Carbon leakage prospects under Phase III of the EU ETS and beyond

Report prepared for DECC

Final report
June 2014

Acknowledgements

Vivid Economics has relied upon the expertise, data, time and timely input from the staff of several industry associations and industrial firms in this work and would like to express its very warm thanks for all their contributions.

Vivid Economics is grateful for the encouragement and support of staff at DECC and other members of the project steering group from the Department for Business, Innovation and Skills, HM Treasury, the Committee on Climate Change and the Emissions Trading Group throughout this project and for the efficiency with which the project has been managed and the speed at which decisions have been taken.

The work has been a joint project between Vivid Economics and Ecofys. As always, it has been a pleasure working with the Ecofys team and Vivid Economics thanks them for their expert, professional and collaborative approach to the project. All modelling results presented here, and any errors or shortcomings therein, are the exclusive work of Vivid Economics, while all non-modelling results represent a joint effort between Vivid Economics and Ecofys.

This report contains the views of the authors and does not represent or contain the views of DECC or any part of UK Government.

An appropriate citation for this report is:

Vivid Economics with Ecofys, *Carbon leakage prospects under Phase III of the EU ETS*, report prepared for DECC, December 2013

Executive Summary

Carbon leakage risk in the EU ETS is potentially significant for carbon- and trade-intensive sectors under high carbon prices; a number of measures can tackle leakage but no perfect solution exists

Aims

This report investigates the risk of carbon leakage under the EU Emissions Trading System (EU ETS) so far, and over Phase III and beyond.

It addresses the following questions:

– What does the evidence tell us about the extent of carbon leakage during Phase II of the EU ETS?
– What are the characteristics of sectors that are particularly exposed to risk of leakage and what determines the rate of leakage?
– How suitable is the current approach to identifying sectors at risk from leakage and what alternative eligibility criteria might be proposed for doing so?
– How does the risk of carbon leakage depend on the carbon price level?
– How suitable are different policy options as a means to mitigate leakage risk, including alternatives to free allocation?

The report shows modelled estimates of the impact of a range of carbon prices on a selected, diverse list of manufacturing sectors out to 2030. These impacts cover revenue, output, margin, market share and emissions. The report also critiques part of the current policy framework for dealing with carbon leakage, in the form of the EU's carbon leakage criteria, and provides a brief appraisal of the major alternative leakage-mitigation policies available. In addition to free allocation, the set policies include compensation, exemptions and border carbon adjustments, and the report measures their performance in terms of efficiency, effectiveness, political feasibility and administrative cost.

Evidence of carbon leakage under the EU ETS so far

In this report, the term 'carbon leakage' refers to the effect in which carbon prices drive up relative costs and reduce the relative competitiveness of EU firms such that their output falls. Some of the output transfers to overseas producers with the rest accounted for by reduced domestic consumption, which leads to changes in carbon dioxide emissions both within and outside the EU. Carbon leakage refers to the increase in emissions resulting from the relocation of production.

This report considers both 'output leakage' and 'carbon leakage'. The former is measured as the ratio between increases of *output* in less-stringently regulated regions to falls in output in the reference region, and the latter is the ratio between increases in *emissions* in unregulated regions and falls in emissions in the reference region.

The literature to date on carbon leakage can be divided, broadly speaking, into two main streams:

– *theoretical* or *ex ante* research, which employs calibrated economic models to predict the impact of hypothetical carbon prices;

– *empirical* or *ex post* research, which uses econometric techniques in attempts to estimate the impact of real-world carbon prices

Numerous issues complicate both the theoretical and empirical estimation of carbon leakage rates. These issues arise in the construction of basic models of how leakage occurs, in teasing out carbon effects from other influences, in gathering appropriate data, and in interpreting results. The modelling in this report is classed as theoretical research.

Empirical studies of carbon leakage in the EU ETS generally fail to find convincing evidence of substantial leakage. Ideally, analyses are done by quantifying the impact of the EU ETS on competitiveness and comparing it to a counterfactual scenario where the EU ETS is not implemented, but there is no straightforward natural experiment available in this case. In reality, the impact of the EU ETS is difficult to disentangle from other macro-economic factors, especially in economically dynamic times and when the allowance price is low.

The theoretical literature generally suggests that leakage rates could be fairly substantial, albeit with substantial differences in predictions between general equilibrium and partial equilibrium models.
The papers surveyed here generally make specific assumptions about the structure of the markets they cover, the climate change policy environment, the production technology at work and the possibility of technological progress, and the carbon price. As is inevitable in economic modelling, the assumptions confer some limitations on the interpretation of results, with model outputs being sensitive to parameter values, model type and choices in the model design.

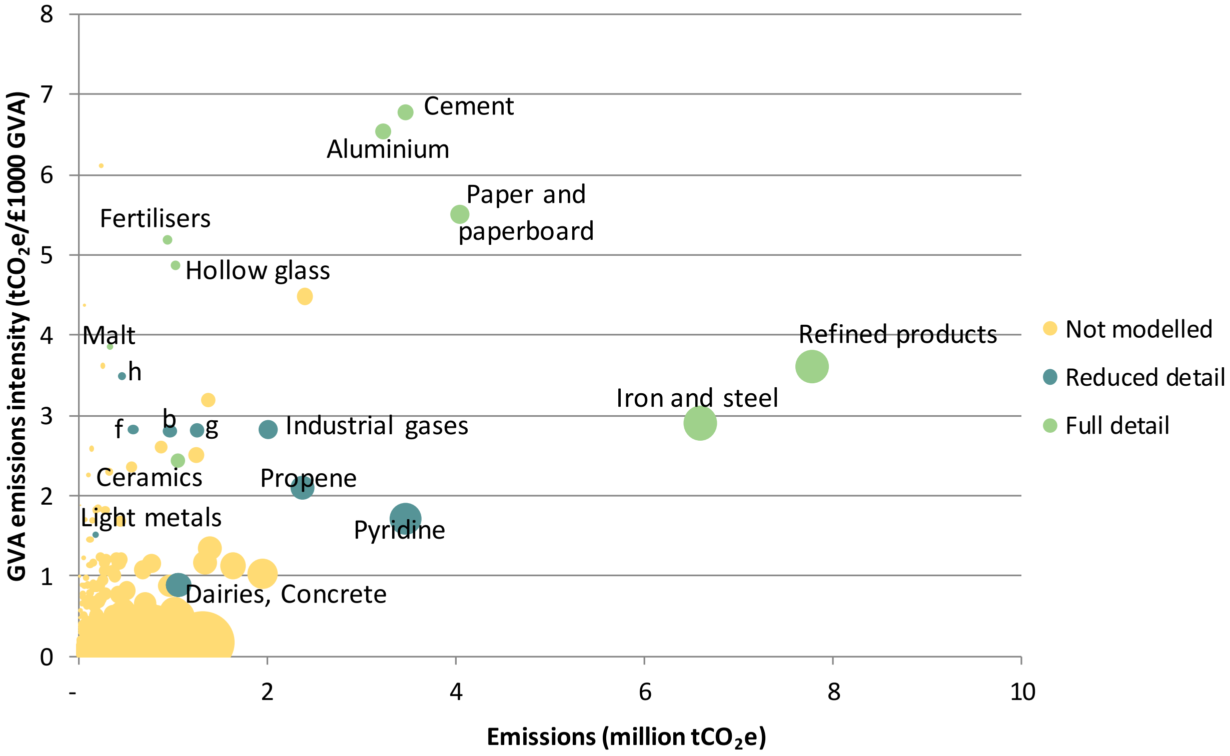
Between the two areas of literature, and to a lesser extent within each, no consensus emerges on leakage estimates.

Assessment of carbon leakage for a selection of sectors

Sectors investigated

Twenty six sectors were selected for model-based investigation, some more detailed than others. They span a range of emissions intensities, levels of trade exposure, and other characteristics (Figure 1). The intention of the sector selection process was to cover a range of industries having different carbon and trade intensities, with a bias towards relatively carbon-intensive and trade-exposed sectors including cement, refined products and fertilisers. This was balanced against practical modelling issues, such as data availability. They include sectors for which there are estimates reported in the literature and those which are studied here for the first time, such as heavy clay ceramics, malt and distilled air products.

