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Addressing leakage in the EU ETS: results from the CASE II model

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Abstract

The European Union Emission Trading System (EU ETS) covers CO₂ emissions from electricity generation and heavy industry. Industry representative criticise it on the ground that it would create a competitive disadvantage for European manufacturers and increase emissions abroad, which is called carbon leakage. Several options have been proposed to tackle carbon leakage. To assess these proposals, we build a partial equilibrium model focusing on the main sectors affected by the EU ETS: cement, aluminium, steel and electricity. We analyse eight policy scenarios with various provisions aimed at tackling leakage, and compare them to a scenario with full auctioning of allowances and no anti-leakage provision. We conclude that the most efficient way to tackle leakage is auctioning with border adjustment, which even induces a negative leakage (a spillover). Another relatively efficient policy is to combine auctioning in the electricity sector and free allocation of allowances proportional to current production in the exposed industry, especially if free allowances are given both for direct emissions and for indirect emissions, i.e. emissions generated by the electricity consumed.

Keywords:

Emission trading, border adjustment, output-based allocation, competitiveness, leakage

1. Introduction¹

The fears of competitiveness losses and of carbon leakage are the main arguments put forward by industry lobby groups against stringent climate policies, and in favour of free allocation of allowances. Competitiveness and leakage are also the motivations of border adjustments proposals. In the US, these issues are among the most debated in the preparation of the forthcoming national ETS (Houser et al., 2008). In the EU, they have been the dominant driver in the changes made to the European Commission climate-energy package by the Council and Parliament in December 2008.

As a part of this package, the Council and Parliament adopted a revision of the European Union Emissions Trading System (EU ETS). Changes will take place during the 3rd period of the ETS, i.e. from 2013 onward. They include a higher share of auctioning, especially in the electricity sector. To limit the impact of the directive on industrial competitiveness and carbon leakage, most industrial sectors will get allowances for free. However, the degree to which free allocation will be conditional to continued production is not completely defined yet. Some electricity-intensive industries may also be compensated for the rise in power price entailed by the ETS, although the modalities of such compensation are not defined either. Also, the prospect of a border adjustment is not abandoned, at least for imports.

Hence, in spite of the December 2008 decisions, the debate on the competitiveness impact of the EU ETS and of the most adequate policies to reduce this impact (if any) is not politically over. Neither is it over from an academic point of view: there is disagreement among researchers both on the quantitative importance of leakage (Gerlagh and Kuik, 2007) and on the effectiveness of the policy instruments proposed to limit leakage and competitiveness impacts (Graichen et al., 2008).

In this report, we provide a quantitative assessment of several "anti-leakage" policy options, compared to a scenario without a climate policy, and to a scenario featuring auctioned allowances, without any specific "anti-leakage" feature. The "anti-leakage" policy options are several variants of border adjustments and of free allowances allocation. The rest of the report is organised as follows: we first present the scenarios (section 2), then the model (section 3) and the results (section 4) before concluding (section 5).

2. Scenarios

We analyse nine climate policy scenarios and compare them to a no-policy ("business-as-usual") scenario. None of the policy scenarios aims to represent the actual choices made in

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December 2008 by the Council, since these choices are too complex (and still too imprecise) to be modelled. Rather, the scenarios aim to compare contrasted policy options that have been proposed by some researchers and/or stakeholders.

2.1. Common features across climate policy scenarios

We present results for the mid-term of the third period of the EU ETS, i.e., 2016. All scenarios assume a cap at 85% of 2005 emissions, following the decision made in December 2008 by the Council and the Parliament (cf. Table 1 and European Commission, 2008).

Table 1. Emission cap

Period	year	EU ETS cap (adjusted to perimeter changes)	% of 2005 emissions
1 st	2005	2.177	100%
	2006	2.177	100%
	2007	2.177	100%
2 nd	2008	2.083	95.7%
	2009	2.083	95.7%
	2010	2.083	95.7%
	2011	2.083	95.7%
	2012	2.083	95.7%
3 rd	2013	1.974	90.7%
	2014	1.937	89.0%
	2015	1.901	87.3%
	2016	1.865	85.7%
	2017	1.829	84.0%
	2018	1.792	82.3%
	2019	1.756	80.7%
	2020	1.720	79.0%

Source: European Commission (2008).

Another point shared by the scenarios is that we assume that no other country implements a climate policy. Whilst unrealistic, especially since the election of Barack Obama, this assumption allows assessing the consequences of the EU ETS in the worst case scenario of future climate change negotiations. It is also consistent with the emission target modelled: in case of a satisfying international climate policy agreement, the EU target will be strengthened at -30% instead of -20% in 2020.

A last common feature across the scenarios is that we do not account for the Kyoto mechanisms, i.e. CDM and JI, because the amount of CDM and JI projects available to EU firms after 2012 is very uncertain. However the reader should keep in mind that by doing so we overestimate the CO₂ price hence the competitiveness impact of the ETS.

2.2. Differences across climate policy scenarios

The nine policy scenarios are as follows:

1. *AUCTION*: 100% auctioning of allowances, without border adjustment. Note that a pure lump-sum free allocation would lead to the same results under standard assumptions, except on revenue distribution²; hence the reader interested in the impact of pure lump-sum free allocation is invited to look at the results for the *Auction* scenario.
2. 100% auctioning, with border adjustment. We distinguish five variants.
 - i. *BA full*: border adjustment on both exports and imports. In every sector, the export adjustment is proportional to the EU average unitary emissions (direct and indirect, i.e. emissions due to the production of electricity used in this sector) while the import adjustment is proportional to the Rest of the World (RoW) average unitary emissions (again, direct and indirect). The next four scenarios represent various weaker forms of border adjustments, which are less efficient to prevent leakage but may be chosen nevertheless, in order to improve the likelihood of WTO acceptance or because they might be more easily accepted by other countries, hence threatening less the international negotiations on climate change.
 - ii. *BA import*: same as *BA full* but without the export adjustment.
 - iii. *BA direct*: same as *BA full* but only for direct emissions, not indirect.
 - iv. *BA EU average*: same as *BA full* but the import adjustment is proportional to the EU average emissions.
 - v. *BA import direct*: same as *BA full* but without the export adjustment and only for direct emissions, not indirect.
3. Output-based scenarios: allowances are distributed for free in proportion of current production. This requires an update of the allocation when production is known, i.e. in year $n+1$. Note that the actual allocation method of free allowances in the EU ETS is not based on output but on production capacity (European Union, 2008). Hence it can be seen as intermediate between the pure lump-sum and the output-based allocation method. We distinguish three variants.
 - i. *OB full*: output-based allocation in all sectors. In every sector, the amount of allowances allocated per unit produced is computed by applying a reduction ratio to the 2005 unitary emissions. The reduction ratio is equal across sectors and computed so that the emission cap is 85% of 2005 emissions, as in every climate policy scenario. Note that since we apply the same reduction ratio to several sectors that differ by their abatement cost, the sectors with the cheapest abatement opportunities will typically sell some allowances to the sectors with the most costly abatement.

