Modelling the Impact of Policy Interventions on Carbon Leakage

ASSESSMENT WITH THE E3MG MODEL

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Modelling the Impact of Policy Interventions on Carbon Leakage

Assessment of EU GHG reduction targets, the role and impact of the ETS and policies designed to reduce carbon leakage in three key sectors: an application of the E3MG model

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Executive Summary

Background

In 2009, the European Commission undertook an impact assessment\(^1\) to identify the sectors at risk of carbon leakage as a result of the EU 20% EU GHG emissions reduction target. Carbon leakage is the relocation of production as a result of unilateral climate policy which creates cost differentials in the industrial production process across countries. The EC’s impact assessment identifies 164 sectors at risk of carbon leakage. However, research by Climate Strategies and Cambridge Econometrics suggests that far fewer sectors are at genuine risk. This paper follows this insight and focuses on three sectors widely considered to be at risk of carbon leakage: Iron and Steel, Aluminium, and Cement.

To reduce the risk of carbon leakage, the European Commission has proposed, in Directive 2009/29/EC three measures to address the adverse effects from carbon pricing: free allowances, inclusion of importers into the ETS, and binding sectoral agreements. In this paper we analyse how the inclusion of importers into the ETS would help to offset the impact of increased EU carbon costs. Moreover, this paper seeks to explore the impacts of a shift to a 30% EU GHG emissions reduction and the subsequent impacts of a border measure for the sectors under the spotlight.

Research questions

Broadly, this paper addresses three questions:

1) What is the impact on the EU ETS allowance price of a shift from 20% emissions reduction target to a 30%? We consider two different ETS and non-ETS splits to reach the 30% emissions reduction target.
2) What impact does this have on carbon leakage as a result of the relocation of Basic metals and Non-metallic mineral (as proxies for Aluminium and Iron & Steel, and Cement, respectively) production to outside of the EU?
3) To what extent is this offset by the implementation of a border adjustment?

The analysis has been conducted using the E3MG model of the world economy. The data used in the E3MG model is limited to a NACE 2 digit level of industry detail.

Key Results

The economic modelling suggests that:

- a move to a 30% target, achieved by the EU\(^2\), is likely to have a significant impact on the EU ETS allowance price, even if non-ETS sectors make a substantial contribution, causing the price to increase from €30 in the 20% reference scenario, to between €91 and €75 in the 30% scenarios
- an emissions reduction target where the burden is more evenly split between the ETS and non-ETS sectors reduces the carbon price faced by energy-intensive sectors and therefore the impact on economic output of energy-intensive sectors
- the sectors considered are small in macroeconomic terms, collectively accounting for less than 1% of EU GDP
- although EU output in the three sectors is reduced as a result of the shift to a higher target there is no evidence of substantial carbon leakage through import substitution
- inclusion of importers partially protect EU output, but are not sufficient to keep output unchanged from the reference scenario
- the revenues raised from CO\(_2\) pricing for imports are fairly modest in macro-economic terms and have a negligible impact on the results when recycled

\(^1\) European Commission (2009) DG Climate Action “Commission Decision determining a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage pursuant to Article 10a (13) of Directive 2003/87/EC” http://ec.europa.eu/clima/policies/ets/leakage/docs/sec_2009_1710_en.pdf

\(^2\) We do not assume any use of VERs or other offsetting measures and so the additional effort is met entirely through domestic action.
1. Introduction and Policy Background

**Carbon leakage**

The concept of carbon leakage, carbon emissions arising as a result of the relocation of production outside of regions applying carbon abatement policy measures, is now well established in the academic literature and is recognised by policy makers. Carbon leakage has the potential to reduce the effectiveness of climate policy at the global level, while at the same time damaging local economic prospects; it therefore presents an argument against stricter unilateral measures to reduce greenhouse gas emissions. In developing policy aimed at reducing greenhouse gas emissions, policy-makers also need to consider the impact on carbon leakage and consider remedial policy measures to mitigate this risk as long as there is no coordinated international effort foreseeable.

This issue is currently particularly relevant in Europe as policy makers aim to follow the Europe 2020 Strategy and in particular the European Energy and Climate Package. The question of whether Europe reduces its emissions by 20% or by 30%, compared to 1990 levels is mostly dependent on the outcomes of international negotiations, but is partly dependent on the economic impacts of the proposed reduction measures. Attempts to limit the risk of carbon leakage are apparent in current policy proposals, for example the allocation of allowances in the European Emission Trading System (EU ETS). However, these measures come with their own economic costs.

**Our assessment of carbon leakage in Europe**

This paper presents a macroeconomic assessment of the degree of carbon leakage that could be expected if Europe moves to a 30% emission reduction target in 2020. We then consider in more detail, one of the ways in which carbon leakage could be reduced, through inclusion of importers through border adjustments, which has been proposed in the EC's Directive 2009/29/EC (as an amendment to Directive 2003/87/EC), but has yet to be fully assessed.

Carbon leakage is sector specific, only some production processes are sufficiently carbon intensive to cause firms to relocate production processes, equally if a product is not easily tradable the production process is likely to remain close to the final market. As a result, it is necessary to carry out an analysis at the sectoral level. Our approach is primarily a quantitative, model-based one, using a general (i.e. one that includes the whole economy) approach. This allows us to assess:

- The effects of carbon leakage and carbon leakage policy on the sectors directly affected
- The indirect effects of carbon leakage and carbon leakage policy on other sectors
- The macroeconomic impacts of carbon leakage and carbon leakage policy, e.g. the impacts on economic growth and employment.

The downside of this approach (to use a general model) is that the model can only give a limited degree of detail (to NACE 2-digit level), due to the published data that are available. Our results are therefore intended to sit alongside specific industry analyses which are able to give more detailed impacts within the affected sectors, but lack the interactions with the wider economy.