Figure 1. **The selected sectors cover a range of sizes and emissions intensities at the UK level (size of bubble equates to GVA)**



Notes: *In order to preserve legibility, some sector labels have been replaced by letters, whose code is given as follows: b: Veneer and other boards; f: Man-made fibres; g: Rubber tyres and tubes; h: Flat glass. Dairies and concrete have very similar levels of emissions intensity and so appear to overlap, thus the legend is for both sectors. GVA data is not available for flat and long steel separately. GVA data is not available for all four paper subsectors separately, so emissions and GVA data is reported for the sector 'Paper and paperboard'. GVA or emissions data for the UK for 2007 was not available at the required level of granularity for the following sectors, which are omitted from the chart: Non-dolomitic lime, Sugar and passenger vehicles.*

Source: *Vivid Economics*

Description of modelling

This study uses Vivid's Industrial Market Model to analyse interactions between rival firms and consumers within capital-intensive industries. The intention of the model is to depict individual economic markets and to capture the impact of changes in market structure, including the entrance or exit of individual firms, changes in the nature of demand, or, of particular relevance in the context of carbon prices, changes in production costs.

The model is well-suited to industrial sectors where firms have large fixed costs, such as energy-intensive industries. The model is based around the Cournot model of oligopoly, familiar to academic economists, and is conceptually similar to the qualitative Porter's Five Forces model, widely used in corporate strategy analysis. It is a partial equilibrium model, solved algebraically.

Both the Full Industrial Market Model (FIMM), which incorporates information on individual facilities within the market, and the Reduced Industrial Market Model (RIMM), which is more aggregated, are used in this study estimate the impact of *future* scenarios of carbon price differentials, €5, €15, €30 and €50/tCO_2, between EU and non-EU producers. These impacts vary across sectors, driven by differences in demand elasticity, profit margins, the degree of competition between producers, and particularly the share of non-EU importers in the market. For some sectors, even relatively low carbon prices have a strong impact; for others, the impact is more muted.

The models are of the partial equilibrium type, representing individual firms in competition with each other. Some sectors are studied in detail, with a heterogeneous set of competing firms, and others in less detail, with a homogenous set of firms. The characteristics of these firms and their behaviour reflect market data. The model allows firms to expand, contract and exit, and places some firms in the UK, some in the EU and some outside the EU, in accordance with production and trade statistics. The study uses publicly available data which has been supplemented with some sector specific data provided by sector associations.

Caveats

Whilst the models do allow one to find the destination and magnitude of output and emissions leakage; integrate qualitative information gathered during expert interviews; and explicitly account for strategic interactions between firms (in FIMM) when determining cost pass-through, rather than relying on aggregate relationships, the necessary input assumptions and their associated uncertainty do present a number of limitations that mean modelling results need to be interpreted carefully.

The modelling results give **upper bound** estimates of the impacts of carbon prices because:

- no carbon abatement measures have been undertaken by firms in response to higher carbon prices owing to lack of available data;
- no adjustment is made for future decarbonisation of the electricity supply;
- it is assumed there is no carbon regulation in competing markets;
- the results are long-term, not immediate impacts;
- it is assumed there is no free allocation or any other policies or measures to tackle carbon leakage.

In addition, the models assume that the market is in equilibrium before the cost shock is introduced. This implies that all firms are optimally responding to the production strategies of their competitors, and that, in the absence of a cost shock, firms would not adjust their production plans. This may not be the case in reality; firms may be in the midst of expanding or reducing capacity.

Other mitigating factors might include supply chain relationships which encourage production to remain within Europe, and product heterogeneity which results in less competitive markets than assumed within the model.

Results

In the absence of carbon leakage policy, sectoral abatement measures, or other mitigating factors, the model results suggest that carbon prices can have a significant impact on at least some of the sectors examined in full detail, with production declines in the region of 20 per cent at carbon prices of €15/tCO_2. There is, however, substantial variation in the impact across sectors, and the impact for many sectors, particularly those investigated in reduced detail, is more muted.

An indication of the potential scale of carbon price shocks is provided by Figure 2, which shows gross profit margins and margin loss after a €15/tCO_2 carbon price shock, as a share of retail price. The initial cost shock is larger than the profit margin in several instances, though most sectors succeed in passing on the bulk of the costs. The carbon leakage estimates from the modelling are high relative to estimates in some of the literature; this may in part be because it does not incorporate estimates of emissions abatement measures.

The main factors determining the impact on production are the carbon price, the carbon intensity and proportion of production covered by the EU ETS. Consider each of the above factors in turn.

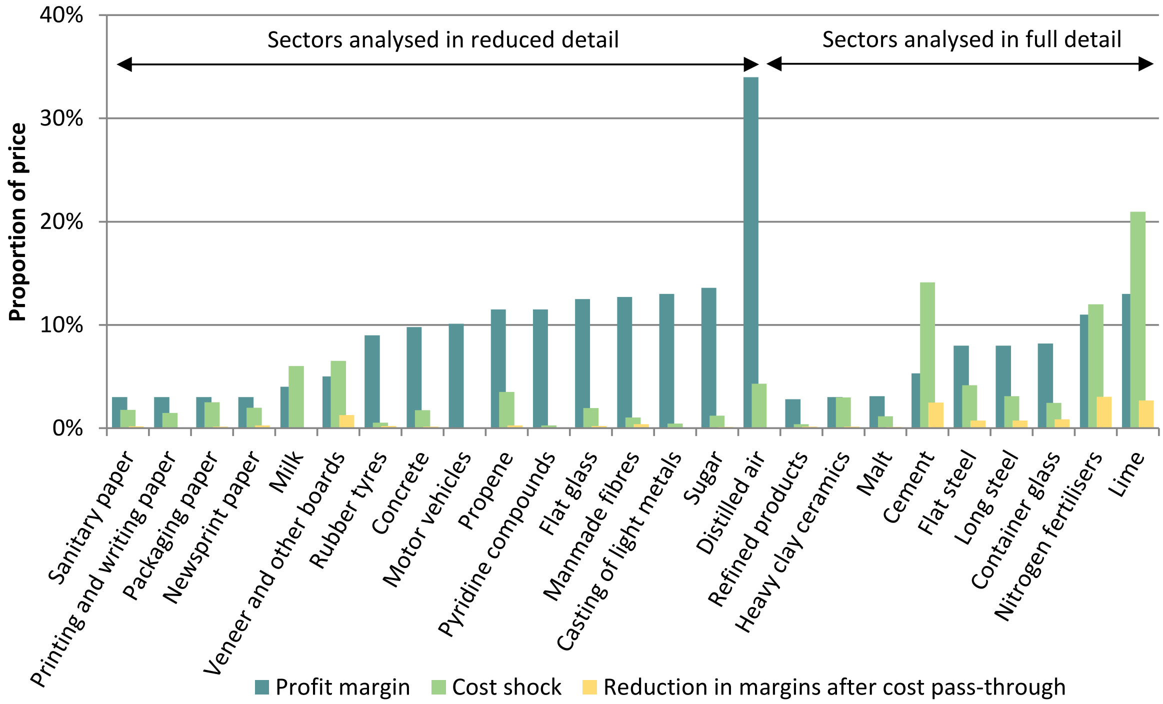
The carbon price determines the magnitude of the cost shock faced by firms. The size of the cost shock affects the change in firms' output, given the elasticity of demand, degree of competition and the market share of inside firms. The impact of the cost shock can be mitigated by the rate of cost pass-through. In the most carbon-intensive sectors, for example, nitrogen-based fertilisers or cement, impacts on output are significant at a carbon price differential of €15/tCO_2. In the most extreme scenario tested, €50/tCO_2, there are large shifts of output in favour of non-EU firms. Other sectors, however, are much more resilient to carbon pricing, such as malt, concrete, distilled air products and milk, see Figure 3, where the impact of the cost shock is mitigated by the rate of cost pass-through.

The carbon intensity of production is a key factor that affects the estimated carbon leakage rate. Sectors in which the relative carbon intensity of outside firms is greater than that of inside firms tend to have larger estimated carbon leakage rates for a given rate of output leakage.

