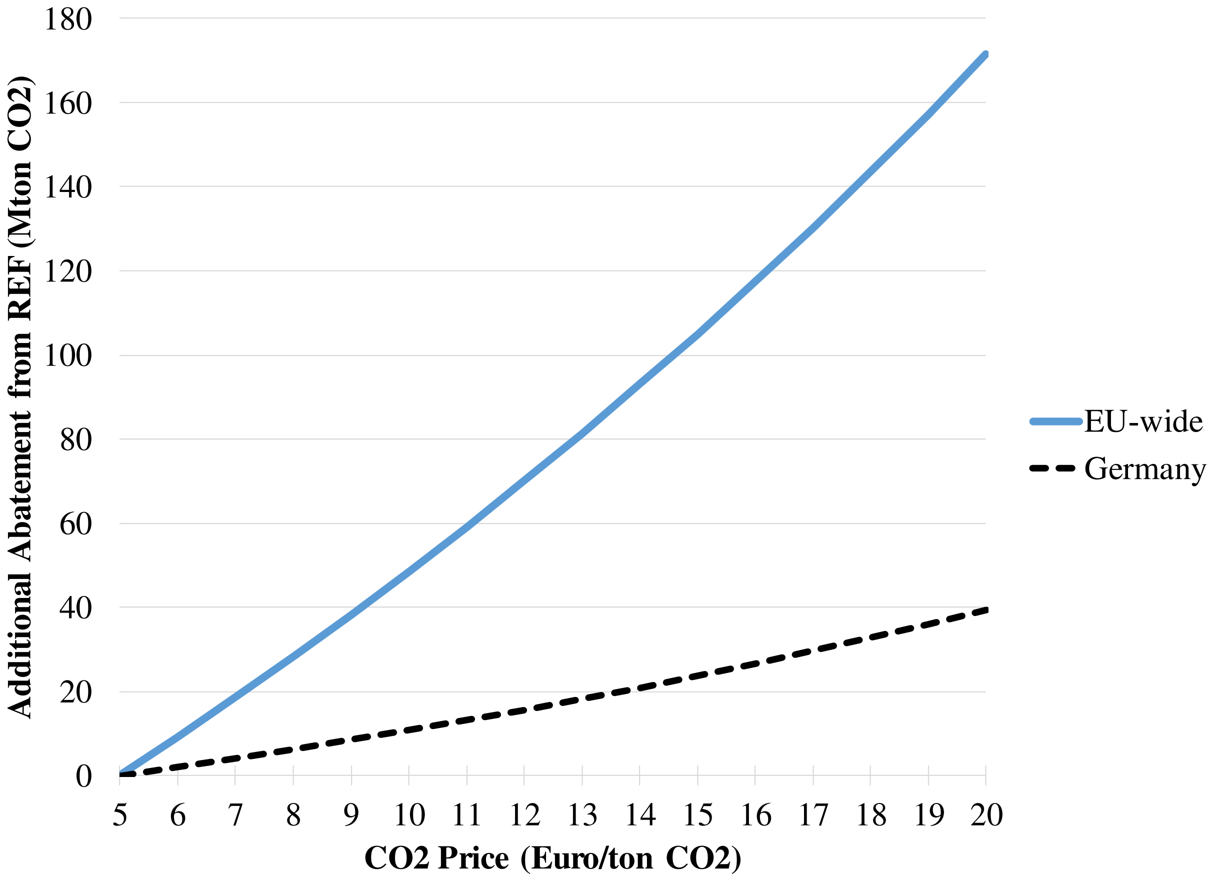
We use a simple numerical partial equilibrium model of the EU-ETS carbon market (see Böhringer et al. 2008 or Böhringer et al. 2014) which we expend for the logic of alternative unilateral pricing options. The core model is based on region- and sector-specific marginal abatement cost (MAC) curves calibrated to empirical data. Marginal costs of emissions abatement may vary considerably across countries and sectors due to differences in carbon intensity, initial energy price levels, or the ease of carbon substitution possibilities.