Building on this previous research, our focus is on three sectors:

- Steel
- Aluminium
- Cement

However, these sectors have strong linkages with other sectors, for example the extraction sectors that supply their inputs or the manufacturing and construction sectors that use their outputs. The inter-linkages

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4 http://ec.europa.eu/clima/policies/package/index_en.htm
5 Other working papers within this Climate Strategies project are available at: http://climatestrategies.org/research/our-reports/category/61.html
between sectors are a feature of the model and therefore the macroeconomic impacts on these sectors are included in the results.

The model that we have used to carry out this analysis is the E3MG model. E3MG is a global computer-based model that has previously been used for similar analyses of environmental policy. The model is described in more detail in Chapter 3. First, however, we consider the wider literature surrounding carbon leakage and its assessment, including the impacts of carbon pricing adjustments at the border. The following chapters present the scenarios and the respective results. In Chapter 6 we present our conclusions.
2. Sector Background

Sectors at risk of carbon leakage

In 2009, the EC undertook an impact assessment of a shift from the 20% GHG emissions reduction target to a 30% reduction. As part of this, the EC assessed whether sectors, defined at the NACE 4-digit level, would be at risk of carbon leakage. The impact assessment suggested that some 164 sectors\(^6\) might be at risk of carbon leakage based on the following criteria:

- The sum of direct and indirect additional carbon costs for an energy-intensive industry sector would lead to a cost increase of at least 5% of its GVA and the sector has a trade intensity (total value of exports and imports divided by the total value of its turnover and imports) exceeding 10%, or
- The sum of direct and indirect additional costs induced by the implementation of the directive would lead to a cost increase of at least 30% of its GVA or
- The sector has a trade intensity (the total value of its exports and imports divided by the total value of its turnover and imports) exceeding 30%

Table 1 shows the sectors with the highest carbon cost per unit of GVA. The sectors selected for this research rank highly: Iron & Steel and Aluminium have both high per-unit carbon costs and trade intensities, while Cement production has one of the highest carbon costs, while the trade intensity is relatively low.

### Table 1 Top Ten Ranked Sectors at Risk of Carbon Leakage on Carbon Cost Metric

<table>
<thead>
<tr>
<th>Sector</th>
<th>Carbon cost per unit of GVA (%)</th>
<th>Trade Intensity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacture of fertilizers and nitrogen compounds</td>
<td>70.2</td>
<td>27.4</td>
</tr>
<tr>
<td>Manufacture of lime</td>
<td>65.2</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>Manufacture of cement</strong></td>
<td><strong>45.5</strong></td>
<td><strong>6.8</strong></td>
</tr>
<tr>
<td>Manufacture of coke oven products</td>
<td>41.4</td>
<td>30.0</td>
</tr>
<tr>
<td><strong>Aluminium production</strong></td>
<td><strong>14</strong></td>
<td><strong>35.9</strong></td>
</tr>
<tr>
<td>Manufacture of other inorganic basic chemicals</td>
<td>11.9</td>
<td>31.7</td>
</tr>
<tr>
<td>Manufacture of refined petroleum products</td>
<td>11.7</td>
<td>16.1</td>
</tr>
<tr>
<td><strong>Manufacture of basic iron and steel and of ferro-alloys</strong></td>
<td><strong>10.6</strong></td>
<td><strong>32.3</strong></td>
</tr>
<tr>
<td>Manufacture of paper and paperboard</td>
<td>10.2</td>
<td>25.7</td>
</tr>
<tr>
<td>Manufacture of flat glass</td>
<td>8</td>
<td>21.0</td>
</tr>
<tr>
<td>Manufacture of fertilizers and nitrogen compounds</td>
<td>70.2</td>
<td>27.4</td>
</tr>
</tbody>
</table>

Note(s): There are a number of sectors with undisclosed carbon costs between 5% and 30% which might feature in this list if the carbon cost was known.

Source(s): European Commission.

Focus on Cement, Aluminium and Iron & Steel

Cambridge Econometrics et al (2010) report that the criteria by which the EC selected 164 sectors at risk of carbon leakage was too broad and deflected attention from sectors considered genuinely at risk. In particular the trade criterion alone, seemed to suggest that too many sectors were at risk of carbon leakage: nearly 120 of the 164 sectors considered at risk had total carbon costs (direct plus indirect costs) below 5% of GVA. As reported in Cambridge Econometrics et al (2010), an econometric analysis of a selection of sub-sectors with low carbon costs and high trade intensity concluded that sectors with these characteristics were unlikely to be at genuine risk of carbon leakage.

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\(^6\) http://192.100.100.252:1812/servlet/com.trend.iwss.user.servlet.sendFile?downloadfile=IRE9670-242408368-4204-4204
A literature review undertaken by Climate Strategies and reported in Cambridge Econometrics et al (2010) shows that certain sectors are regularly considered to be at risk, among the ten or so sectors regularly referenced in the literature, we have selected three for this analysis:

- Iron & Steel
- Cement
- Aluminium

Each sector has different characteristics with respect to carbon leakage. As stated previously both aluminium and iron & steel face substantive carbon costs, combined with high levels of trade, however, costs to aluminium production are predominantly from indirect carbon costs associated with the sector’s electricity consumption, while for Iron and Steel it is more weighted towards direct carbon costs. This is an important distinction, since many policy proposals to reduce the risk of carbon leakage (such as free allowances and border adjustments) only account for direct carbon costs. Cement has the second-highest carbon cost, three times that of Aluminium, but is much less exposed to trade than the other two sectors.

These sectors also account for a considerable proportion of the emissions covered by the EU ETS. In 2008, before the global economic downturn, verified emissions of the EU ETS showed that activities associated with Iron & Steel and Aluminium production (and other metals) under the sector aggregation ‘Coke Ovens’, ‘Metal ore roasting or sintering’ and ‘Pig Iron or Steel’ accounted for 8% of all EU ETS emissions, while emissions from Cement (Cement Clinker or Lime) accounted for a further 9%.