The proportion of production occurring in the EU, and therefore covered by the EU ETS, is also a significant factor that affects the estimated cost pass through rates for different sectors. When imports are low and a high proportion of production is within the EU, the cost shock affects a larger proportion of supply and given the degree of competition in the market, firms are able to pass on a greater proportion of costs. Indeed the relationship between cost pass-through rate and inside market share is approximately linear, although other factors do play a significant role, notably heterogeneity in the competitiveness of inside firms. Due to the large number of firms in most sectors, the cost pass-through rates are between 80 and 100 per cent.

Sensitivity analysis that considers potential upside, downside and central scenarios with varying growth rates and fossil fuel prices indicates that the competitive position of individual sectors is a key factor that determines the degree of sensitivity. Sectors which already face some trade exposure, with between 10 and 20 per cent of the market supplied by outside firms, are the most sensitive to further changes in competitive position. Sectors with somewhat lower trade exposure, of between 5 and 10 per cent, such as container glass, have moderate sensitivity, and those with exposure of around one per cent or less, have the lowest sensitivity. In the sectors investigated in less detail, propene and motor vehicles exhibit the greatest sensitivity.

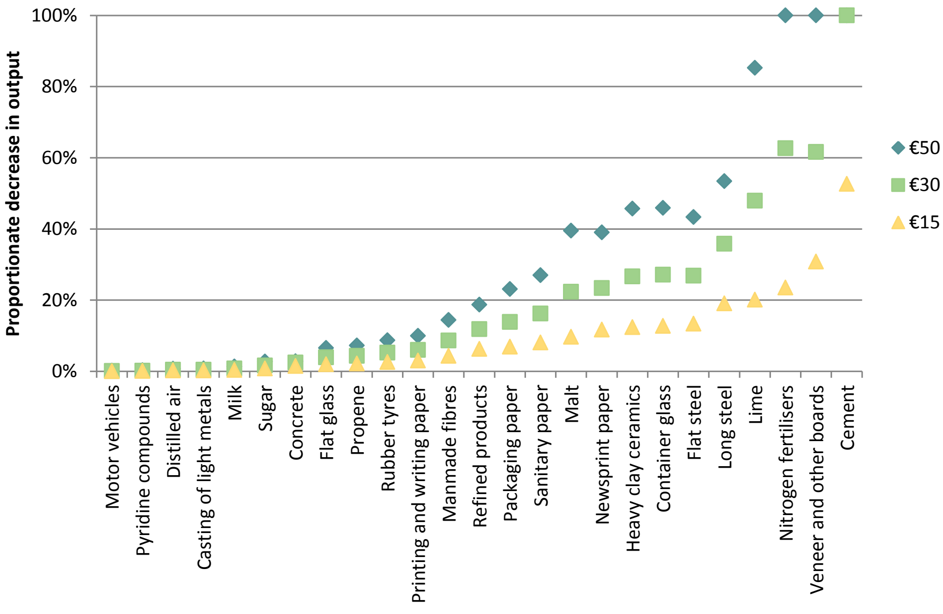
Figure 2. **Share of selling price represented by gross profit margins and a €15/tCO_2 carbon price shock; sectors investigated in reduced and full detail**



Notes: *Gross profit margins are pre-price shock. 'Carbon price shock' refers to the tonnage of carbon dioxide emissions per tonne of production, multiplied by the assumed €15 carbon price. 'Proportion of price' refers to the scale of the carbon price shock as a share of the average selling price of sector production, by tonne. The proportion of price is* not *adjusted to reflect that, in practice, some share of the carbon price shock would be passed on to consumers. Results for aluminium are not shown due to confidentiality concerns. Heavy clay ceramics refers to bricks and tiles.*

Source: *Vivid Economics*

Figure 3. **The impact of carbon price differentials on output varies considerably across sectors (2020)**



Note: *Aluminium excluded for confidentiality considerations*

Source: *Vivid Economics*

Key drivers of leakage risk

Modelling results suggest that a number of factors drive leakage risk. These include the degree of competition from non-EU firms, the share of carbon costs in firm profits, price sensitivity of demand for output and the degree of product homogeneity. The drivers can vary considerably across sectors and lead to differences in leakage risk.

For instance, at one extreme consider the factors that would make a highly exposed sector.

– A highly exposed sector will face aggressive rivals from outside the EU and the carbon costs will represent a substantial share of firm profits. Thus, cost increases cannot be passed on, because of aggressive external competition, and so profits will be significantly eroded, resulting in reduced investment and long-term decline in capacity. Those external rivals will already have costs low enough to allow them to secure a substantial market share in the EU, indicating their capability to take more market share if the opportunity arises.
– Fortunately for the rivals and unfortunately for the EU firms, the product is homogenous and customers are unable to distinguish between goods made within and outside the EU.
– To compound the problem in this hypothetical most exposed sector, consumers are price sensitive, making it harder for firms to pass costs through to them. In this case, the output leakage rate is high. If the external firms have higher carbon intensity per unit output than the internal firms, the carbon leakage rate will be even higher.

In contrast, consider the factors that would make a sector less exposed to leakage risk:

– A well protected sector will face few rivals from outside the EU and those that it does encounter will have low market shares, reflecting their poor competitiveness in selling to EU consumers. This relatively protected sector will sell little of its output outside the EU and thus overall encounter little extra-EU competition.
– This hypothetical sector will further benefit from consumers who are quite insensitive to price increases, allowing a greater proportion of costs to be passed through into prices. However, those cost increases will be small because the sector has low carbon intensity.
– To make the sector’s situation even more secure, the product is also bespoke, enabling EU firms to make many varieties and to establish customer loyalty and niches, which diminish the effective strength of competition. In this case, the output leakage rate is low.

Other factors affecting the risk of leakage include:

– The average emission intensity of electricity production, which varies substantially across European states, with some industries concentrated in particular areas. This suggests the location of industries even within Europe can influence how they are impacted by a carbon price. The variation in indirect emissions intensity between in European firms means that a carbon price in Europe might create redistribution of output between European firms. In addition, electricity prices may be affected by other policy costs that have not been explicitly taken into account in this study. Almost certainly there will also be differences in abatement response country by country, which will cause differences in exposure to leakage risk, though this has not been captured in the modelling here.

– Variation in emissions intensity across import sources is also an influence on the carbon leakage rate. In some cases there are a few small, carbon intensive installations in the EU, which lose market share disproportionately, reducing the carbon leakage estimate. In the other cases, the difference in carbon intensity between EU and non-EU firms is not so great.

Criteria for identifying sectors exposed to carbon leakage risk

While the modelling incorporates a range of factors in producing carbon leakage estimates, the EU's current methodology for classifying sectors as at risk of carbon leakage is based on two criteria: carbon cost intensity and trade exposure. These two metrics may allow the screening out of sectors with low rates of carbon leakage but additional information is needed to determine the rate of leakage itself, in particular, the strength of competition within the sector and the relative carbon intensity of producers within and outside the EU are influential factors.

The EU's criteria are intended to indicate the loss of competitiveness and associated loss of output and margin by EU firms as a result of higher costs of production, driven by a carbon price differential between firms inside and outside the EU. The first criterion reflects the impact on the cost of production normalised as a share of gross value added (GVA). The second criterion reflects the degree of competition from rival firms outside the EU.