To obtain explicit (reduced-form) representations of marginal abatement cost curves we draw on simulations with an established large-scale multi-sector multi-region computable general equilibrium (CGE) model of global trade and energy use (see e.g. Böhringer et al. 2015) based on recent data by the Global Trade Analysis Project (GTAP 9 – Aguiar et al. 2016). The model explicitly features all EU MS as well as the sectors covered by the EU ETS. To generate the marginal abatement cost curves by sectors and regions, we run a sequence of CGE simulations with hypothetical sector- and region-specific CO_2 taxes starting from \$0 to \$100 per ton of CO_2 in sufficiently small steps of \$1. The simulated endogenous emission reductions by sector and region then enter a least-square fit with a flexible polynomial of degree three matching continuous sector- and region-specific marginal abatement cost functions to the "observations" in CO_2 prices and CO_2 emission reductions.[4]

[4] Note that the "observations" are generated by the CGE model where we describe production technologies in industries via nested separable constant-elasticity-of-substitution (CES) cost functions which capture substitution possibilities across different inputs. We adopt a standard KLEM nesting of capital inputs (K), labor inputs (L), inputs of a material composite (M), and an energy composite (E). The energy composite further splits into electricity and a CES composite of fossil fuels with fuel-specific CO_2 content. Emission abatement triggered by CO_2 pricing thus takes place by (i) fuel switching, (ii) substitution between energy and other inputs (emission efficiency improvements) and (iii) output adjustments (energy/emission savings). All these abatement options are then implicitly entering into the reduced-form MAC curves by sectors and regions.

Figure 5 depicts the MAC curves for EU ETS covered sectors as a whole – both for Germany as the largest single holder of allowances to be auctioned as well as for the EU in aggregate.

Figure 5: Additional abatement from raising CO_2 prices above the reference price



3.2. Policy scenarios

Initially, we calibrate the partial equilibrium (PE) model to a reference scenario (REF) with an EU-ETS price (*pets_ref*) of $10. In other words, we know that with emission trading all abatement across EU ETS sectors must be such that the shadow price on the ETS-wide abatement requirement equals the observed EU-ETS price. For our reference scenario, we therefore align emissions to the verified emissions that we get from official reports in 2011 and the emissions price to the ETS reference price in 2011 (*pets_ref*). We then can induce what we call the business-as-usual (BaU) case without ETS emission constraints by simply adding the PE model's estimated abatement at *pets_ref* to the 2011 verified emissions.[5]

From the REF starting point, we do our additional simulations of TAX, BILL, and KILL. We impose unilateral price constraints which go along with the same emissions as in REF for the case of TAX and lower emissions than REF for the cases of KILL (where we delete/ration ETS emission endowments of unilaterally acting regions) and BILL (where we have overcompliance of the ETS industries/sector in the unilaterally acting regions).

The key driver of all model results is the effective carbon price which is faced by the single ETS sector in a single region. Whether emission allowances are freely allocated (no conditional grandfathering) or auctioned does not matter for the simulation results; i.e., the Coase theorem applies. However, it will matter for the reporting of results in terms of revenues and private rents. In the PE setting we have no income effects or other macroeconomic feedbacks.

3.3. Results

In our central case simulations, we focus on Germany alone as a unilateral actor reflecting the fact that Germany stands out for the highest CO_2 emissions (and CO_2 emission allowances) in the EU and is an outspoken advocator of setting minimum carbon prices.

Figure 6 shows how the ETS allowance price changes as the coalition increases its domestic price. As demonstrated in the theory, for the same domestic price, KILL has the

[5] We assume here that the cutback requirement in each region is uniform and corresponds to the sum of the abatement consistent with reference allowance price *pets_ref* over the total EU-wide BaU emissions for all ETS sectors. Our REF scenario thus reflects a uniform reduction requirement across EU ETS sectors which with comprehensive emissions trading leads across ETS sectors to the observed emission allowance price *pets_ref*.

strongest upward effect; BILL has less than a one-to-one effect, and TAX has the waterbed effect of driving down prices for ROE.