However, the E3MG model is defined only at the NACE 2 digit level which requires us to map the NACE 4 digit sectors to the aggregate (parent sectors), see Table 2.

<table>
<thead>
<tr>
<th>Sector of Interest</th>
<th>E3ME Fuel User sector</th>
<th>E3ME Industry Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and Steel</td>
<td>Iron and steel</td>
<td>Basic metals</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Non-ferrous metals</td>
<td>Basic metals</td>
</tr>
<tr>
<td>Cement</td>
<td>Non-metallic minerals</td>
<td>Non-metallic minerals</td>
</tr>
</tbody>
</table>

3. The E3MG Model

Introduction

This section provides a very brief introduction to E3MG. A more complete description of the model is provided in Annex A and on the model website, www.e3mgmodel.com.

E3MG is a computer-based model of the world's economies, energy systems and the environment. It is a simulation model used for the assessment of economic and environmental policy. The model has recently been used for evaluations of the outcomes from the Copenhagen summit and the impacts of high oil prices on the global economy.

The modelling approach is one that is scenario-based. The starting point is a baseline or ‘business-as-usual’ model run that assumes that current policy remains in place. In a scenario one or more new policies are added and the model is rerun. The (usually percentage) difference between the two sets of model results is the impact of adding the new policies.

Key features of the model

E3MG has the following key characteristics:

- Detailed sectoral disaggregation – E3MG splits the economy into 42 economic sectors and 19 users of twelve energy carriers (fuels). This allows for the specification of detailed policy inputs and the analysis of detailed outcomes. This recognises that different fuel users (e.g. industry and transport) use different fuels in different ways. It is particularly relevant to the scenarios in this study as the policies are applied to specific sectors.

- Energy-Environment-Economy linkages – From the outset, E3MG has been designed to incorporate these linkages in detail, including feedbacks between the different components. This is clearly a requirement for this study and allows for both the economic assessment of environmental policy and an environmental assessment of economic policy.

- Econometric specification – In contrast with the more standard Computable General Equilibrium (CGE) approach to economic modelling, the behavioural parameters in E3MG are derived using econometric techniques. This means that not only does the model have a strong empirical grounding but it is also suitable for short-term disequilibrium outcomes. For example, if energy prices suddenly increase the model will show both the long-term impacts of this and the transitional period in between. This approach also means that the model does not rely on strong theoretical assumptions such as rational behaviour and perfect foresight.

E3MG is a global model that splits the world into 20 trading regions. Thirteen of these regions are countries (USA, Japan, Germany, UK, France, Italy, Canada, Australia, Russia, China, India, Mexico, Brazil), with the other regions being groups of economies, so that global totals are met. The model’s trade equations include the interactions between the different regions.

In this study the model solves annually over the period up to 2020. For presentational purposes, most of the results are given for the year 2020, although any significant shocks in the preceding years are noted.

Specific features of the model with respect to the scenarios are given in the next chapter.
How carbon leakage is represented in E3MG

Following from the definition of carbon leakage presented in Dröge (2009) which outlined three potential channels for carbon leakage, we consider four channels (as the model implicitly separates the short term competition channel impacts from the longer term investment channel) through which carbon leakage can take place:

- Short-term competition channel
- Investment channel
- Fossil-fuel channel
- Spill-over channel

The E3MG model has previously been used in assessments of climate policy, including carbon leakage, for studies carried out for the European Commission. The European E3ME model has also been used for this purpose; Figure 1 is copied from Barker et al (2007) and describes how carbon leakage is represented in either model.

The diagram shows how climate policy (a tax is depicted here, but it could be equally applied to a trading scheme) reduces competitiveness in participating regions, which could lead to a shift in production, and associated emissions, to other regions (depicted in the lower half). However, Figure 1 presents a pessimistic scenario, because:

- Fuel demand and emissions do not only decrease in the participating region because of loss of output, higher energy prices will also reduce demand for fuel directly
- The spillover and technology transfer effects are not included in the diagram

Barker et al (2007) in fact found that the spillover effects (where firms that must pay the new taxes find more efficient production methods, which are then adopted in other countries) in Europe could outweigh the competitiveness effects, resulting in a small but negative amount of carbon leakage.

It is, however, noted that the results in that study, like our results in this paper, negate the fossil-fuel channel for carbon leakage. This is where reductions in demand for fuels lead to lower international energy prices and possible increases in demand elsewhere. As both the E3ME and E3MG models treat international energy prices as exogenous (due to the documented difficulties of finding an empirical relationship) this channel is not represented in the results, although the impacts are likely to be small.
Figure 1: Representation of Carbon Leakage in E3MG

- Domestic prices increase
- Imports relatively cheaper
- Carbon-energy tax
  - Unit tax costs increase
  - Export prices increase
  - Imports volumes increase
  - Export volumes fall
  - Output decreases
  - Fuel demand decreases
  - Emissions decrease

- Exports more price-competitive
- Exports volumes increase
- Fuel demand increases
- Emissions increase
- Output increases
- Domestic produce more price-competitive
- Import volumes fall

Identity relationship
Estimated relationship
4. Description of the Scenarios

Description of scenarios

In this study, two sets of scenario analyses are undertaken, differing only in the assumptions on how the EU 30% target is to be achieved, in terms of the distribution of emissions reductions between EU ETS and non-EU ETS sectors. Each set is made up of three scenarios:

- **Baseline with Recycling of ETS Auction Revenues** – the EU achieves the 30% target (through the EU ETS as well as a carbon tax for non-EU ETS sectors) while the rest of the world enacts emissions-reduction policies in line with each region’s ‘low’ Copenhagen pledge (modelled as a carbon tax). EU ETS revenues from the auctioning of allowances bought by EU power generators are recycled to reduce labour costs (through reductions in employers’ social security payments). Cooper and Grubb (2011) estimate the revenues raised from auctioning could be in the range of €150-190 bn.