Several criticisms can be made of the EU's approach, including:

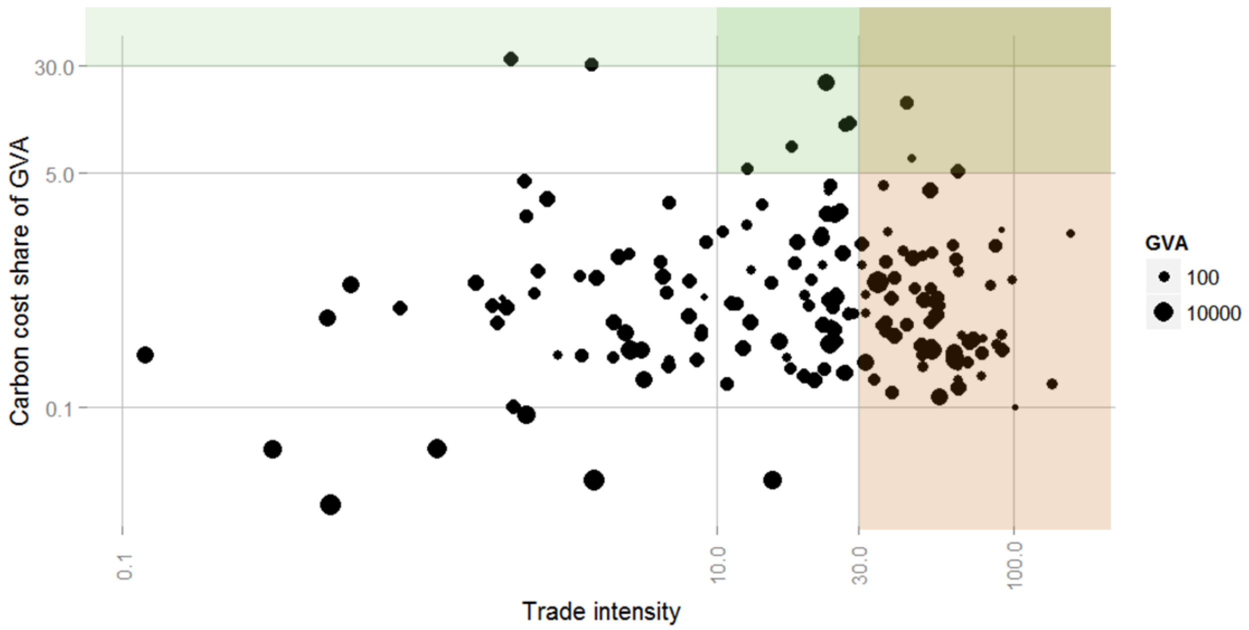
– the basic definitions of both criteria could be disputed, including the use of administrative, rather than economic criteria to define market boundaries for trade exposure, and the use of GVA in carbon cost intensity;
– several variables relevant to leakage risk are not included, such as carbon policies outside the EU, abatement potential, the price elasticity of demand and market structure;
– trade exposure does not account for the carbon intensity of production in trading partners, making it more relevant to output leakage than carbon leakage;
– the justification for the current choice of the thresholds for the criteria, and the means by which sectors can qualify, are unclear. The majority of sectors currently classified as at risk achieved their status through the trade exposure criterion (see Figure 4).

In addition, the EU's quantitative carbon leakage criteria, which assumes the cost pass-through rate is zero or constant across all sectors, misses sectoral distinctions. Where profit margins are low, even a high cost pass-through rate for a given cost shock may leave a firm facing a significant reduction in profitability.

Some of the shortcomings identified are, to some extent, inevitable given the difficulty of the task at hand; others might be solved in a fairly straightforward manner. The immediate suggestions to address these shortcomings are:

– removing systematic errors of false eligibility by: basing the intensity metric on a carbon price that better reflects prevailing market prices; revoking the trade-only criterion; using 'inside market share' in the denominator when measuring trade intensity for competition relating to EU sales; using profit or revenue instead of GVA when measuring carbon cost intensity;
– accounting for carbon rather than output leakage by taking into account the emission intensity of non-EU trade partners, and variation in indirect emission intensity across Europe; and,
– improving robustness by: taking into account significant imminent abatement improvements such as those to be delivered via regulation (such as the application of Best Available Techniques), and; making the trade criterion more accurate by applying the eligibility criteria to a definition of an economic market in a way that relates more closely to the definitions used in the regulation of competition.

Figure 4. **Most UK sectors that would qualify if the test was performed at the UK level do so due to having non-EU trade exposure above 30 per cent**



Source: Vivid Economics, ONS, CITL, Eurostat (2013)

Policy options for mitigating carbon leakage

There are various policy options available for mitigating carbon leakage. These are classified in this report into the following categories:

- provision of financial compensation to firms;
- exemption of economic sectors from the trading scheme;
- provision of free allowances to firms;
- application of a financial instrument at points of trade in relation to embodied carbon, that is, Border Carbon Adjustments.

All of the policy options have limited effectiveness and/or practicality. The first, direct financial compensation, does not effectively mitigate carbon leakage and being a sovereign fiscal matter would be difficult to implement on an EU-wide basis. The second, exemption of sectors, does not achieve the original policy goal of reducing carbon emissions even though it addresses leakage risk. The third, free allowances, has proven feasibility and can be effective in controlling carbon leakage, but it has a weakness in theory, in that it acts indirectly and its performance has not been demonstrated in empirical studies. The last, border carbon adjustment, is theoretically stronger, but has no operational track record and faces certain, significant practical problems, including that it can only be implemented in an approximate manner, and that it is likely to attract legal challenge or retaliatory trade action, or both, from non-EU countries.

Conclusions

Carbon prices in the EU ETS have been relatively muted to date, with periods of higher prices not being sustained. Nevertheless, with the possibility of carbon pricing being used to pursue serious mitigation efforts in the future, substantially higher carbon prices may arise. As the carbon price differential rises, all other things remaining equal, the risk of both output and carbon leakage increases, and so does the importance of competitiveness protection policies.

While understanding of this problem has advanced over the last five or so years, the economic evidence remains incomplete and inconclusive. The empirical estimates of small impacts appear to offer comfort, while theory tells us where the risks might lie and suggests that they may be significant. There are some candidate next steps in policy development.

In the medium term, carbon leakage risk can be mitigated by the current policy framework, but the cost-effectiveness of free allowance allocations could be improved by making revisions to the eligibility criteria which the European Commission uses. In the longer term, the prevention of carbon leakage may warrant more substantial policy reforms. The problem of carbon leakage may have to be addressed more directly, by solving the problem of differential marginal costs of production rather than relying on compensation through free allowances. It does not appear that free allocations can resolve these differences in production cost while being environmentally effective, because by resolving them through allocation in proportion to output, they reduce the effective carbon price. The most promising alternative, border carbon adjustment, may in theory be an economically and environmentally effective option, but its political and administrative feasibility is currently poor, or at best uncertain. Considering the potential future importance of carbon leakage, both free allocations and border carbon adjustments deserve to receive further effort in their evaluation, design and assessment.

Contents

List of tables

List of figures

1 Introduction

Objectives and structure of the work

Section contents:

1.1 Objectives, approach and structure

Four questions which probe carbon leakage

1.1.1 Objective

An ongoing concern in the operation of the EU ETS has been the extent of carbon leakage. This report reviews carbon leakage issues under the EU ETS, including policy options, and develops new estimates of impacts out to 2020 and beyond.

1.1.2 Definition of leakage

The term ‘carbon leakage’ refers to the possibility that carbon prices may drive up relative costs or reduce the relative competitiveness of EU firms so much that output would relocate to regions with less stringent environmental regulation, potentially leading to an increase in emissions that would offset some of the efficiency improvements and emissions reductions within the EU.

Carbon leakage is commonly measured as the ratio between increases of emissions in unregulated regions and decreases of emissions in regulated regions. The carbon leakage rate is frequently expressed as a percentage of emissions reductions in regulated regions. For instance, if, as a consequence of a particular policy, total carbon emissions in the UK declined by 200 tonnes but foreign emissions increased by 60 tonnes, the leakage rate would be reported as 30 per cent, 60 divided by 200.

1.1.3 Four questions

The work was commissioned by DECC to address four sets of questions:

– What does the evidence tell us about the extent of carbon leakage during Phase II of the EU ETS?
– What are the characteristics of sectors that are particularly exposed to risk of leakage and what determines the rate of leakage?
– How suitable is the current approach to identifying sectors at risk from leakage and what alternative eligibility criteria might be proposed for doing so?
– How does the risk of carbon leakage depend on the carbon price level?
– How suitable are different policy options as a means to mitigate leakage risk, including alternatives to free allocation?

1.1.4 Approach and report structure

These questions were addressed in various ways:

Leakage under the EU ETS to date was examined in a review of the available literature (Section 2), covering both theoretical and empirical research, and spanning both academic and non-academic or ‘grey’ sources such as technical reports, consulting documents and official reviews.