Figure 6: Market price of allowances (\$/ton CO_2)

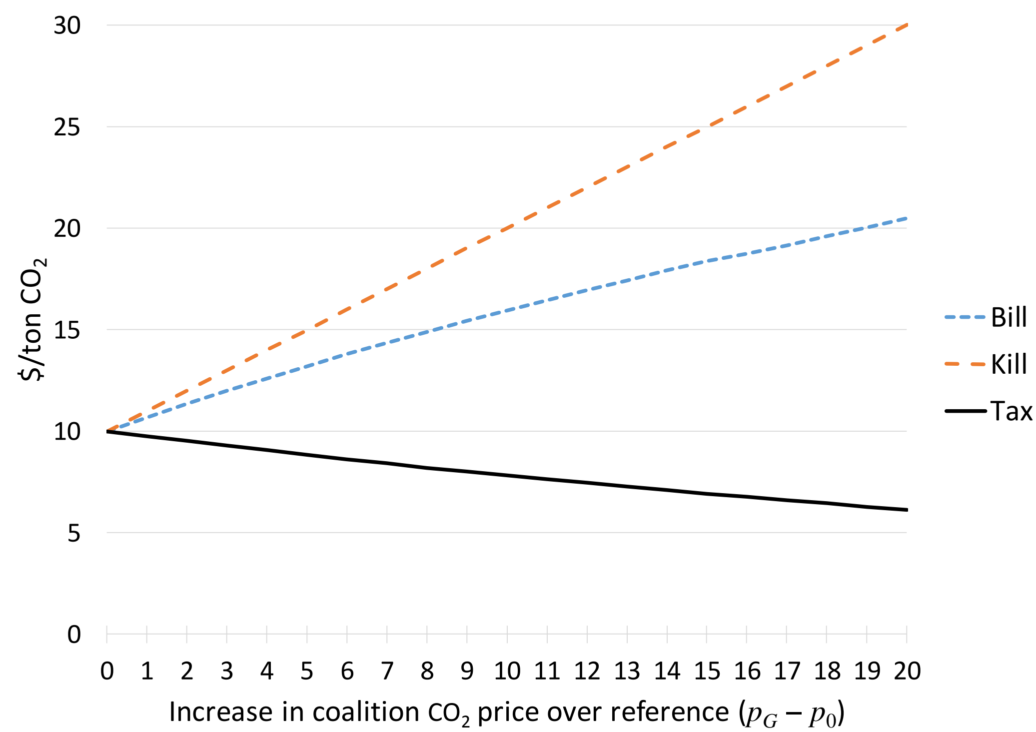


Figure 7 illustrates the effects of unilateral measures on the coalition's total revenue (in actuality, since we do not yet distinguish free allocation to firms, $TR_G + PV_G$). Following the theory, we see that TAX raises most revenues, then BILL, then KILL, which raises revenues initially but then declines.

Figure 7: Total revenues for the coalition ($millions)