- **Border Adjustment without Recycling of Border Revenues** – in this scenario, a CO2 price is imposed on the rest of the world’s exports of Non-metallic mineral products (cement) and Basic metals (steel and aluminium) to the EU. This is modelled as an increase in the price of imports from the rest of the world faced by EU countries. The revenues from the border adjustment carbon cost/CO2 price are not recycled and are thus implicitly used to reduce public debt (with no other modelling implications) to allow for comparison with the scenario below where revenues are recycled.

- **Border Adjustment with Revenue Recycling of Border Revenues** – this scenario differs from the previous one in the treatment of the border revenues, which are now, like the revenue from EU ETS allowance auctioning, recycled into reducing labour costs.

The scenario analysis is structured in this way to first identify the effects of border adjustments in terms of the trade effects (Baseline compared to Border Adjustment) and to then identify the further compensating effects of directing the revenues raised to achieve other policy goals (Border Adjustment with Revenue Recycling compared to Border Adjustment). The overall effect can also be analysed (Border Adjustment with Revenue Recycling compared to Baseline).

As mentioned, two sets of scenarios were run, differing in the EU ETS/non-EU ETS split of emissions reductions. In the first set of scenarios, EU ETS sectors and non-EU ETS sectors face different carbon prices in order to achieve the reductions set out in the EC’s ‘Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage’\(^8\). In the second set of scenarios, a common carbon price in each year was set across all EU sectors to achieve the 30% target by 2020.

The purpose of the two sets of scenarios is to analyse the effects of border adjustments under differing levels of sectoral emissions-reduction effort. The EU ETS/non-EU ETS split has an effect on the carbon prices required to achieve the targets and also has a bearing on the revenues for recycling from the carbon pricing as well from border adjustments.

The nature of burden sharing between sectors matters (in terms of the differences between carbon prices faced by different sectors) because allowances auctioned to power generation, a fully-traded sector, are the only direct source of revenue from carbon pricing.

The nature of the carbon pricing also has an impact on CO\(_2\) pricing at the border because of the differing cost structures across industries. These different cost structures affect the extent to which increases in input costs translate into increases in end-user prices. These in turn affect the border adjustment required to offset the EU domestic price increases. For example, iron and steel faces a higher carbon price in the scenarios where the EU ETS sectors are expected to carry a larger share of the burden. As a result, a

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greater carbon adjustment would be required at the border to make sector prices equivalent (in carbon cost terms).

The scenarios analysed in this study are numbered as follows:

- **Reference Scenario (R0)** – EU 20% target achieved
- **Baseline 1 (B1)**: rest-of-world Copenhagen low pledges and the EU 30% target achieved according to the EU ETS/non-EU ETS split outlined in the EC’s ‘Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage’
- **Scenario S1a** – Border Adjustment: as Scenario 1, with border adjustments applied on rest-of-world exports of Non-metallic mineral products and Basic metals to the EU
- **Scenario S1b** – Border Adjustment with Revenue Recycling: as Scenario 2, with border-adjustment revenues recycled into reducing employers’ social security payments
- **Baseline 2 (B2)**: rest-of-world Copenhagen low pledges and the EU 30% target achieved by a single sector-wide carbon tax
- **Scenario S2a** – Border Adjustment: as Scenario 4, with border adjustments applied on rest-of-world exports of Non-metallic mineral products and Basic metals to the EU
- **Scenario S2b** – Border Adjustment with Revenue Recycling: as Scenario 5, with border-adjustment revenues recycled into reducing employers’ social security payments

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5. Results

Introduction

This chapter presents the results of the scenario analysis carried out using the E3MG model. We have looked at (1) the impact on the EU ETS allowance price, industry prices, industry output and carbon emissions of moving from the EU 20% target to the EU 30% target, results are shown below. We have also analysed (2) border adjustments, (3) its trade impacts, (4) its implications and trade effects on EU industry output, and (5) its consequences for emissions and carbon leakage.

The impact of moving to a 30% EU reduction target

In the first set of scenarios (B1, S1a and S1b), the EU ETS and non-EU ETS sectors face differentiated carbon prices to achieve the required EU emissions reductions, in other words, the EU ETS sectors face a higher price than the non-ETS sectors. To achieve a reduction target split between ETS and non-ETS sectors in this way, the EU ETS allowance price must be higher than the non-EU ETS carbon tax, €91/tCO\textsubscript{2} compared to €63/tCO\textsubscript{2} (in 2008 terms). This compares to a uniform price across all sectors in the second set of scenarios (B2, S2a and S2b) of €75/tCO\textsubscript{2} in 2020 (again, in 2008 terms). The sector-wide carbon price set in the second set of scenarios is, unsurprisingly, a price between the EU ETS and non-EU ETS prices in the first set of scenarios. These carbon prices, to achieve the 30% target, compare to a carbon price of €33/tCO\textsubscript{2} to achieve the 20% target (2008 terms). In the PRIMES reference scenario, in which the 20% GHG reduction target is reached, a €16.5 per tCO\textsubscript{2} (2008 terms) is required by 2020. To reach 30% a European Commission Communication\textsuperscript{10} suggests that this would need to nearly double to €30 per tCO\textsubscript{2}e, although in the 30% scenario it is assumed that some 5pp of the 30% target is met by ‘international emissions reduction credits’. Without the use of emissions reductions credits, we might expect the carbon price to be closer to €45-50 per tCO\textsubscript{2}e in this scenario, which would be in line with our relative scenario results (a tripling of prices).