Following the selection of a list of sectors, a process managed by DECC with input from Vivid, each sector was researched using a combination of official sources, technical reports, other available documentation, and interviews with industry associations and, in many instances, firm representatives. The subsequent compilation of data was used to construct case studies for ten manufacturing sectors, contained in the Appendices to this report.

Those same ten sectors, as well as fourteen others, were subject to quantitative analysis using Vivid Economics' Industrial Market Models, in order to estimate the potential for carbon leakage risk. The sector selection process and the functionality of these models are discussed in Section 3, which also covers the timeframe, prices, and use of scenarios. Section 4 presents a summary of the modelling results while detailed discussion of modelling results for individual sectors is contained in the case studies.

The modelling helps inform a discussion of the appropriateness of the EU's carbon leakage risk assessment methodology, which is found in Section 5. This assessment was largely conducted by a thorough review of the EU's methodology, an attempt to replicate the methodology which informed the sector selection process, a review of the literature, and the application of the economic and policy expertise within Vivid Economics and Ecofys.

Finally, the discussion of policy options for mitigating leakage, contained in Section 6, followed a similar process, involving both literature research and expert appraisal. Both the policy assessment and the critique of the EU's criteria are qualitative analysis, with no quantitative attempts to evaluate the impact of the various effects identified.

2 Literature review: carbon leakage under the EU ETS

Evidence for leakage to date is limited

Section contents:

Theoretical studies suggest higher leakage rates than those supported by empirical studies

An increasingly large body of literature has investigated the extent of carbon leakage under the EU ETS, adopting both theoretical, or ‘ex ante’, and empirical, or ‘ex post’, approaches. The theoretical literature tends to predict relatively large leakage rates, while the empirical literature struggles to identify significant leakage to date (the modelling conducted as part of this report would be classed as theoretical literature).

This disparity could be attributed to a number of factors, including differences between theoretical assumptions and real world variables, the time frame over which leakage can be expected to occur, and the innate econometric difficulties in empirically identifying leakage rates. This makes it difficult to draw firm conclusions regarding potential leakage risk under higher carbon prices in the future.

2.1 Introduction

A large body of literature, with divergent approaches, has investigated EU leakage

This section reviews the existing literature, theoretical and empirical, on the extent of carbon leakage. The foundations, strengths and limitations of the available evidence are considered, together with its insights for policy makers. The empirical evidence for carbon leakage from the EU ETS is limited and it suggests low rates of leakage, but it is not yet of sufficient depth and quality to be relied upon. Meanwhile theoretical studies indicate a different conclusion: that significant leakage rates might occur. The true picture remains ambiguous.

2.1.1 Four mechanisms relating to leakage

Three main channels of carbon leakage have been identified (Reinaud, 2008):

- *the short term competitiveness channel,* where carbon constrained industrial products lose international market shares to the benefit of unconstrained competitors, for example in the recent beginnings of economic recovery;
- *the investment channel:* where differences in returns on capital associated with unilateral mitigation action provide incentives for firms to direct capital towards countries with less stringent climate policies, for example, as a consequence of recent economic recession;
- *the fossil fuel price channel:* where reductions in global energy prices due to reduced energy demand trigger higher energy demand and CO_2 emissions elsewhere, all things being equal.

In addition, Dröge (2009) identifies technological spill-overs as a fourth channel of carbon leakage. However, in Dröge’s model the direction of shifts in production is reversed: the hypothesis is that stringent climate policies could stimulate technology development and innovation, improving the international competitiveness of firms in climate action regions. This might lead to a decrease in global emissions if new low-carbon technologies become the most cost-effective production method, with firms in the stringent climate policy regions gaining international market share. This relies on the assumption that there is a direct link between stringent policies and abatement action; that is, it does not consider abatement potential and technological availability.

This study will focus on the short term competitiveness and investment channels, as these relate directly to the impact of the EU ETS on the competitive position of firms in the UK and the EU.

2.1.2 Two broad approaches in the literature

Carbon leakage has become an increasingly popular research topic in recent years, especially following the introduction of the EU ETS. Though not all such research is relevant to the purposes of this document, the portion that is remains quite substantial. The various studies can be broadly divided into:

- work in which a theoretical model of the economy in whole or in part is devised and then calibrated with existing data;
- retrospective empirical studies, which use econometrics and other tools, including industry surveys, to assess historical leakage.

The former studies adopt a frequently more rigorous theoretical approach, but are sensitive to the assumptions that they make. The model used later in this study is a theoretical model of part of the economy. Retrospective studies have the benefit of using historical data to assess real-world leakage, but are limited by the quality of data available to them. In addition, the time-period that they cover may not be long enough to meaningfully assess leakage. Nevertheless, empirical models will account for the mitigating effects of policy action, such as free allowance allocation, and market action, such as abatement investment. These are sometimes omitted from theoretical models, as they are from the modelling presented later in this report.

The studies generally consider both output leakage and carbon leakage, where the former is measured as the ratio between increases of *output* in less-stringently regulated regions to falls in output in the reference region, and the latter is the ratio between increases in *emissions* in unregulated regions to falls in emissions in the reference region. Output leakage may occur for a variety of reasons; the challenge attempted by the literature is to identify the role played by carbon mitigation costs. This is challenging for empirical studies because carbon prices in Europe have been low and their variation small relative to other relevant variables such as energy prices.

Cost pass-through, that is, the change in output prices as a result of a change in input prices, is also a common topic for research, being closely linked to leakage rates; it is discussed by, for example, Ritz (2009) and Sijm, Chen, & Hobbs (2009). It is discussed in several places throughout this literature review. Some other studies cover the impact of environmental regulation on firm profitability, and a small minority trace the impacts of various leakage mitigation policies on welfare.

Several studies pursue specific policy issues, particularly Output-Based Allocation of allowances (OBA), which is a free allocation of emissions allowances linked to the quantity of goods produced. Studies considering OBAs frequently compare their efficacy with border adjustments. These measures, also known as Border Carbon Adjustments, Border Tax Adjustments or Border Adjustment Mechanisms, encompass policies that impose a tariff on imports of commodities from unregulated economies, or export subsidies of commodities from regulated firms. A few papers consider other methods of allowance allocation, including auctioning and grandfathering, in which emissions allowances are allocated based on production units' past emissions. Where this literature is useful in understanding the performance of these policy instruments, it is discussed in Section 6.

Table 1 summarises the more significant estimates of leakage rates in the literature. A more detailed discussion of individual studies follows.

Table 1. **A range of estimates of leakage are available from the academic and grey literature**

Study and core methodology	Study type	Period covered	Sector and Geography covered	Carbon costs considered	Reported carbon leakage rates from EU to non-EU (per cent)	Notes
Theoretical: Computable General Equilibrium (CGE) models						
Burniaux & Martins, 2000	Academic	pre EU ETS;1996-1999	Global; international coal market	A range of prices including carbon taxes is considered, but no explicit carbon tax is mentioned	2 to 27	Static GE model, calibrated on the OECD GREEN model; Assumptions regarding free allowances unspecified
Carbone, (2013a)	Academic	1995-2011	Global; 112 regions; 57 sectors;	No explicit carbon tax considered, but tax is set so as to reduce emissions generation by 20%	-9 to 28	Findings of positive leakage driven by assumptions of substitutability between energy and non-energy factors of production; Assumptions regarding free allowances unspecified
Caron, 2012	Academic	1995-2008	International; 51 sectors;	Assumes a carbon price between 41 and 55 USD/kgCO_2	1 to 17; finds that on average aggregation overstates output leakage with higher carbon prices	Compares aggregation bias across measures of emissions reduction; Assumptions regarding free allowances unspecified
Kuik & Hofkes (2010a)	Academic	data calibrated to 2001 - 2006 data,	Global; Mineral sector;	Assumes a carbon price of 20 Eur/tCO_2	Under EU ETS: 17-33; under border adjustments: 14-27	In line with other findings suggest that there may not be an environmental case for Border Tax Adjustment imposition, but may be justified on the grounds of sectoral competitiveness
Kuik & Gerlagh (2003)	Academic	(Kyoto Protocol); 1995 trade and production statistics	OECD; GTAP economy-wide dataset	Endogenous calculation of carbon tax required for various regions to reach their emissions targets: for the US, \$3.5/tCO_2; for Japan, \$28/tCO_2; for the EU: \$17/tCO_2; Other OECD, \$24/tCO_2	11-15;	Implementing import tariff reductions raises leakage, but reduces welfare by a more than offsetting amount
Gerlagh & Kuik (2007)	Academic	1999-2005	Global; Energy-intensive goods	Carbon prices are determined by the model so that countries achieve their emissions reductions target as in Kyoto Protocol statements	-17-17	Key finding: carbon leakage can become negative with even small amounts of technology spill-over