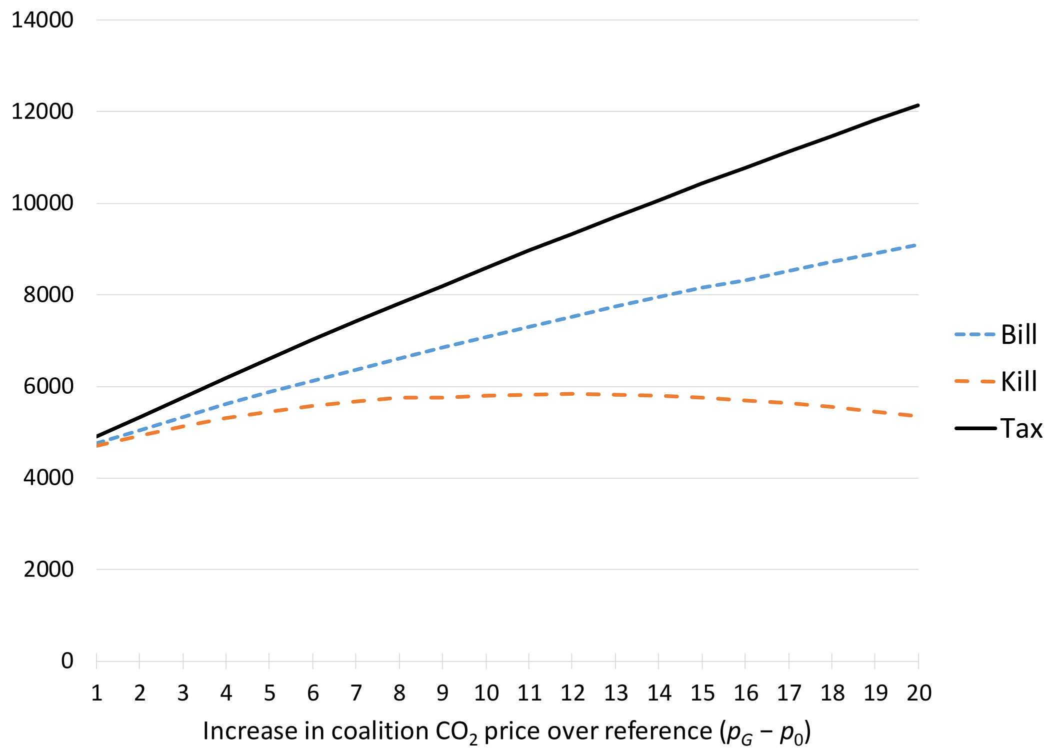
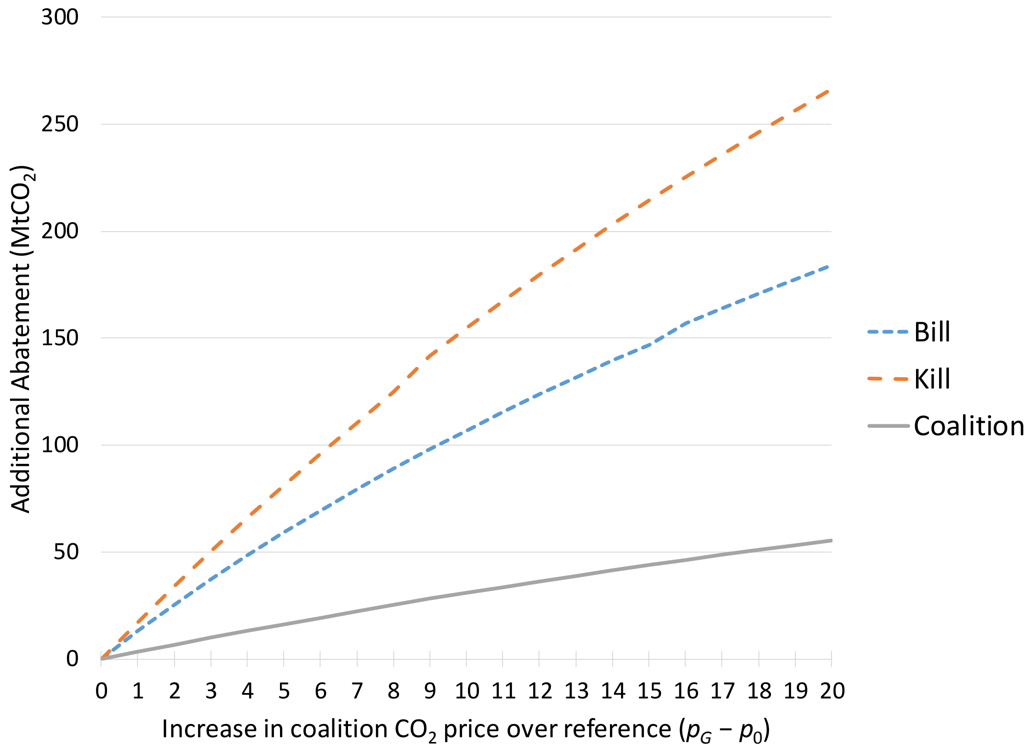