The change in EU industry prices from moving to the 30% target is more modest than the increase in the carbon price. While the carbon price does raise the cost of (fossil fuel) energy, energy is not the sole input to production, lessening the impact on total unit costs. Moreover, if cost pass through is not 100%, the full increase in unit costs will not necessarily be passed on to final consumers. However, the increase in industry output prices does include the indirect impact of increased electricity prices, as well as the direct EU ETS allowance price impact, as well as other supply chain effects from increased costs in other input sectors.

Table 3: Carbon and Industry-output prices in 2020

<table>
<thead>
<tr>
<th></th>
<th>EU 20% target (R1)</th>
<th>B1</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU ETS allowance price (€2008/tCO\textsubscript{2})</td>
<td>32.6</td>
<td>91.2</td>
<td>75.4</td>
</tr>
<tr>
<td>Non-EU ETS carbon tax (€2008/tCO\textsubscript{2})</td>
<td>63.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in EU non-metallic minerals price (% increase on EU 20% target)</td>
<td>-</td>
<td>3.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Increase in EU basic metals price (% increase on EU 20% target)</td>
<td>-</td>
<td>10.7</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Source: E3MG

In the first set of scenarios (separate EU ETS and non-EU ETS carbon prices), industry prices of non-metallic mineral products increase by around 3% as a result of the higher carbon prices in 2020, when compared to the prices under the 20% reduction target (see Table 3). The increase in the price of EU basic metals products (which includes both steel and aluminium production) is higher, owing to higher energy intensity as well as somewhat higher cost pass-through rates. The end-user prices in this industry increase by almost 11% in the EU.

\textsuperscript{10} European Commission (2012), COMMISSION STAFF WORKING PAPER. Analysis of options beyond 20% GHG emission reductions: Member State results, see: http://ec.europa.eu/clima/policies/package/docs/swd_2012_5_en.pdf
In the second set of scenarios (a single, sector-wide carbon price), the increase in the price of EU non-metallic mineral products (cement) is around 2.5% as a result of moving from the 20% to the 30% reduction. As a result of moving to the 30% reduction target, the price of EU basic metals products (aluminium and iron & steel) is increased by around 8%. These relatively smaller price increases are principally a reflection of the lower carbon price faced by EU ETS sectors in this second set of scenarios.

In contrast to the different carbon prices for EU ETS and non-EU ETS sectors in the first set of scenarios, all EU industries face a common carbon price in the second set of runs. This price lies between the EU ETS and non-EU ETS carbon prices of the first set of scenarios i.e. EU ETS sectors face a relatively lower carbon price and non-EU ETS sectors face a relatively higher one, when comparing the second set of scenarios to the first. This alters the EU ETS/non-EU ETS split of the emissions reductions; the non-EU ETS sectors take up relatively more of the emissions-reduction burden than they do in the first set of scenarios because they face a higher carbon price and the EU ETS sectors a lower one.

Interestingly, the rest of world output of basic metals and non-metallic minerals is hardly affected, increasing by just 0.1%. This is similar to the findings in Cambridge Econometrics (2010) which suggested that while exports and domestic output might be reduced as a result of additional unilateral EU action to reduce emissions by 30%, there was little evidence for import substitution. As a result the increase in sector emissions in the rest of the world in the baseline scenarios is negligible.

Table 4: Change in EU and Rest-of-World Industry Output 2020 (% compared to R0)

<table>
<thead>
<tr>
<th>EU Output</th>
<th>R0</th>
<th>B1</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic metals</td>
<td>-</td>
<td>-5.0</td>
<td>-4.4</td>
</tr>
<tr>
<td>Non-metallic minerals</td>
<td>-</td>
<td>-2.8</td>
<td>-2.7</td>
</tr>
<tr>
<td>RoW Output</td>
<td>R0</td>
<td>B1</td>
<td>B2</td>
</tr>
<tr>
<td>Basic metals</td>
<td>-</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Non-metallic minerals</td>
<td>-</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 5: Change in EU and Rest-of-World Energy User Emissions 2020 (% compared to R0)

<table>
<thead>
<tr>
<th>EU CO2 emissions</th>
<th>R0</th>
<th>B1</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron &amp; Steel</td>
<td>-</td>
<td>-10.6</td>
<td>-8.5</td>
</tr>
<tr>
<td>Non-ferrous metals</td>
<td>-</td>
<td>-15.1</td>
<td>-12.1</td>
</tr>
<tr>
<td>Non-metallic minerals</td>
<td>-</td>
<td>-7.0</td>
<td>-4.6</td>
</tr>
<tr>
<td>RoW CO2 emissions</td>
<td>R0</td>
<td>B1</td>
<td>B2</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>-</td>
<td>-0.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>Non-ferrous metals</td>
<td>-</td>
<td>-0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Non-metallic minerals</td>
<td>-</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

In total, emissions in the rest of the world (see Table 6) are estimated to remain unchanged as a result of unilateral EU action. The primary reason for this is that even a high carbon price has a small impact because:

- total production (GDP) has a low carbon content (an EU wide carbon price of €75 t/CO2 is only equivalent to a cost of approx. 1% of EU GDP)
- not all of the cost is passed on to purchasers
- relatively low trade as a proportion of total EU GDP serves to further reduce the impact

The small decrease in RoW emissions arises from a small reduction in EU imports from the rest of the world and small learning curve effects (technology transfer) in the power sector.