Study and core methodology	**Study type**	**Period covered**	**Sector and Geography covered**	**Carbon costs considered**	**Reported carbon leakage rates from EU to non-EU (per cent)**	**Notes**
Monjon, Stéphanie, Quirion, 2009	Academic	Calibration year 2005	Global; multi-sector;	Between 14 and 27 €/tCO_2	5 to 12;	Assumptions regarding free allowances unspecified. The quantity of allowances allocated freely or auctioned is determined as an output of the model. BAs reduce leakage more, but output-based allocations may raise equivalent revenue without adverse impacts on output
Theoretical: Partial Equilibrium models						
Allevi et al. (2013)	Non-academic		Focuses on EU-ETS-covered part of cement in Italy	Carbon price between 32 and 100 €/tCO_2	17–100 clinker carbon leakage depending on transportation costs and CO_2 price	
Demailly & Quirion, 2006	Academic	Projections from 2008-2012; policy calibrated to 2004.	Global; Focuses on cement	Assumes a carbon price of 20 €/tCO_2	0 to 50	
Droge, Grubb & Counsell (2009)	Non-academic		Focuses on electricity, steel, cement and aluminium; draws on studies focussing on these industries in the UK, US, Poland and the EU	Assumes a carbon price of 14 €/tCO_2	0 to 39	
Healy, Pilippe Quirion, and Schumacher (2012)	Non-academic		EU; focuses on the grey clinker market	Assumes carbon price of 20 €/tCO_2	22	
Linares & Santamaria (2012)	Non-academic		Focuses on EU-ETS-covered part of cement, steel and oil refining in Spain; leakage risk is inferred from declining net margins of domestic production	35 €/tCO_2 for cement and steel	For cement, coastal regions have leakage risk over 88% for carbon prices over 18 Eur/tCO_2; similarly for BOF steel, leakage is significant for prices higher than 12 Eur/tCO_2; for refining, a carbon price over 40 Eur/tCO_2 results in losses for domestic firms.	

Study and core methodology	Study type	Period covered	Sector and Geography covered	Carbon costs considered	Reported carbon leakage rates from EU to non-EU (per cent)	Notes
Ponssard & Walker, 2008	Academic	1995-2007; production data calibrated to 2006	Focuses on cement in a "typical Western European country market".	Assumes a carbon price of 50 €/tCO_2	70 to 73	
Ritz, 2009	Academic	ex ante; market data for 2004; parameters calibrated using data between 2003 and 2005	Focuses on EU ETS-covered steel	Assumes a price of emissions of 20 €/tCO_2	9 to 75	
Szabó, Hidalgo, Ciscar, & Soria, 2006	Academic	1990-1997	European Union and Kyoto Protocol Annex B countries: focuses on cement	Carbon price between 28 and 40 €/tCO_2	Carbon leakage:29; production leakage:33	Includes scenarios for technology development in various parts of the cement production process under the EU's Business-as-Usual scenario
Econometric studies: Multisectoral Energy-Environment-Economy (E3MG)						
Barker et al. (2007a)	Academic	pre EU ETS;1995-2005	Economy-wide coverage of six EU Member States	Considers Environmental Tax Reforms (ETR) in the form of taxes between 0.07 and 1.08% of GDP in 2004	-3 to 2	Not a world model, and thus can only capture possible carbon leakage to other EU member states
Pollitt, Summerton, and Thoung (2012)	Non-academic		Focuses on Iron and Steel, Aluminium and Cement	assumes carbon price of 75-91 €/tCO_2	Output falls between 2.7 and 5; Emissions change between -0.2 and 0.1	
Regression						
Abrell, Zachmann, and Ndoye (2011)	Academic	2005-2008	Panel regressions; economy-wide coverage of the EU		No strong evidence of leakage economy-wide; some sectors are more affected than others	
Chan, Li & Zhang (2012)	Academic	2001-2009	Panel regressions covering power, cement, iron and steel in the EU		For cement, iron & steel no evidence of carbon leakage	
Cummins (2012)	Academic	2005-2007	Panel regressions; economy-wide coverage of the EU		No strong evidence of leakage economy-wide	
Ellerman, Convery & Perthuis (2010)	Academic	Phase I of the EU ETS	Focuses on oil refining, aluminium, iron & steel, cement		No observed impact on competitiveness in oil refining, cement, aluminium or steel	

Study and core methodology	**Study type**	**Period covered**	**Sector and Geography covered**	**Carbon costs considered**	**Reported carbon leakage rates from EU to non-EU (per cent)**	**Notes**
Lacombe (2008)	Academic	Phase I EU ETS	Focuses on Petroleum		No strong evidence of leakage or competitiveness effects	
Sartor (2012)	Academic	first 6.5 years of EU ETS	Focuses on Aluminium		No strong evidence of leakage	
Surveys and Case studies						
The Boston Consulting Group (2008)	Non-academic	Phase III EU ETS	Focuses on cement in EU-27;	Carbon price between 5 and 80 €/tCO_2; free allocation between 0 and 100%	By 2020: 100% reduction of EU production at CO_2 prices of higher than 35 €/tCO_2 without free allocation; 80% of EU production gone at CO_2 prices of 25 €/tCO_2; Rise of 7-38 Mt CO_2 due to carbon leakage	
Cobb, Kenber, and Haugen (2009)	Non-academic	Phase I of the EU ETS	8 firms, operating EU-wide in the sectors: steel, cement, aluminium, retail, pharmaceutical, power, glass		Steel and aluminium firms suggested a qualitative negative impact of the EU ETS on competitiveness, but no specifics	
Graichen et al. (2008)	Non-academic	Phase III of the EU ETS	Focuses on sectors in the EU ETS with more than 3 installations in Germany		For Germany sectors at risk of carbon leakage are basic iron and steel, fertilizers and nitrogen compounds, paper and paperboard, aluminium, other basic inorganic chemicals	
Martin et al. (2012)	Academic	Phases I and II of the EU ETS	Economy-wide; EU		Other minerals, glass, fuel and iron & steel are the sectors most vulnerable as per survey outcome	
Martin, Muûls, and U. Wagner (2011)	Non-academic	Phase I of the EU ETS up to 2009	800 companies in the EU ETS		No strong evidence that the EU ETS has an impact on innovation	
Reinaud (2008)	Non-academic	Phase I of the EU ETS up to 2009	Covers steel, cement, aluminium and refining in EU-25 nations		The lack of carbon leakage observed is attributed to the free allocation and long term power contracts	

Study and core methodology	**Study type**	**Period covered**	**Sector and Geography covered**	**Carbon costs considered**	**Reported carbon leakage rates from EU to non-EU (per cent)**	**Notes**
Oliver Sartor (2013)	Academic	After introduction of EU ETS, anticipating Phase III; 1971-2010	Focuses on energy-intensive industries in Poland	Carbon price of between 20 and 30 €/tCO_2; aid intensity of between 50 and 75%; carbon cost pass-through rates of 88% in electricity markets; benchmark-based free allocations of allowances.	Under current policy circumstances, negative risk of leakage	

Notes: 'Period covered' is not always obvious and in some cases has been omitted, particularly for theoretically-based studies.