² A caveat is that under lump-sum free allocation, the electricity generators on regulated markets would not pass the opportunity cost of allowances on to consumers (Burtraw et al., 2002).

- ii. *OB exposed direct*: auctioning in electricity, output-based allocation in exposed industries (cement and steel) for direct emissions. The amount auctioned is 85% of the electricity sector 2005 emissions. In every other sector, the amount of allowances allocated per unit produced is computed by applying a reduction ratio to the 2005 unitary emissions. Again, the reduction ratio is equal across sectors and computed so that the emission cap is 85% of 2005 emissions, as in every climate policy scenario.
- iii. *OB exp. dir.&ind.*: auctioning in electricity, output-based allocation in exposed industries for direct *and indirect* emissions. The amount auctioned is 85% of the electricity sector 2005 emissions *minus indirect emissions by cement, steel and aluminium*. In every other sector, the amount of allowances allocated per unit produced is computed by applying a reduction ratio to the 2005 unitary emissions. Again, the reduction ratio is equal across sectors and computed so that the emission cap is 85% of 2005 emissions, as in every climate policy scenario.

3. The CASE II model

CASE II is an evolution of the CASE model (Demailly and Quirion, 2008). It is a static and partial equilibrium model, which represents four sectors: electricity, steel, aluminium and cement. Direct emissions from the aluminium sector are currently not represented. The three EU ETS sectors modelled in CASE represent around 75% of the emissions covered by the system (Kettner et al., 2007).

3.1. Utility and demand

The model comprises two regions: the European Union (EU) and the rest of the world (RoW).

In each region $r = \{eu, row\}$, we assume an exogenous but growing GDP Y_r .

We make industry level expenditures exogenous by assuming a Cobb-Douglas upper level utility function, giving rise to fixed expenditures shares out of income. We suppose that the expenditures parameters stay constant between 2005 (year used to calibrate the model) and 2016 (year used for the simulations of the different climate policies). The upper tier of the utility function is then, for each region r :

$$U_r = \prod_{i=\{c,a,s,e,z\}} (u_r^i)^{\alpha_r^i} \quad (1)$$

Where α_r^i is the expenditure share of industry i in region r . We thus have:

$$\sum_{i=\{c,a,s,e,z\}} \alpha_r^i = 1$$

The indexes c , a , s , e and z represent, respectively, cement, aluminium, steel, electricity and a composite good, chosen as the numéraire. Expenditures in region r in goods produced by industry i are then $\alpha_r^i \cdot Y_r$.

For the industries c , a and s , the sub-utility u_r^i is a constant elasticity substitution (CES) aggregate of the two varieties: the domestic variety and the foreign variety.

In turning to the lower-tier choice between varieties in each industry, we will omit the subscripts i and r from now on and examine expenditures allocation in a representative industry consisting of a domestic variety and a foreign variety. Individuals can have different preferences over varieties depending on their place of production, as in Armington's (1969) model, allowing in particular for home bias. This preference parameter of consumers for the domestic variety is denoted $pref_d$ while the preference parameter for the imported variety is denoted $pref_f$. The sub-utility function is then:

$$u = \left((pref_d \cdot Q_d)^{(\sigma-1)/\sigma} + (pref_f \cdot Q_f)^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)} \quad (2)$$

Where σ is the elasticity of substitution.

Maximising this sub-utility function subject to expenditures and the delivered prices from the two possible product origins, we obtain the demand curves:

$$Q_d = \alpha \cdot Y \frac{(pref_d)^{\sigma-1} \cdot (p_d)^{-\sigma}}{(pref_d)^{\sigma-1} \cdot (p_d)^{1-\sigma} + (pref_f)^{\sigma-1} \cdot (p_f)^{1-\sigma}} \quad (3)$$

$$Q_f = \alpha \cdot Y \frac{(pref_f)^{\sigma-1} \cdot (p_f)^{-\sigma}}{(pref_d)^{\sigma-1} \cdot (p_d)^{1-\sigma} + (pref_f)^{\sigma-1} \cdot (p_f)^{1-\sigma}} \quad (4)$$

where p_d and p_f are the prices of the domestic and of the foreign variety, respectively.

For electricity, demand is the sum of the demand from the other three sectors modelled and of a fixed expenditures share out of income $\alpha_r^e \cdot Y_r$ for region r .

3.2. Supply and emissions

The CES specification of the representative consumer's utility has mostly been used in perfect competition models or in monopolistic competition models following Dixit and Stiglitz (1977) and Krugman (1980) where firms are not strategic. In our paper we assume a CES utility function and use them in an oligopoly model where firms are strategic. This setting is more relevant for the industries analysed.

In the steel, cement and aluminium sectors, the number of firms is n_r^i where $r = \{eu, row\}$ and $i = \{c, s, a\}$.

We assume that production costs per tonne are exogenous (for a given CO₂ price) and that the costs of production (marginal and fixed) differ across regions. Trade between the regions entails a constant per-unit transportation cost.

The profit function of a firm localised in region the EU can be defined as:

$$\pi = (p_d - mc) \cdot q_d + (p_f - mc - tc_{eu \rightarrow row}) \cdot q_f - FC \quad (5)$$

Where p_d is the price of the EU variety in the EU, p_f the consumer price of the EU variety in ROW, mc the marginal production cost, q_d the volume sold in the domestic market, q_f the volume exported, $tc_{eu \rightarrow row}$ the transportation cost and FC the fixed cost.

At the equilibrium, all firms from the same region being symmetric, we have $Q_r = n_r \cdot q_r$.

Each firm sets its prices to maximise its profit, under Cournot competition with the firms of the same region and of the other region. To determine the number of firms in each region, we assume that free-entry sets profits equal to zero in both regions.

In the steel, cement and aluminium sectors, the marginal cost is defined as follows:

$$mc = uac + P_{CO_2} \cdot (ue - ob) + P_{el} \cdot ec + oc \quad (6)$$

Where

$$uac = \int_0^{ua} (\beta_1 \cdot ua + \beta_2 \cdot ua^2) d ua \text{ is the unitary abatement cost, } ua \text{ the unitary abatement, } P_{CO_2}$$

the CO₂ price, ec the electricity consumption, P_{el} the electricity price for industry (increasing with P_{CO_2}), ue the unitary CO₂ emissions, ob the unitary allowance allocation (in the OB scenarios) and oc gathers the other costs, which are exogenous. We thus assume that the abatement cost increases the variable production cost, not the fixed production cost, which is exogenous.