Table 6: Change in EU and Rest-of-World CO2 Emissions in 2020 MtCO2 (% compared to R0)

<table>
<thead>
<tr>
<th></th>
<th>R0</th>
<th>B1</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total EU emissions</td>
<td>-</td>
<td>-483 (-12.5%)</td>
<td>-483 (-12.5%)</td>
</tr>
<tr>
<td>Total RoW emissions</td>
<td>-</td>
<td>-17.3 (-0.1%)</td>
<td>-23.1 (-0.1%)</td>
</tr>
</tbody>
</table>

The size of the border adjustments

Although there is little evidence of carbon leakage, particularly by way of import substitution in our results, it is still worth assessing the impact of border adjustments as a policy tool since it is a possible policy option
and because other studies\textsuperscript{11} (and industry) do claim that carbon leakage could be important for these sectors. Moreover, it is important to consider the macro-economic impact of introducing such a policy to understand the relative scale of impact that a border adjustment might have. However, given the modelling results of the shift to an EU 30\% reduction target we expect the policy to have a fairly limited impact on output, trade flows and emissions.

Since the E3MG model is based on the concept of pooled trade, rather than a series of bilateral trade relationships; the border taxes levied are computed by first calculating the carbon content of global (non-EU) production of the product (steel, aluminium and cement) per volume unit of production and then multiplying it by the EU ETS allowance price. This equates to a border tax designed to offset the direct carbon cost only.

The EU price increases described above are applied as border taxes on the same goods manufactured in the rest of the world for import to the EU. These taxes are applied in the ‘a’ and ‘b’ scenarios in each set (Border Adjustment and Border Adjustment with Revenue Recycling). The impact of the border measure is to increase the price of EU imports for Basic metals and Non-metallic minerals by 6-7\% and 12-14\% respectively (see Table 7).

\begin{table}[h]
\centering
\caption{Change in EU Import Prices in 2020 (% difference from Baseline)}
\begin{tabular}{lcccc}
\hline
 & B1 & S1a & S1b & B2 \\
\hline
Non-metallic mineral products & - & 13.9 & 13.9 & - \\
Basic metals & - & 7.2 & 7.1 & - \\
\hline
\end{tabular}
\label{tab:import_prices}
\end{table}

\textbf{Table 7: Change in EU Import Prices in 2020 (% difference from Baseline)}

In the case of the ‘b’ scenario, the revenues from the border adjustments are recycled into lower employers’ social security contributions. The revenues raised from border adjustments to these sectors are fairly modest in macro-economic terms (see Table 8), but are reasonable in absolute terms.

\begin{table}[h]
\centering
\caption{Additional revenue recycled from border adjustment, 2020 (€ bn 2008)}
\begin{tabular}{lrr}
\hline
 & S1b & S2b \\
\hline
Revenue recycled (€ bn 2008) & 6.3 & 5.2 \\
\hline
\end{tabular}
\label{tab:revenue_recycled}
\end{table}

\textbf{Table 8: Additional revenue recycled from border adjustment, 2020 (€ bn 2008)}

The impacts on EU demand for imports from the rest of the world

As discussed, the border adjustments lead to higher import prices for Non-metallic mineral products and Basic metals produced outside of the EU, for EU consumption and as expected, the higher prices lead to lower EU demand for production from the rest of the world. When the two Border Adjustment scenarios are compared against their baseline projections, EU demand for imports of Non-metallic mineral products falls appreciably, by 15.6\% in the first set of scenarios (Scenarios 1a and 1b, with separate EU ETS and non-EU ETS carbon prices). Because the carbon prices faced by the EU ETS sectors are lower in the second set of scenarios, the border taxes are correspondingly smaller, leading to a smaller reduction in extra-EU import demand of around 13.2\% (see Table 9). The reductions in demand for non-EU Basic metals products are more modest, falling by around 1.9\% in the first set of scenarios and 1.6\% in the second set, indicating less elastic EU demand for these products (and less substitution towards EU-produced output).

The differences between import demand in the Border Adjustment scenarios and the Border Adjustment with Revenue Recycling scenarios are small. This is because the policy actually raises relatively little in the way of revenue because of low levels of extra-EU imports of the goods in question. Revenue recycling does lead to a slight increase in EU import demand (from slightly higher domestic economic activity) when the second and third scenarios are compared, but this increase is small.

\textsuperscript{11} For example, Quiron and Demailly (2006) “Leakage from climate policies and border tax adjustment: lessons from a geographic model of the cement industry” see http://halshs.archives-ouvertes.fr/docs/00/06/01/89/PDF/cement_industry.pdf
The impacts of border adjustments on EU output

EU imports of non-metallic mineral products and basic metals from the rest of world are, respectively, 8.5% and 23% of EU industry (gross) output. For a given level of EU demand (i.e. holding all other things constant), if EU imports from the rest of the world were to fall, EU production must increase to make up the difference. Higher EU output in the industries under analysis is indeed a feature of the scenario results.

In 2020, output from the European non-metallic mineral products sector increases by 1.4% in the first set of scenarios (S1a and S1b) as a result of the border adjustment (see Table 10). The increase in output from EU basic metals producers as a result of the border adjustment is slightly lower in percentage terms when compared against the baseline (B1), around 0.5%. This is a reflection of the EU’s comparatively higher dependence on production in the rest of the world (almost a quarter of the EU’s own production), even though the reduction in imports from the rest of the world is lower in percentage terms.

The lower border adjustments imposed in the second set of scenarios (which have lower EU ETS allowance prices) lead to smaller reductions in import demand for rest-of-world production and, in line with these smaller impacts, smaller increases in EU industry output: around 1% in 2020 in Non-metallic mineral products and 0.3% in Basic metals.

The two sectors analysed in this study are small, relative to the economy as a whole. In both baselines, these sectors’ GVA accounts for less than 1% of the EU total. As such, the overall impacts on EU GDP of border adjustments are small, little more than 0.05% in 2020; the impact on EU economic growth in the intervening years is thus negligible.

The effect of the border adjustment on rest of the world output in the two sectors is negligible. In both sets of scenarios, rest of the world output in Basic metals is unchanged as a result of the border adjustment while output in Non-metallic minerals decreases by 0.2% and 0.1% in the first and second set of scenarios respectively. The small size of the border adjustments means that the economic effects are too small to have any appreciable inflationary impact.