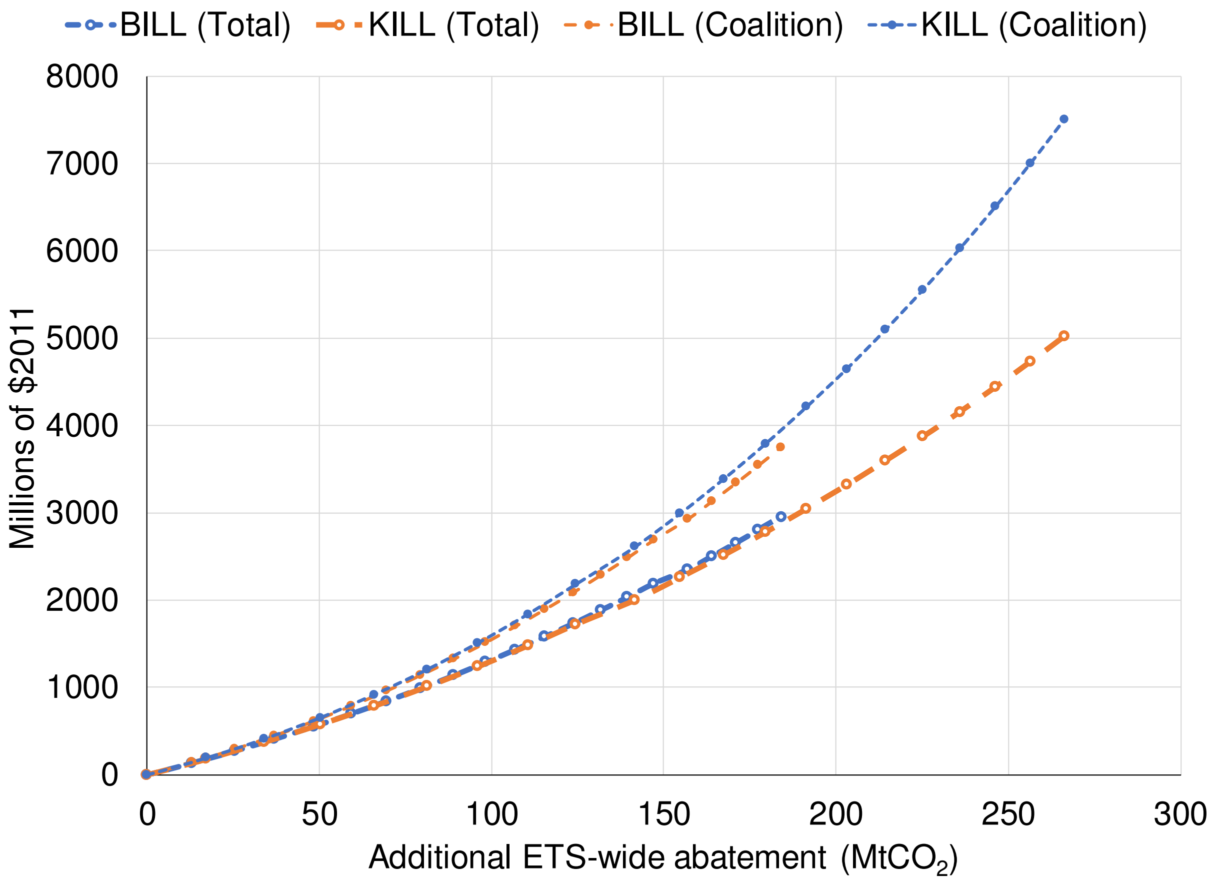
Figure 8 gives a sense of the scale of additional emissions abatement achieved by the different coalition policies. TAX has no effect, of course, but for the same domestic price increase, KILL results in more than a third more abatement than BILL.

Figure 8: Total ETS-wide and coalition abatement with unilateral coalition policies



However, when one considers the total social costs for this additional abatement, KILL and BILL are surprisingly similar. Figure 9 plots the ETS-wide social costs (change in gross surplus) and the coalition costs ($TS_G + TR_G$, equally weighted) against the additional abatement fostered by unilateral policies. KILL does have lower total social costs than BILL, but despite the DWL associated with the price differential, the total cost differences appear to be small. In contrast, the coalition has a slight preference for BILL, although the cost difference to the coalition is rather small too. Their cost burden is higher than the total, revealing that ROE tends to benefit from these policies (so the increase in their allowance values outweighs their additional compliance costs).