Unitary abatement is determined by the equalisation of P_{CO_2} with the marginal abatement cost, assumed linear-quadratic:

$$P_{CO_2} = \beta_1 \cdot ua + \beta_2 \cdot ua^2$$

In each sector, the marginal abatement cost curve is fitted to the results of the PRIMES model (Blok et al., 2001).

In the cement sector, we take into account that the substitution between clinker (the CO₂-intensive intermediate product) and CO₂-free substitutes (e.g. fly ashes or blast furnace slag) as well as the substitution between domestic and imported clinker. The market share of imported clinker in the EU and the clinker ratio (the share of clinker in cement) are modelled through nested logit functions³:

$$Sck_{eu} = \frac{(Cck_{eu})^{-\eta^2}}{(Cck_{eu})^{-\eta^2} + (Cck_{row})^{-\eta^2}}$$

³ Such functions are used in hybrid energy-economy models such as CIMS (Murphy et al., 2007) and IMCALIM-R (Crassous et al., 2006).

$$Sck = \frac{(Cck)^{-\eta_1}}{(Cck)^{-\eta_1} + (Csub)^{-\eta_1}}$$

Where $Cck = Sck_{eu} \cdot Cck_{eu} + (1 - Sck_{eu}) Cck_{row}$

Cck and $Csub$ represent, respectively, the cost of using clinker and of using GHG-free substitutes (flying ashes, blast furnace slag...) in cement production; Cck_{eu} and Cck_{row} represent, respectively, the cost of using domestic and imported clinker to produce cement in the EU; and η_1 and η_2 are positive parameters representing the responsiveness of Sck and Sck_{eu} to the changes in relative costs.

The logit functional form conserves the mass, which is a great advantage over a CES function since we want to represent physical quantities of cement and of CO₂ emissions. In the logit function representing the choice between imported and domestic clinker, the parameters are calibrated to represent the 2006 situation and to fit the GEO-CEMSIM model, a detailed geographic model of the world cement industry featuring transportation costs and capacity constraints (Demailly and Quirion, 2006).

In the logit function representing the choice between clinker (either imported or domestic) and substitutes, the parameters are calibrated to represent the share of substitutes in cement in 2006 (23%) and an assumption that a doubling of the clinker cost, other things equal, would entail a doubling of the share of substitutes in cement.

The aluminium sector only covers primary aluminium, international trade occurring mainly at this stage of transformation. We do not consider secondary aluminium, i.e. recycled aluminium, which is around ten times less energy and GHG intensive and whose market is mainly influenced by the scrap availability issue. Moreover our model does not cover Iceland and Norway, which will be covered by the ETS and account for almost half the aluminium exports to the EU (Reinaud, 2008).

For the steel sector, we aggregate long and flat products and the two production routes (basic oxygen furnace and electric arc furnace). We represent semi-finished products (e.g. slabs), because they feature higher CO₂/turnover and CO₂/value added ratios than finished products hence carbon leakage is more likely to happen at this stage of the production process. Besides, sector experts agree on the fact that the flat semi-finished products, for which differentiation is a less important issue and whose production cost differ widely across countries, may be more subjected to relocation than downstream production activities (Hourcade et al., 2007).

In the model, all sectors are first linked through the electricity market. We do not take into account the fact that some industrials produce their own electricity or the role of long-term power supply contracts. Moreover, we do not consider electricity savings in the sector modelled following the rise in the power price. The cement sector consumes electricity both at the stage of clinker production and at the stage of cement grinding.

The steel, cement and electricity sectors are also linked through the CO₂ market. The CO₂ price clears the market: thanks to unitary abatement and production drop, the sum of the

emissions from these sectors equals the total amount of allowances given for free or auctioned.

The steel, aluminium and cement sectors are linked to the rest of the world through product competition. There is an international trade in both cement and clinker.

We do not model emissions in the rest of the ETS or emissions outside the ETS. These emissions could differ across our scenarios, due to some indirect effects (e.g. substitution between electricity and gas in building heating), although this is likely to be limited.

3.3. Data sources

Data on production, consumption prices and international trade are from Eurostat, except for cement and clinker (Cembureau) and steel (Eurofer).

Data on CO₂ emissions are taken from the CITL (Trotignon and Delbosc, 2008), for electricity, from the Cement Sustainability Initiative "Getting the Numbers Right" database for clinker, and from the UNFCCC for steel.

Data on electricity consumption are from the Cement Sustainability Initiative "Getting the Numbers Right" database for clinker and cement, and from the IEA energy balances for steel.

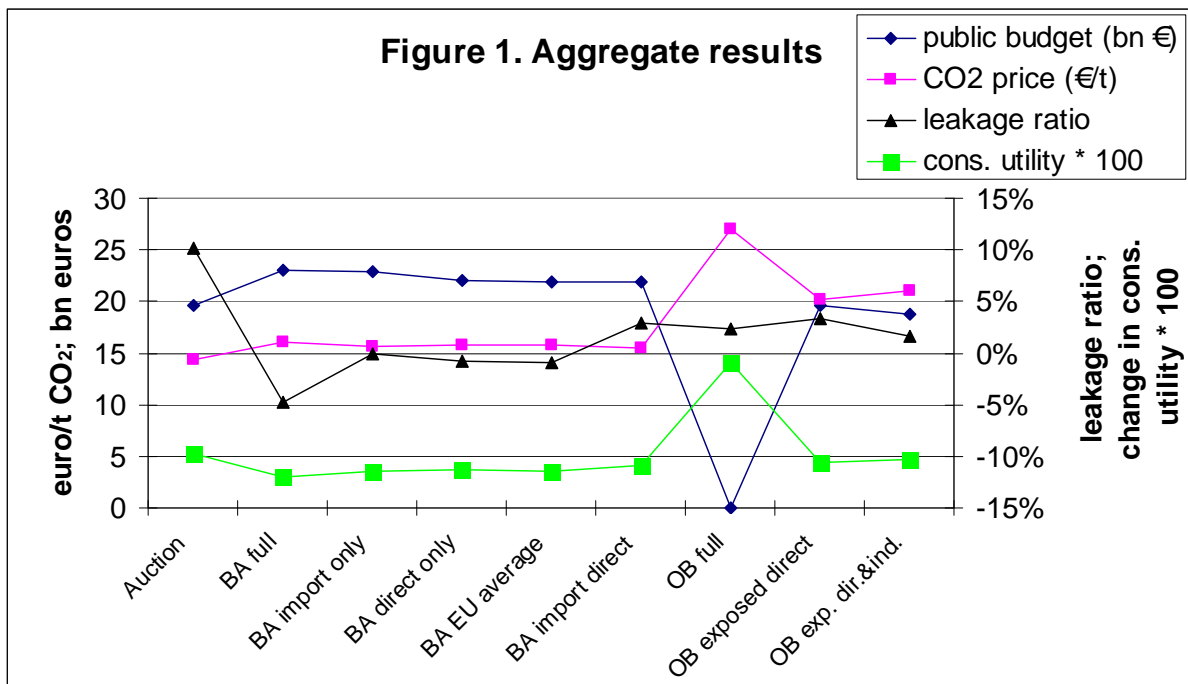
The GDP growth is taken from the IEA (2007) World Energy Outlook: 2.3%/yr in the EU for 2005-2015, then 1.8%; 4.2%/yr in the ROW for 2005-2015, then 3.3%.