Source: Vivid Economics

A subset of studies considers the Kyoto protocol and its potential impacts on regions outside the EU. These are listed below:

Table 2. **A range of estimates is available from studies of regions outside the EU**

Study and core methodology	Study type	Period covered	Sector and Geography covered	Carbon costs considered	Estimated carbon leakage rates (per cent)	Notes
Aichele and Felbermayr (2010)	Academic	1995-2005	Global coverage; Kyoto Protocol	Regressions do not explicitly factor in carbon price assumptions	Carbon imports of a committed country from a non-Kyoto exporter are about 8% higher than if the country had no commitments	Theory-based gravity regressions by country and time; the authors note that countries may self-select into the Kyoto Protocol and thus the causal impact of membership on outcomes such as leakage cannot be determined
Demailly & Philippe Quirion (2009)	Academic	calibrated to 1997	Focuses on cement and member states of the Kyoto protocol		20	
C. Fischer & Fox (2009)	Academic	2004	CGE model focusing on energy-intensive industries in USA, Canada and Europe	Assumes carbon price of $\$14/tCO_2$	4.9 and 27.1	
Fowlie (2009)	Academic	2004-2007	PE model focusing on California	Assumes a carbon price of $\$25/tCO_2$	Complete regulation reduces domestic emissions by 8-11	
Ho, Morgenstern, and Shih (2008)	Grey	2002	Shorter time horizons use PE; longer-term use CGE models; economy-wide coverage of the USA	Assumes a carbon price of $\$10/tCO_2$	Overall approximately 25. For chemicals, non-metallic mineral products and primary metals approximately 40	

Source: Vivid Economics

2.2 The identification of carbon leakage rates is a difficult task

Various statistical issues complicate empirical identification of leakage rates

Numerous issues complicate both the theoretical and empirical estimation of carbon leakage rates. These issues arise in the construction of basic models of how leakage occurs, in teasing out carbon effects from other influences, in gathering appropriate data, and in interpreting results.

The theoretical discussion of leakage contains contradictory claims regarding the impact of climate change policy on competitiveness, emissions or output. For example:

- the pollution haven hypothesis suggests that energy-intensive industries will relocate to regions without environmental regulations, which will have a competitive advantage in these products through economies of scale;
- the factor abundance hypothesis is that capital-abundant countries will specialise in capital-intensive industries, which are associated with carbon emissions, and that environmental policy makes processes more capital intensive by inducing abatement. Whether output increases in nations under the environmental policy depends on their relative capital abundance;
- the Porter hypothesis is that climate change policy, if implemented correctly, can make firms subject to it more competitive by inducing them to adopt more efficient technologies.

Of these models of leakage, the pollution haven hypothesis is the most modelled and tested in the literature examined here.[1] The Porter hypothesis was investigated by Dechezleprêtre & Calel (2012) and Martin, Muûls, & Wagner, (2012); the latter conclude, along with other sources, that the evidence in favour of it is not compelling.

As noted, carbon leakage is usually measured as the change in GHG emissions in carbon-unregulated economies relative to the change in emissions in regulated economies, and is usually imputed from output leakage. Consequently, changes in the geographical composition of output for reasons independent of climate change policy, such as technology, factor availability, underlying economic conditions and transport costs, can confuse the identification of the impact of carbon prices. This is particularly true for those cases in which carbon prices are a minor part of the costs of firms, and thus a small influence compared to other factors: for example, as Martin, Muûls, & Wagner, 2011b find, trade exposure with least-developed countries can have a higher impact on a firm's propensity to relocate than can higher carbon costs. When models are constructed, it will rarely be possible to incorporate all these relevant factors and give them appropriate

[1] One exception is the work of Gerlagh & Kuik, (2007), who consider a competing model of globally integrated technology markets, and find that the observed data is better matched by a model in which firms are able to adopt innovation leading to more energy-efficient technology.

weight. Unsurprisingly, many of the caveats set out alongside the model used in this report relate to factors which have been omitted.

Further, there may be basic difficulties in obtaining suitable data: emissions intensity in particular can be hard to estimate precisely, particularly in economies which do not attempt to regulate carbon production. Individual industry sectors may be influenced to different degrees by climate change policy, and there is a question of how to aggregate individual industry effects to the whole economy. Data sources are discussed in section 3. In the modelling used later in this report, a reduced form model is applied to around half of the sectors examined, to cut the cost of data acquisition.

In practice, models are calibrated to data of varying degrees of aggregation. For instance, production and trade data is frequently available with greater granularity than is energy consumption data. It should be noted, though, that Caron (2012) suggests that aggregation overstates carbon leakage, but not significantly. A related issue is that of measurement error and interpretability of results. For the empirically-focused studies in particular, aggregation and small sample sizes lead to estimates spanning wide ranges and an inability to reject the hypothesis of no carbon leakage, rather than a positive prediction of no or small leakage. There is sufficient advantage from disaggregating to market level that the EU's approach has been to examine sectors at 4-digit NACE level and below, and for this level of detail, general equilibrium or macro models are not suitable for many sectors, becoming too complex.

Statistical attempts to identify carbon leakage suffer from other problems common in the econometric literature. Not only is no controlled experimental procedure possible, but even 'natural' experiments – where climate change policy is adopted within a region independently of that region's initial emissions, energy-efficiency, competitiveness, or output – are practically non-existent. Econometric studies can determine whether or not higher carbon prices are correlated with competitiveness or output, but there is no clear causal link from one to the other. The theoretical models are more explicit about drivers and causation but at the expense of omission of various real-world factors.

A particular empirical problem is that the period over which leakage may take place could be several years or even substantially longer. This is particularly the case with regards to industries that are highly dependent on energy, which also generally tend to be quite capital intensive. Thus, from the point in time when investment decisions are made, the impact on capacity and output can take several years to appear. Partly owing to this difficulty, relatively few of the surveyed studies consider the impact of incomplete environmental regulation on investment decisions or location; the bulk focuses on short-term competitiveness impacts. Again, this contrasts with theoretical models, which tend to offer commentary on the long term only and not on short-term effects, nor the pace of adjustment. Along with the other reasons identified above, this helps to explain why the two approaches would not be expected to generate similar results, and why one approach might not corroborate the results of the other.

From industry's perspective, the long-run uncertainties surrounding the carbon price may discourage low-carbon investment (or disinvestment), reducing carbon leakage rates. For many industrial investments, although strategic investment decisions may consider the market environment for 15 to 20 years into the future, the value of the project is most strongly influenced by its performance in the first five to seven years, because of the effects of discounting in valuation models.

2.3 Theoretical studies

The theoretical literature spans a broad range of leakage estimates

The body of work classed here as theoretical largely consists of theoretical models calibrated to historical data, based on the period before Phase III of the EU ETS. Some studies published entirely before the imposition of the EU ETS are also included.

2.3.1 The theoretical literature generally adopts either partial or general equilibrium models

The theoretical studies use a variety of modelling approaches. Some deal with the scope of the study, for instance, whether it concerns the whole economy or is sector-specific, and some deal with assumptions characterising market structure.

Some studies use Partial Equilibrium (PE) analysis to consider the impact of climate change policy on output, emissions, leakage and frequently profitability for a subset of sectors, modelled in detail. They are frequently calibrated to a specific industry. Demailly & Quirion (2006, 2008, 2009), Fowlie (2009), Ponssard & Walker (2008) and Szabó et al. (2006) primarily consider cement, while Kuik & Hofkes (2010), Monjon & Quirion (2011), Smale, Hartley, Hepburn, Ward, & Grubb (2006) and Ritz (2009) deal with steel either alone or with other large manufacture groups.

One particularly common type of PE model concerns oligopolistic competition between firms who compete on output quantity, rather than on price, that is, Cournot competition. This is applicable to relatively homogeneous products with little differentiation, such that producers face a single price and choose output as their strategic variable. Examples include Ritz (2009), Fowlie (2009), Ponssard & Walker (2008) and Demailly & Quirion (2006). The model used later in the report is of this type.

Other theoretical models use Computable General Equilibrium (CGE) frameworks, considering the impact of climate change policies on output, emissions and leakage for the whole economy. That is to say, they characterise the behaviour of economic actors, such as households, the government, producers of energy and non-energy goods, through a series of equations and demand elasticities, and then simulate outcomes of interest with economic data. These models are frequently calibrated with the comprehensive Global Trade Analysis Project (GTAP) dataset. This is a database covering international bilateral trade flows, production, consumption, and other key macroeconomic variables. While comprehensive in its global coverage, it is, inevitably, somewhat aggregated. Examples that make use of the GTAP dataset include Fischer & Fox (2009), Carbone (2013a), and Caron (2012).