Implications for emissions and carbon leakage

Total EU emissions are unchanged because they are capped to the reduction target (see Table 11). The slight increase in output in the border adjustment scenarios puts a small upward pressure on the carbon price of between €2-4 per tCO\textsubscript{2} whether with or without revenue recycling.

In the rest of the world, the change in emissions is also small. In the Border Adjustments scenarios, CO\textsubscript{2} emissions fall slightly, as a result of lower EU demand leading to lower production. With the addition of revenue recycling, EU economic activity increases, leading to higher demand for goods produced in the rest of the world, which leads to higher emissions.

<table>
<thead>
<tr>
<th>Table 10: Change in EU Industry Output in 2020 (% difference from Baseline)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
</tr>
<tr>
<td>Non-metallic mineral products</td>
</tr>
<tr>
<td>Basic metals</td>
</tr>
<tr>
<td>Source: E3MG</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 11: Change in EU and Rest-of-World CO\textsubscript{2} Emissions in 2020 MtCO\textsubscript{2} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
</tr>
<tr>
<td>Total EU emissions</td>
</tr>
<tr>
<td>Total RoW emissions</td>
</tr>
</tbody>
</table>

Source: E3MG
6. Conclusions

In this paper, a large-scale econometric E3 model, E3MG, was applied to analyse the economic and emissions impacts of a shift to a 30% reduction target and the subsequent impact of introducing border adjustments. The study focuses on three industries; iron and steel, aluminium and cement. Due to the data set used in this model, the three sectors are aggregated under two headings: non-metallic mineral sources (includes cement) and basic metals (includes iron&steel and aluminium). The purpose of the analysis was to calculate the impact on the EU ETS allowance price of a shift from 20% emissions reduction target to a 30%, considering two different ETS and non-ETS splits to reach the 30% emissions reduction target. Moreover, the paper shows the impact from a higher unilateral policy target on carbon leakage, measured as a result of the relocation of Basic metals and Non-metallic mineral production to outside of the EU. And finally we have looked into the extent to which this leakage would be offset by the implementation of a border adjustment.

The border adjustments levied are computed by first calculating the carbon content of global (non-EU) production of the product (steel, aluminium and cement) per volume unit of production and then multiplying it by the EU ETS allowance price. This equates to a border adjustment designed to offset the direct carbon cost only. Two alternative 30%-reduction scenarios were analysed, that differed in the split of emissions reductions between the EU ETS and non-EU ETS sectors.

The first set of scenarios (B1, S1a and S1b) assessed the impacts of border adjustments if the emissions-reduction efforts were split between the EU ETS and non-EU ETS sectors according to the shares in the EC’s ‘Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage’. The second set (B2, S2a and S2b) assessed the impacts of border adjustments from a 30% reduction achieved by a single, sector-wide carbon price. Because the analysis in this paper focuses on sectors covered by the EU ETS, the split in the emissions reductions has a bearing on the economic and emissions impacts. Burden shares that place more emphasis on EU ETS emissions reductions require higher carbon prices, which have a greater impact on the sectors of interest.

It is important to note that the kind of model-based scenario analysis undertaken in this paper is intended to shed light on the implications of border adjustments purely in a ‘what if’ manner, to explore future possible outcomes under a range of assumptions. No discussion is made (or intended) in this paper as to the feasibility of the policies.

Overall, the impacts of the border adjustments assessed in this paper are small. While the increases in carbon prices to achieve the 30% target are quite large, energy is a relatively small share of total production costs (accounting for less than 5% of turnover even in the energy-intensive NACE 2-digit sectors), reducing the total increase in unit costs. Moreover, not all of the cost increase is necessarily reflected in the final price of output, as a result of less-than-100% cost pass through. The price increases faced by consumers are therefore substantially smaller than the increases in the carbon prices.

Imports from the rest of the world account for a relatively small share of EU supply in the three sectors examined and, combined with relatively small import-price increases, the output effects in the EU are themselves small at the sectoral level. Modest sector-level impacts, in industries that are small relative to the EU economy as a whole, lead to even smaller macroeconomic effects. In addition, low levels of border adjustments on low import volumes yield little in the way of border adjustment revenue and the effects of revenue recycling are, again, small.

While the results suggest that border adjustments, in the presence of revenue recycling, can boost EU output even within the emissions constraint, the size of the impacts is quite small and the conclusion is that, for this scale of emission reduction, the effects are broadly neutral at the macroeconomic and 2-digit sectoral level.
Annex A: Description of E3MG

Introduction and model overview
This annex presents a non-technical description of the E3MG model. Further information is available from the model website (www.e3mgmodel.com).

E3MG is a computer-based model of the world’s major economies, energy systems and the environment. It has been developed by teams at 4CMR at University of Cambridge (www.4cmr.group.cam.ac.uk) and Cambridge Econometrics (www.camecon.com). Other than geographical coverage, it is very similar in design to the European E3ME model\(^{12}\) and the UK’s MDM-E3 model\(^{13}\). A key feature of the model is its high level of disaggregation, which allows for the analysis of detailed policy measures and enables the model to produce a detailed set of results. The main model classifications in the current version of the model are:

- 20 world regions
- 19 energy-using groups
- 12 fuels
- 14 emission types
- 42 economic sectors
- 28 consumption categories

For the scenarios discussed in this paper E3MG has been set to produce annual solutions in the period up to 2020.

E3MG is intended to provide a framework for analysing the short and long-term implications of global Energy-Environment-Economy (E3) policies. The model incorporates two-way linkages with feedback effects between the economy, energy demand/supply and environmental emissions.

E3MG first explains existing behavioural patterns before using these to make future projections, in contrast to the computable general equilibrium (CGE) method, which generally imposes many of these relationships by assumption.