Armington elasticities and price elasticities of demand are taken from Demailly and Quirion (2008).

4. Results

Results are reported for the year 2016, i.e. around the mid-term of the 3rd phase of the EU ETS.

Figure 1 presents the main results aggregated across the sectors covered by the model.



The CO₂ price is the lowest under *Auction* (14 €/t) and the highest under *OB full* (27 €/t). The explanation is straightforward: free allowances under *OB full* constitute a subsidy to the production of CO₂-intensive goods, so to get the same aggregate emissions under *OB full* as under *Auction*, lower CO₂ emissions per unit produced are required, which implies a higher CO₂ price (cf. e.g. Fischer, 2001). The CO₂ price is at an intermediate level under *OB exposed direct* and *OB exp. dir.&ind.*, which is intuitive since these two scenarios are a combination of auctioning and output-based allocation. The CO₂ price is a bit higher under the BA scenarios than under *Auction*, because the border adjustment prevents (completely or partially) the substitution of foreign production to domestic production, which is a way of reducing CO₂ emissions in the EU. Hence a higher CO₂ price is needed to get lower unitary emissions, for the BA scenarios to comply with the emission cap set by the ETS. This effect is higher under *BA full* than under the other BA scenarios, which is again intuitive.

All scenarios entail a loss in consumer utility, although in a very limited amount: at worst 0.12% of the utility consumers derive from the four sectors modelled. The loss is the lowest under *OB full*, for the reason indicated above: compared to auctioning, the output-based allocation constitutes a subsidy to production and consumers benefit from a higher consumption of CO₂-intensive goods, at a lower price. Interestingly, the two scenarios combining auctioning with output-based allocation entail a loss in consumer utility similar to the scenarios with 100% auctioning. The explanation is that consumers lose less in goods produced by exposed industries (which benefit from output-based allocation) but more in electricity, because the higher CO₂ price raises the price of electricity further, as will appear in Figure 4 below. Under the BA scenarios, the loss in consumer utility is slightly higher than under *Auction*, first because EU consumers of steel, aluminium and cement suffer from an increase in the price of imported products, and second because the CO₂ price, hence the price of CO₂-intensive goods produced in the EU, is slightly higher.

The impact of the different climate policy scenarios on public budget is somewhat symmetric to that on consumer utility. The impact is nil of course for *OB full*, and is around 20 billion euros for the others. The BA scenarios, especially *BA full*, brings more receipts than *Auction*, partly because there are slightly more imports than exports (expressed in embedded CO₂), partly because the CO₂ price is higher under the BA scenarios, as explained above. Interestingly, the two scenarios combining auctioning and output-based allocation provide almost as much receipts as *Auction*, although a significant part of the allowances are given for free. This is because the remaining allowances are sold at a higher price.

As expected, the leakage ratio, i.e., the increase in RoW emissions divided by the decrease in EU emissions, is the highest (10%) under *Auction*. This figure is in the range of 5 to 20% presented in the IPCC third assessment report (cf. Hourcade and Shukla, 2001)⁴. The OB scenarios drop this figure down to 2-3%, the *OB exposed direct* scenario being the least efficient in this regard because electricity-intensive sectors (mainly aluminium and steel) suffer from the rise in power price. *OB exp. dir.&ind.* is more efficient in preventing leakage than *OB full* because it entails a lower CO₂ price, hence less abatement per ton produced and less increase in production cost.

Under all BA scenarios except the last one, the leakage ratio is negative, meaning that emissions in the RoW actually decrease. The main explanation is that these climate policies decrease the consumption of steel, aluminium and cement in the EU, hence exports from RoW to the EU, hence production and CO₂ emissions in these RoW industries. For *BA full*, another explanation is that since, in most sectors, EU firms emits less per tonne produced than RoW firms, EU firms face a lower increase in production cost than RoW firms. Thus they win some market shares, which reduces emissions in RoW further. Even when the adjustment is set only on imports (*BA import only*), only on direct emissions (*BA direct only*) or when the adjustment on imports is set at the EU average rather than on RoW average (*BA EU average*), the border adjustment is more efficient than the output-based allocation to prevent leakage. Only *BA import direct* entails a higher leakage ratio than some of the OB scenarios.

Figure 2 splits up the absolute level of leakage (i.e., the increase in RoW emissions between BaU and climate policy – the numerator of the leakage ratio) into sectors. Indirect emissions from aluminium, steel and cement are presented together under the label "electricity". In the *Auction* scenario, around half the leakage comes from steel. There is a net leakage in the cement sector under all scenarios (although the amount varies a lot) because CO₂ emissions per tonne of clinker are (slightly) lower in the RoW, hence the RoW wins some market shares vis-à-vis the EU even under *BA full*.

⁴ Most of these leakage estimates are produced by General Equilibrium models, which take into account other leakage channels that the loss in market share, in particular the drop in world fuel prices, and which cover the whole economy (Sijm et al. 2004). Hence these figures are not directly comparable.