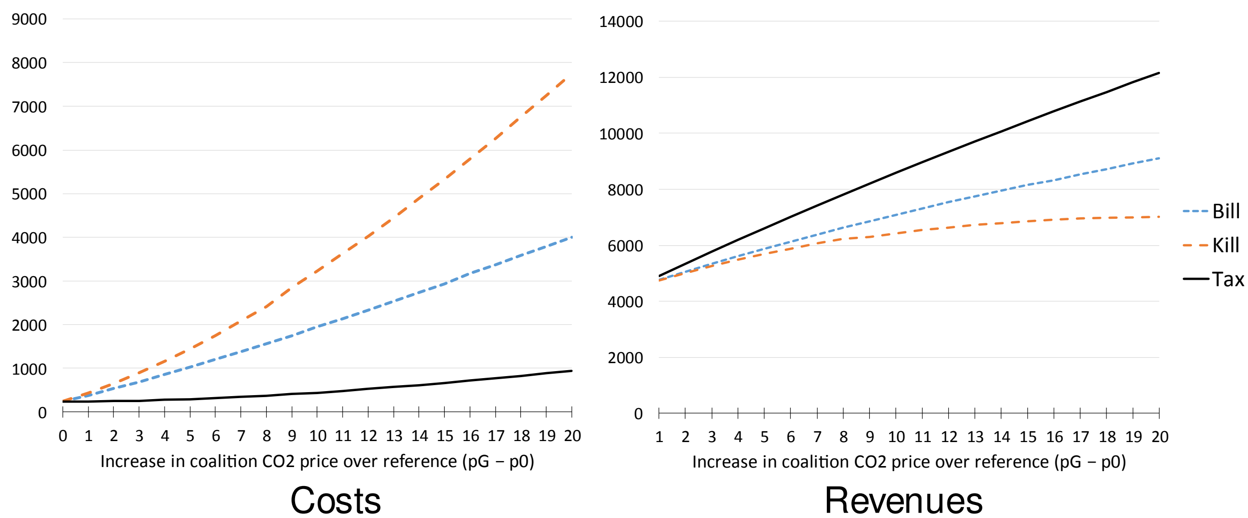
Figure 9: Total and coalition costs of additional system-wide abatement



In these figures, we have assumed that $\gamma = 1$, so no extra value is placed on revenues for public coffers. Furthermore, the division of allowance allocations between public auction and grandfathering to private actors does not matter. When we break out the different components of the welfare change, however, we see how the revenue component can easily change a region's preferences about which action to take.