E3MG’s underlying methodology is post-Keynesian, based on an econometric approach which, on a dynamic year-to-year basis, explains the evolution of the world’s economies and energy systems. The specific techniques are cointegration and a system of error correction (see below) that allow short-term deviations while moving towards a long-term trend (usually interpreted as equilibrium). We do not impose assumptions that the long-term outcomes are met, in the period up to 2020.

E3MG includes several other features that are often missing from equilibrium-based models include varying returns to scale, voluntary and involuntary unemployment, varying degrees of competition and the possibility of non-optimal outcomes.

Another important feature of the E3MG model is its endogenous treatment of technology. E3MG measures technical progress as a function of accumulated investment enhanced by R&D spending. Technical progress leads to more efficient production, higher-quality products and, ultimately, higher rates of economic growth. In some key technologies, spillover effects are taken into account.

\(^{12}\) http://www.camecon.com/AnalysisTraining/suite_economic_models/E3ME.aspx
\(^{13}\) http://www.camecon.com/AnalysisTraining/suite_economic_models/MDM-E3/MDM-E3_overview.aspx
The economics of E3MG

The economic structure of E3MG is fully consistent with the structure of the National Accounts, as defined by ESA95 (Eurostat, 1995). The sectors are linked by their intermediate purchases through input-output tables, while the countries are linked through estimated equations for international trade.

Figure A.2 shows how the economic module is solved as an integrated global model.

Most of the economic variables shown in the figure are defined by sector. The whole system is solved simultaneously for all 42 sectors and all 20 global regions, although single-region solutions are also possible.
Data and classifications

Classifications play a central role throughout the E3MG model and are strictly adhered to. The classifications provide the model with its sectoral detail and ensure consistency with the national accounts, for example by avoiding double counting. The main industry sector classification has been carefully designed to reflect both the requirements of the model users and the available data. Most of the 42 sectors are defined at the NACE (revision 1.1) two-digit level. However, more detail is provided for the main energy-producing sectors and some of the energy-intensive sectors, which is particularly relevant for this study.

A combination of data sources is used in E3MG, with recognised international databases being used wherever possible. These include Eurostat, the OECD’s Structural Analysis (STAN), the UN, the World Bank, the IMF and the Asian Development Bank. Where gaps remain in the data, national sources are consulted. In each case the data are collected by sector and checked against macroeconomic totals.

A key part of constructing a working model is completing the data. This presents a particular challenge for modelling non-OECD and developing countries. The algorithms used at Cambridge Econometrics are based on the Ox software package (see Doornik, 2007) and are designed to combine data sources to make the best use of the available information. They apply interpolation and extrapolation techniques (usually constrained to an available total) to complete the data sets.

Energy-environment interactions

The links between the economy and the energy system are central to the design of E3MG and the model includes two-way interactions between each area, including full feedback effects.

Energy sub-model

The energy equations play a key role in the modelling. As is the case with the other estimated model equation sets, each equation is estimated independently for each sector (fuel user) and country, with no cross-elasticities imposed; this reflects the inherent differences in patterns of energy use between sectors and, to a lesser extent, between countries. Aggregate energy demand is determined as a function of economic activity, the relative price of energy, and investment/R&D (which can improve efficiency). The equations for the four main fuel types are then solved using the same specification but with the relative prices for each particular fuel type. Results for the other fuels are obtained by using fixed shares (so for example if demand for natural gas increases, demand for derived gas also increases) specific to each sector. Finally, the results are scaled so that fuel consumption by each fuel adds up to the aggregate figure.

The energy submodel feeds back to the economy through adjustments to input-output coefficients and changes in final consumer demands.

The long-run price elasticities for aggregate energy demand are imposed in the estimation routines and are taken from relevant publications, usually based on cross-sectional estimates that look at differences between countries rather than differences over time. The main sources are the same as those used for the E3ME model’s parameters, including Roy et al (2006) and Franzén and Sterner (1995).

The energy modelling is based on IEA data, which is aggregated to the twelve fuel types and 19 fuel-user groups and stored on E3MG’s databases. These are closely linked to the model’s main industry classifications so that the linkages between the energy and economic systems are explicit.

Power sector sub-model

E3MG includes a highly-specialised submodel of electricity generation, which is based on engineering, decision-based, principles. This detailed treatment is based on a list of up to 28 energy technologies (including conventional and renewable options) that are used to meet a desired level of capacity and generation. Time series for capacity and generation are required for each of these technologies; the data have been obtained from the IEA database. The decisions on which technology is selected for expanding the electric system and for meeting the demand for electricity are based on minimising “levelised” costs, which take into account capital costs, fuel costs, labour costs, any charges or taxes (including environmental taxes or emission-trading costs), but also consider historical data. Crucially, the model incorporates a function of
learning-by-doing, so that, over time, as new technologies are developed and implemented the cost of these
technologies falls.

For further details on the treatment of power generation, see Barker et al (2006).

Emissions

E3MG produces results for 14 types of air-borne emissions, although our focus is on energy-related CO2
emissions. The E3MG database incorporates figures from the EDGAR database, disaggregating wherever
possible. Emission coefficients are estimated from the historical data and these are held constant throughout
the modelling.

All the data sets are completed using the same procedures as described above for the economic data.

Econometric specification

The E3MG model includes 22 stochastic sets of equations, in which behavioural parameters are estimated
using econometric techniques. These equation sets cover the components of final demand, prices and the
labour market, plus energy demands. Each equation set is disaggregated by sector and by country; for
example there are 42x20 equations in the set for employment.

Equation parameters are estimated independently for each of these equations, with no cross-sectoral or
cross-regional restrictions (i.e. no panel data techniques) imposed on the estimation. In some regions the
data series are not long enough to estimate robust long-term parameters so a method of shrinkage is used,
assuming long-term convergence between global regions. The general method of estimation is based on the
References