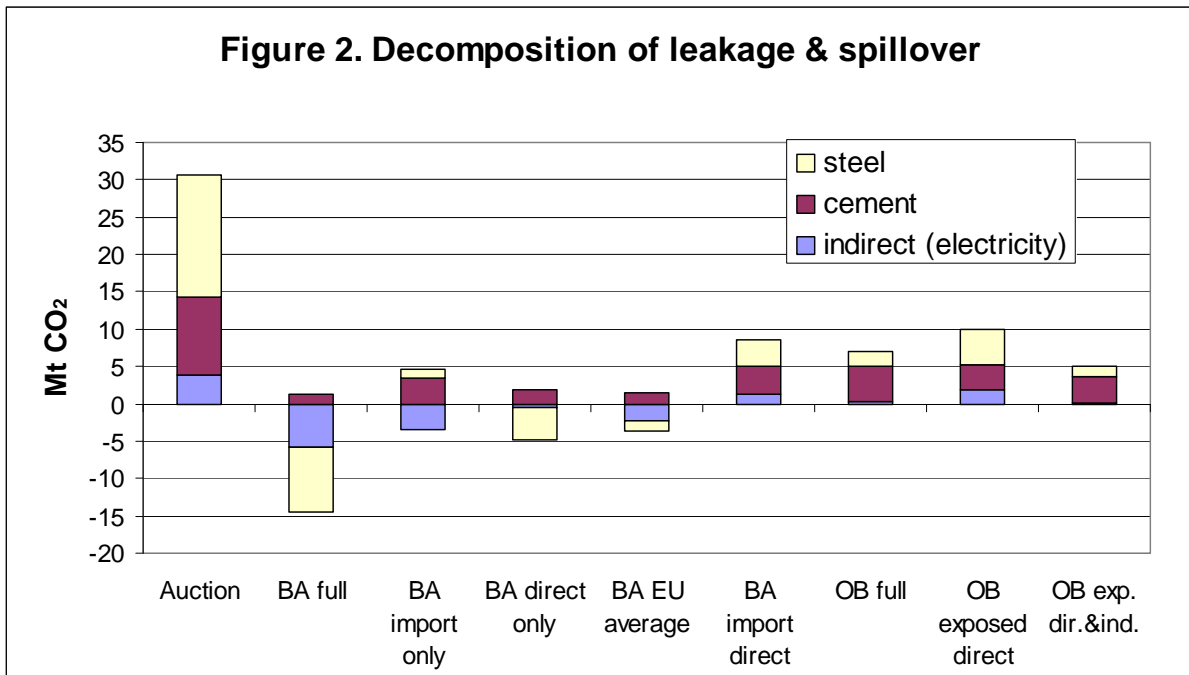
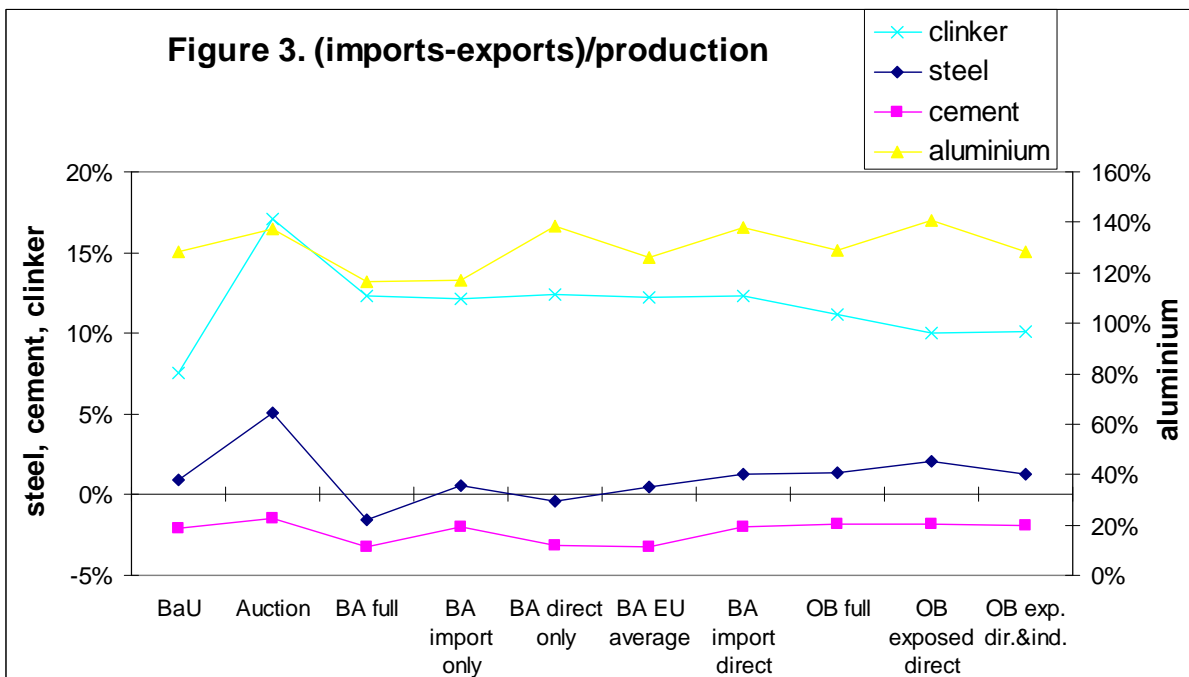
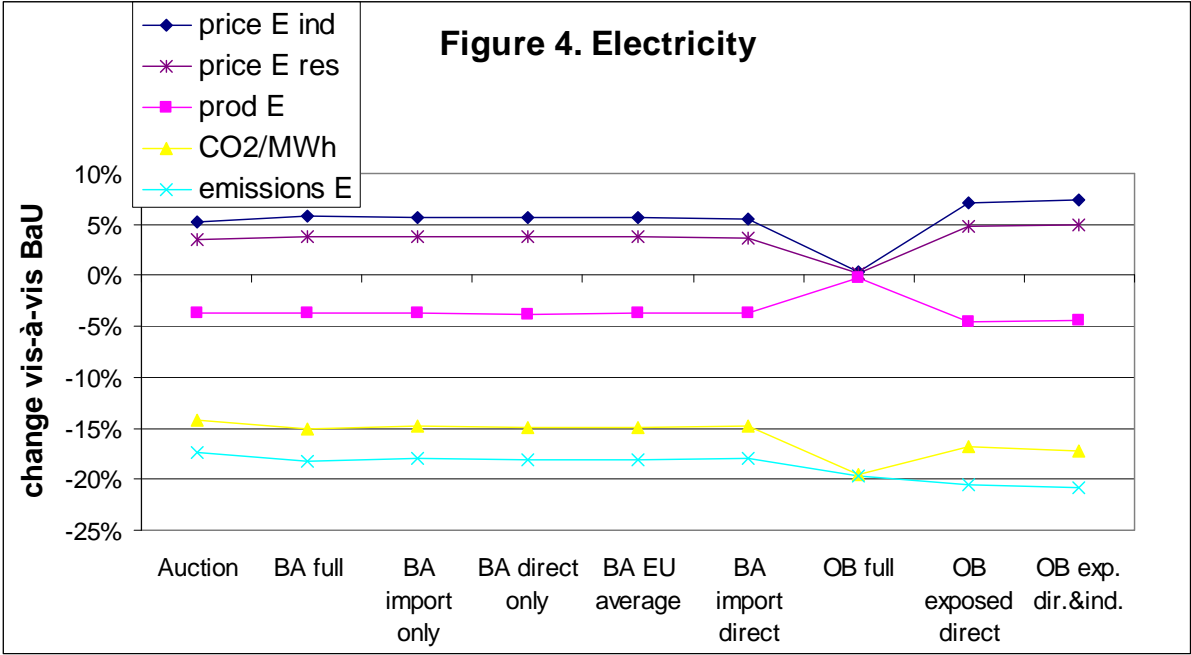


Figure 3 displays the net import ratio, i.e. (import-export)/production. This ratio rises significantly under *Auction* for clinker and steel but remains close to the BaU level for the other sectors and scenarios.