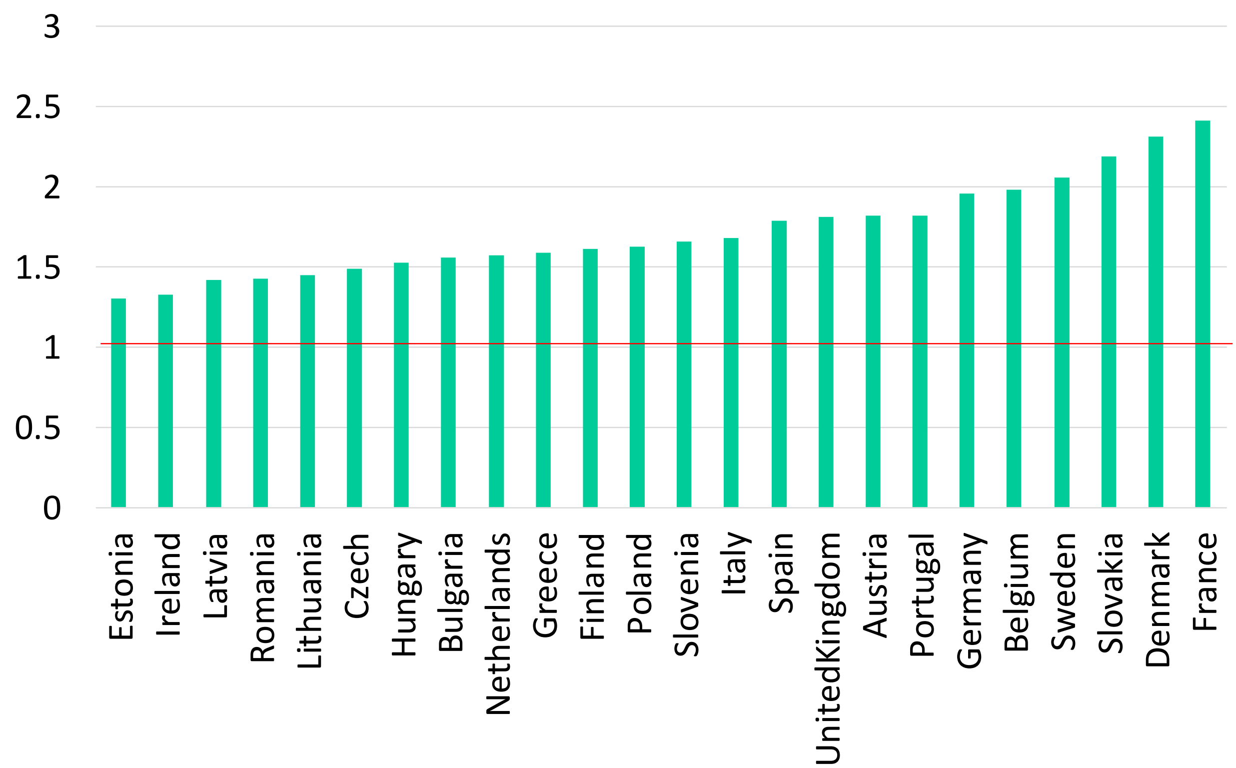
Error! Reference source not found. compares the scope of the compliance costs for the coalition (S_G) versus the total tax and allowance values ($TR_G + PV_G$). The latter are considerably larger for all options, with the exception of KILL after the revenue-maximizing allowance price is reached. Therefore, if even a fraction of the region's allocation is auctioned, a modest MCPF can make the BILL policy even more interesting than KILL, and the TAX policy even more preferred, given the ability to transfer rents from allowance values toward public revenues.

Figure 10: Coalition costs versus revenues ($millions)



As an indication of the potential extra value of revenues from an environmental tax, Barrios et al. (2013) estimate the marginal cost of public funds associated with labor taxes in the EU member states (Figure A12). All are above one, and the member states most seriously considering a floor price have relatively high opportunity costs of tax revenues.

Figure 11: Marginal cost of public funds from labor taxes in the EU (Source: Barrios et al. 2013)



4. Conclusion

In conclusion, we find that a domestic carbon floor price implemented as a TAX is only attractive if revenues and relocating—as opposed to not reducing—emissions is paramount. (An exception may be if the coalition is close to a grand coalition, in which case the tax could render the cap obsolete.) Still, the MCPF is large enough that taxing carbon may be a credible unilateral strategy, despite the waterbed effect, as the TAX policy is the most effective at raising revenue.

For actually reducing system-wide emissions with unilateral policies, KILL and BILL are quite close in cost-effectiveness. KILL generates a bit more abatement and BILL generates a bit more revenue for the coalition. As a consequence, despite some system-wide inefficiencies, BILL is likely to be preferred by a coalition acting unilaterally.

We are interested in several potential extensions of our model. First, the benefits from emission abatement including ancillary benefits from conventional pollutants, which vary by member state –would be interesting to include in a model of strategic unilateral floor price policies. Second, the interaction between unilateral policies and the market stability reserve (MSR) is an important question. The flip side of the possibility of excess allowances being cancelled is the possibility that emissions reductions (or unilaterally retired allowances) enable some future allowances that would otherwise be cancelled to remain in the system. To analyze this issue, a dynamic model would be needed. Finally, an important motivation for minimum prices is creating adequate incentives for investment and technological innovation. To the extent that such innovation creates spillovers in terms of the MAC and policy incentives of other member states, the EU-wide and domestic benefits of unilateral action can be quite different and influence current strategies.

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