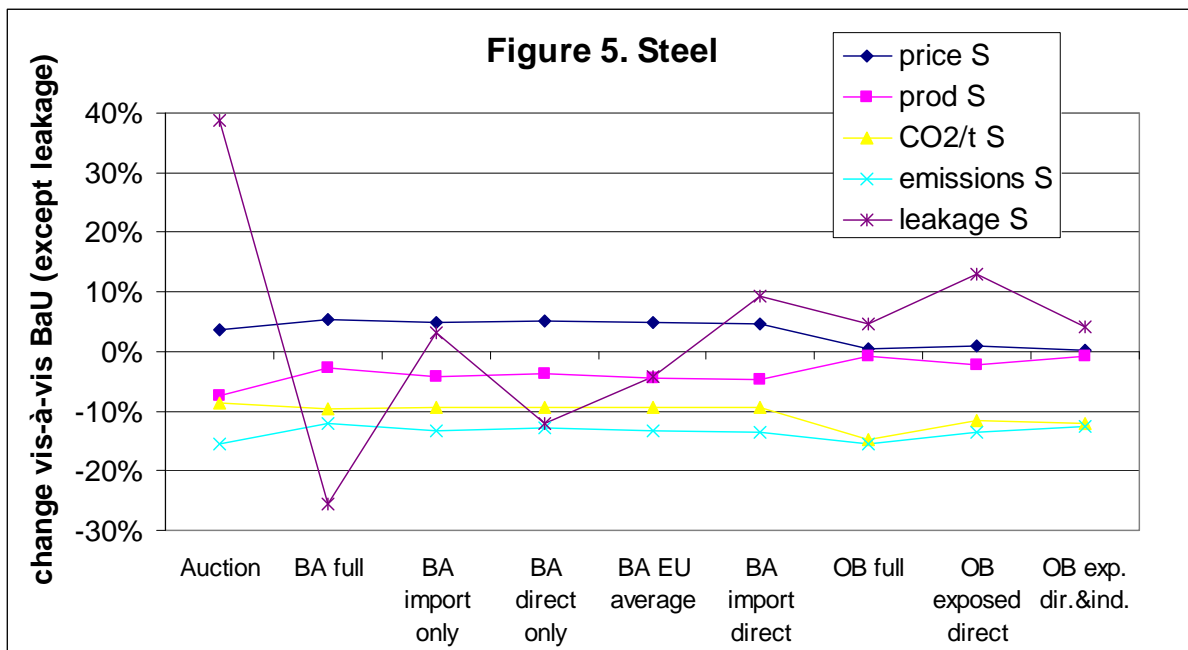


Under *Auction*, as shown in Figure 4, the electricity price increases by 3% for households and 5% for industry. The increase is slightly higher under the BA scenarios and even higher under the last two OB scenarios, because of the higher CO₂ price. The increase in electricity price is almost nil under *OB full* since power producers have an incentive to sell more electricity in order to get more free allowances. The drop in production is directly proportional to the price increase.

Unitary emissions drop by around 15% under *Auction*, a bit more under the other scenarios since the CO₂ price is higher.

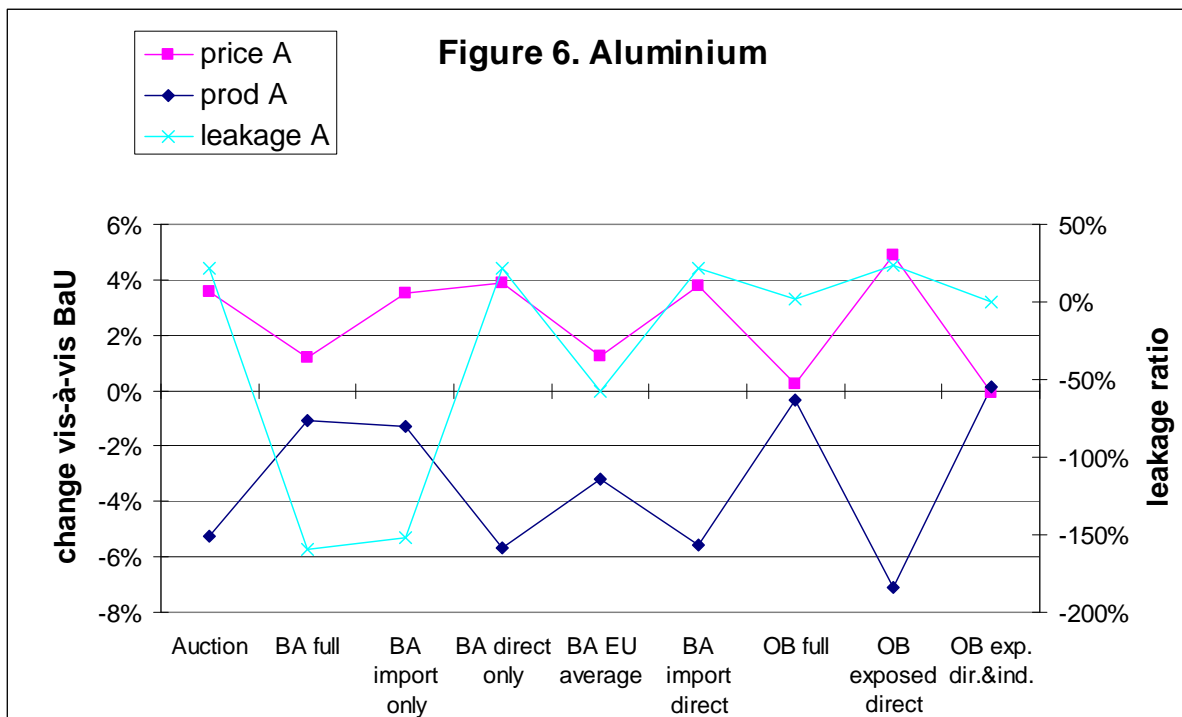


Evolutions are more complex for steel due to international trade. Figure 5 displays the price index of steel for EU consumers, the production of steel in the EU, unitary and total emissions from steel production and the leakage ratio (including indirect emissions). Price rises slightly more under the BA scenarios than under *Auction*, because of the higher CO₂ price, but the drop in production is lower under the BA scenarios since EU producers lose less (or even win some) market shares vis-à-vis the RoW. Under the OB scenarios, both the price and the production level are closer to BaU than under the other scenarios. Unitary emissions are strictly proportional to the CO₂ price hence do not deserve more comments, and finally total emissions are roughly similar among scenarios, several mechanisms cancelling out.



In aluminium (figure 6) the price increase and the production drop are relatively similar to that of steel. Since we do not model direct emissions, these impacts only stem from the rise in electricity price. Hence the BA and OB scenarios that do not cover indirect emissions (*BA direct only*, *BA import direct* and *OB exposed direct*) are ineffective at reducing the production loss and leakage ratio. They even worsen the situation since they raise the electricity price. The other scenarios effectively reduce production losses to around 1% (from 5% under *Auction*) except *BA EU average* (3%) because of the much lower emissions per MWh (hence per tonne of aluminium) in the EU than in the RoW. The leakage ratio exhibits very high variations across scenarios but this is due to the very low value of the numerator (emissions reduction in the EU). However, the absolute level of leakage in this sector is very low, so this particular figure should not get much attention.

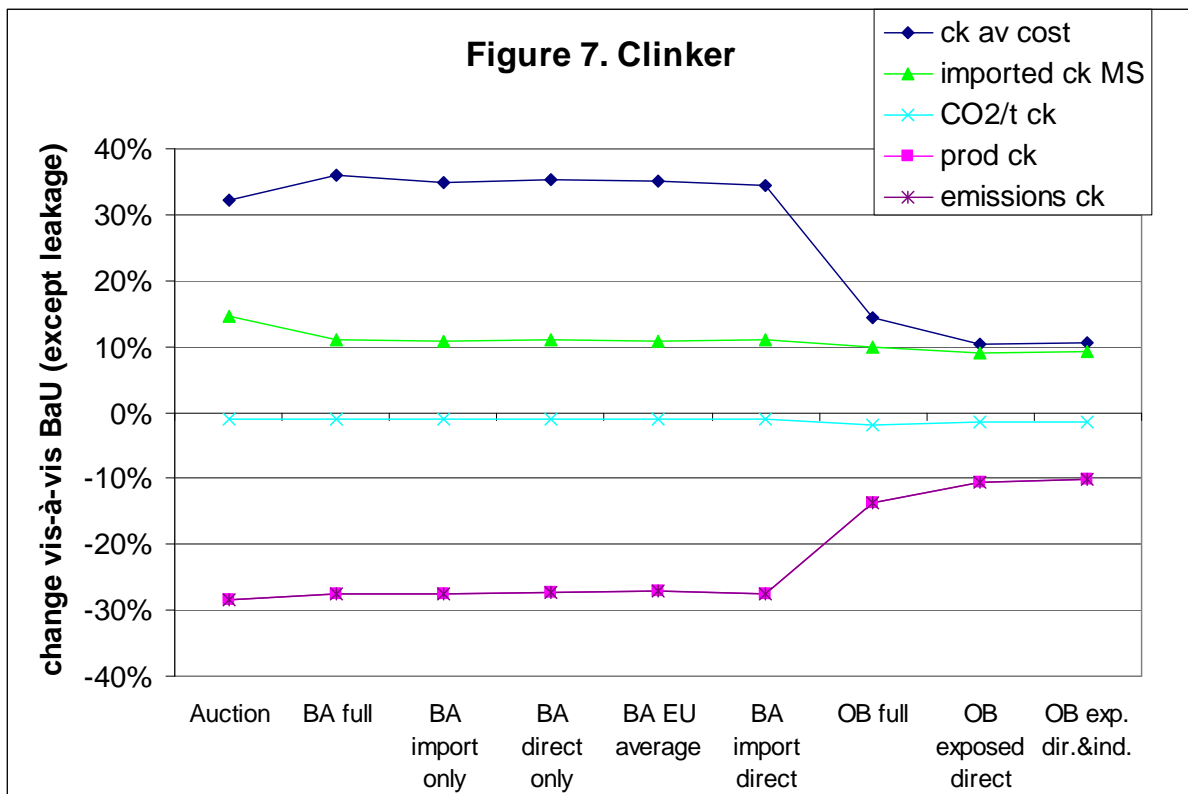
Since, even in BaU, the EU exports much less primary aluminium than it imports (cf. Figure 3 above), a BA covering only imports is almost as efficient in reducing production loss and leakage ratio as a BA covering both imports and exports.



As explained above, for cement we distinguish two production steps: manufacturing of clinker, which entails direct CO₂ emissions and requires electricity, and manufacture of cement from clinker (imported or domestic) and substitutes, which consumes electricity but does not entail direct CO₂ emissions.

Clinker (Figure 7) has the highest CO₂ intensity among the products covered by our model so it features the highest increase in average cost: around +35% for the *Auction* and *BA* scenarios. As a consequence the decrease in production is also the sharpest: between 25 and 30% for the *Auction* and *BA* scenarios and 10-15% for the *OB* scenarios. The share of imported clinker in EU cement production more than doubles, from 6% in BaU to 15% under *Auction*. The *BA* and *OB* scenarios roughly halve this increase, leading this ratio to 9-11%.

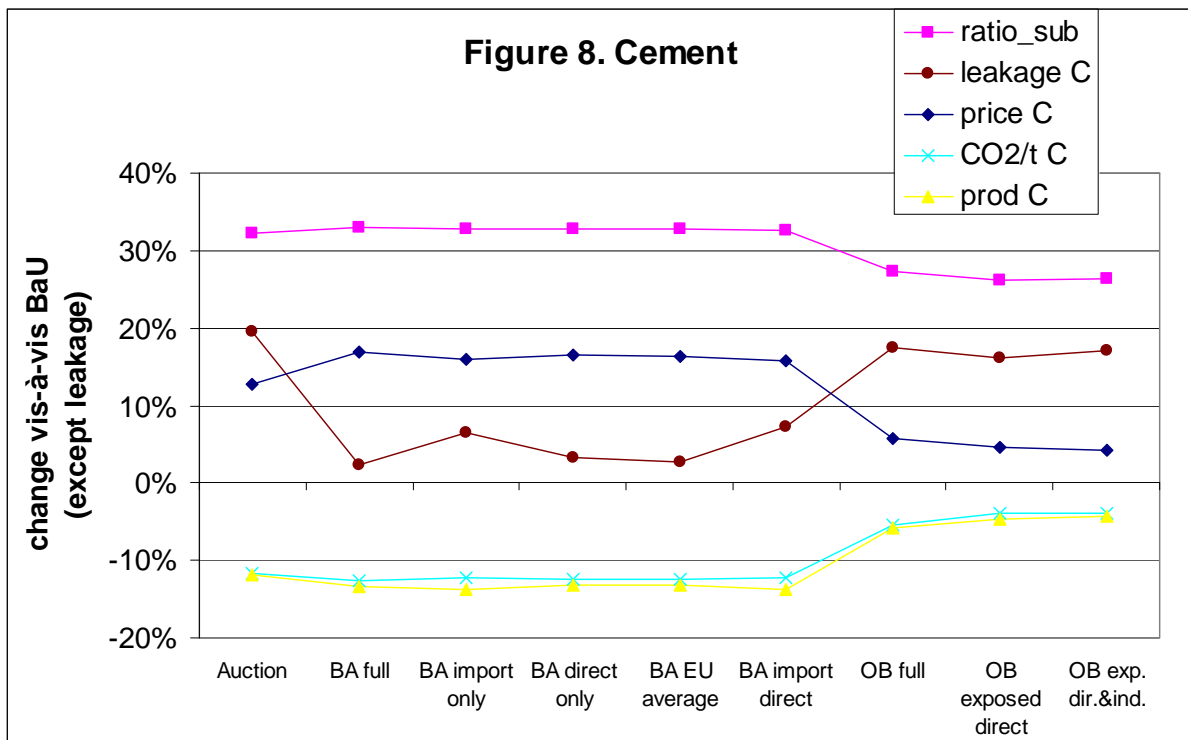
The decrease in unitary emissions is very limited (1-2%) because 60% of clinker emissions are process emissions than cannot be cut and only limited opportunity exist to reduce the remaining 40%, which are due to fuel combustion. As a consequence total emissions are almost proportional to production.



The rise in cement price (Figure 8) is more limited than the increase in clinker average cost but it is higher than in the other sectors. As usual, the rise is the highest for the BA scenarios and the lowest for the OB scenarios. However, the price increase under *OB full* is much higher for cement (+ 6%) than for the other sectors. This is because, first, the marginal abatement cost curve is steeper for cement than for the other sectors, and, second, we assume that the output-based allocation is based on a uniform decrease from the 2005 unitary emissions level in all sectors. As a consequence, cement producers have to buy allowances from the other sectors, which increases their marginal cost (cf. equation 6 above).

In the cement sector, leakage comes from market share losses both in the cement and in the clinker market. Under auction, the leakage ratio is lower than that of steel, which is due to the highest transportation cost of cement and clinker, but it is significant (20%). As for the other sectors, the BA scenarios are more efficient than the OB scenarios to decrease this ratio.

Cement unitary emissions (t CO₂/t cement) drop by 12-13% under *Auction* and the BA scenarios and 4-5% under the OB scenarios. Since, as we have seen, clinker unitary emissions (t CO₂/t clinker) decrease by only 1%, the bulk of the reduction in cement unitary emissions is due to the increase in the share of substitutes in cement, which rises from 23% in BaU to 32-33% in the *Auction* and BA scenarios. Under the OB scenarios, this ratio only rises to 26-27%: with an output-based allocation, cement manufacturers have less incentive to reduce the share of clinker in cement.



Conclusions

Does leakage have to be addressed, and if so, how? The answers to these questions are not straightforward. Our simulations indicate that even without any "anti-leakage" policy, the leakage ratio in case of full auctioning in the EU ETS is only of 10%. In light of this result, leakage can thus be seen as a benign problem. The main explanation is that there is no leakage in the power sector, so the aggregate figure is much lower than the leakage ratios in the steel (39%), aluminium (21%) and cement (20%) sectors.

However, in our model as in others, the leakage ratio depends crucially on the Armington elasticities, estimates of which vary a lot across available studies (Graichen et al., 2008). Hence we cannot exclude that the "real" figure be higher, in which case anti-leakage policies would be more useful. In this paper, we simulate two families of anti-leakage policies: five variants combining auctioning and border adjustments and three variants featuring output-based allocation in some or all sectors.

All the "anti-leakage" policies simulated are successful at reducing significantly the leakage ratio, which falls below 4%. Among the two families of "anti-leakage" policies simulated, border-adjustments and output-based allocation, the former is more efficient in this respect. Moreover, most border adjustment policies entail a negative leakage ratio, meaning that emissions in the rest of the world decrease following the EU climate policy. This spillover is mainly due to the reduction of EU demand for CO₂-intensive goods, which entails a decrease in exports of these goods from the rest of the world to the EU, hence of the production of these goods in the rest of the world. Because of this mechanism, even if the border adjustment

only covers imports, not exports, or if it only covers direct emissions, not indirect emissions, the leakage ratio is almost zero. This result gives room for manoeuvre to design a border adjustment without threatening the goodwill in the international negotiations on climate change. For example, a border adjustment covering only imports may be easier to negotiate because it generates public receipts, which may be redistributed to exporting countries. The latter would then probably be less likely to interpret the border adjustment as a protectionist policy. Another option to increase the acceptability of a border adjustment on imports is to exempt from this border adjustment products subject to a sufficient export tax in their country, which is currently the case for steel in China, although not for climate reasons (Wang and Voituriez, 2009).

Although the output-based allocation variants lead to a generally higher leakage ratio, it remains very limited (1.7 to 3.4%). The most efficient variant in this respect is the one with auctioning in the power sector and output-based allocation in the cement, steel and aluminium sectors, covering both direct and indirect emissions. The aggregate leakage ratio drops to 1.7% (17% in cement, 4% in steel and 0% in aluminium). In this scenario, the CO₂ price is much higher than under auctioning (21 € instead of 14) because the incentive to decrease the consumption of cement, steel and aluminium is much lower, and so it goes for the incentive to reduce the clinker ratio in cement since allocation is proportional to current clinker production. As a consequence of this higher CO₂ price, the public receipts almost equal that of the scenario with full auctioning, in spite of the fact that a part of the allowances are given for free. The impact on consumer utility is also very similar to that of full auctioning: compared to full auctioning, consumers lose from a higher increase in electricity price (+5% instead of +3.5% for domestic consumers) due to the higher CO₂ price but benefit from a lower increase in the price of cement, aluminium and steel. Hence, if one considers that leakage is a serious problem and that border adjustments should not be applied for some reason related to the international climate negotiations or to trade relations, a policy combining auctioning in the power sector and output-based allocation in the cement, steel and aluminium sectors, covering both direct and indirect emissions, is attractive.

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