A subset of theoretical studies was carried out in the period before the imposition of the EU ETS. They use, in general, similar techniques to the models described above, and do not derive radically different predictions. Examples include Burniaux & Martins (2000) and Barker, Junankar, Pollitt, & Summerton (2007). Some studies consider the potential impacts of environmental regulation in other regions, particularly the United States. Notable examples include Fowlie (2009), who considers the impact of incomplete environmental regulation in California, the Pacific Northwest and Southwest, and finds, in line with Ritz (2009), that the impact of incomplete regulation on emissions depends crucially on the relative size and energy inefficiency of the unregulated market. There is also and Ho, Morgenstern, and Shih (2008), who, using both partial equilibrium models (to analyse the short-term impacts of carbon price policies) and CGE models (to analyse longer-term impacts), find that regulation leads to sectoral recomposition of output and employment longer-term. Houser et al. (2008) provide a qualitative discussion of the impacts of carbon taxes, emissions trading systems and border tax adjustments across the US economy in line with those considering the EU.

2.3.2 The theoretical literature suggests a range of possible leakage rates

The theoretical literature generally suggests that leakage rates could be fairly substantial, albeit with substantial differences in predictions between general equilibrium and partial equilibrium models (refer Table 1).

The theoretical, partial equilibrium models similar to the model used later in this report are covered by eight studies in the literature review. The studies are predominantly concerned with the cement sector. They state carbon leakage rates of 17 – 100, 0 – 50, 22, 88, 70 – 73 and 29 per cent for cement, and 9 – 75 per cent for steel. Two studies which look in particular at Phase III of the EU ETS, offer estimates of carbon leakage of 0 – 39 per cent. In the model in this report, the estimates are 75 – 125 per cent, across a range of sectors, and not taking account of emissions abatement measures.

In comparison, computable general equilibrium models produce carbon leakage estimates generally in the range 5 – 15 per cent. Econometric studies produce estimates of 0 – 5 per cent and do not confirm any causal relationship between CO_2 prices and production.

Where cost pass-through is high, output leakage as a result of environmental regulation is expected to be lower, see Ritz (2009). While cost pass-through is influenced by various factors, it can be expected to vary inversely with the price elasticity of demand. As noted by Sijm et al. (2009), the impacts of environmental regulation on electricity prices depends on the relative size of unregulated firms and the elasticity of demand: where the unregulated firms comprise a small part of the market, environmental policy has a small impact, and vice versa. In the model results presented later, sensitivity to the price elasticity of demand is tested and found to be modest. Carbon leakage is assumed to work through two channels (see Droege, 2009): declining market-share of regulated firms, and declining profitability of regulated firms. The latter channel does not appear to be a strong effect in the power industry.

2.3.3 Assumptions are necessary to ensure tractability, but result in limitations

The papers surveyed here generally make specific assumptions about the structure of the markets they cover, the climate change policy environment, the production technology at work and the possibility of technological progress. As is inevitable in economic modelling, the required assumptions produce some limitations on the interpretation of results, with model outputs being sensitive to parameter frameworks and choice.

The papers discussed usually use static models: they usually do not take into account dynamic incentives to innovate in energy efficiency and technological improvements of efficiency. This is true of the model used later in this report. Notable exceptions include Gerlagh & Kuik, (2007), McKibbin & Wilcoxen, (2009), and Ritz (2009), which account for endogenous technological change. Also, the models studied are deterministic and do not incorporate uncertainty in either the supply of inputs or the demand for output. Thus the validity of the results they present can be somewhat softened should substantial variation in economic growth occur, as during the global financial crisis.

Climate change measures such as the EU ETS are usually assumed to take place unilaterally and other regions are assumed to have no climate change policy themselves. This may be explained as a measure of the relative impact of climate change policy in the EU compared to unregulated economies, but since a crucial determinant of leakage rates is where output is leaked to, changes in the international policy environment may weaken, or even invalidate, leakage estimates. Models frequently implicitly assume homogeneity of firms outside the ambit of the climate change policy. The modelling presented later in this report follows these traditions for pragmatic reasons of data availability and transparency of scenarios. It tests scenarios in which there is a carbon price only in the EU and nowhere else.

The findings of these studies are frequently sensitive to the assumptions of the Armington elasticities of substitution: that is, the substitutability in internationally traded goods between goods produced in regulated economies and those produced in unregulated economies. Where the Armington elasticity is high, carbon leakage effects are high and vice versa. Monjon, Stéphanie, Quirion (2009), for instance, find that under full auctioning of carbon allowances, a high Armington elasticity (3 for cement, 3.5 for aluminium and 5 for steel) implies carbon leakage of 11.4 per cent, versus 4.5 per cent with low elasticities (1.5 for cement, 2 for aluminium and steel). These studies are also sensitive to estimates of the substitutability between various factor inputs in the production process. In the case of studies on climate change, this generally relates to the substitutability between energy and non-energy factors of production. In addition, Carbone (2013a) notes that many predictions of leakage (that is, emissions reduction in regulated economies are offset by emissions increases in unregulated economies) can be driven by assumptions of inelastic fossil fuel supply. Allowing for greater elasticity in fuel supply and allowing regulated economies to switch production to cleaner technologies can lead to lower leakage (that is, emissions reductions in regulated economies are greater in magnitude than emissions increases in unregulated economies).

The assumption of quantity, or Cournot, competition may not always be appropriate: Ritz (2009) notes that when firms are trading close substitutes (as is often the case in energy-intensive industries) and compete on price, resulting leakage rates should be higher. This is a consequence of price competition placing downward pressure on the extent of cost pass-through. The model used later encompasses Cournot competition, but is calibrated with market data to set the relative degree of quantity versus price competition.

The models studied are usually, though not always, static models in which producers rarely make technology investment or improvement decisions. As per the Porter hypothesis, dynamic incentives, technological progress or technology spillovers could result in negative leakage, see Gerlagh & Kuik (2007) and Kuik and Gerlagh (2007), but, as noted, the evidence in this regard is unconvincing.

The models studied frequently need to make assumptions about the carbon price, often calibrating it to the observed price just before or at the beginning of the EU ETS, approximately €20/tCO_2 in Demailly & Quirion (2006). While some allow for variation in carbon prices over time, they usually assume a reference price between €15 and €30/tCO_2, higher than that which has typically been observed on the market since trading began. These are two of the price points tested in modelling later in the paper. The price €30/tCO_2 is significant as it is used in the eligibility test for free allowances, discussed in Section 5. The use of carbon prices that are higher than real-world prices could lead to over-estimates of carbon leakage. There is some suggestion that where regulated firms form a small part of the market, leakage effects are likely to be greater.

In addition, data of sufficient granularity can be difficult to obtain. Studies using the GTAP dataset (which include Caron, (2012a) and Fischer & Fox, (2009b)) have to trade off comprehensive geographic or sectoral coverage with considerable aggregation. This can render results difficult to interpret for policy makers.

2.4 Retrospective or empirical studies find little evidence of leakage

Various methodologies fail to demonstrate unambiguous strong leakage

Empirical studies of carbon leakage in the EU ETS generally fail to find convincing evidence of substantial leakage. Ideally, analyses are done by quantifying the impact of the EU ETS on competitiveness and comparing it to a counterfactual scenario where the EU ETS is not implemented. In reality the impact of the EU ETS is difficult to disentangle from other macro-economic factors, especially in economically dynamic times. This might partly explain why there are fewer such studies than those that take a theoretical approach.

Empirical studies can be classified as econometric trade analyses or surveys/interviews. These classifications, and some of their pros and cons, are as follows:

- *econometric trade analyses* use statistical data on trade, production and CO_2 prices to estimate relationships between these factors, and consequently to draw conclusions regarding carbon leakage. Using elasticities derived from the analysis, results can also be tested against robustness by varying the input and comparing the output with empirical data. However, the accuracy of the analysis depends largely on the amount of data available and the model specifications. Furthermore, given the time period in which the EU ETS has been operational, only short term leakage can be determined.
- *surveys/interviews* collect data based on a series of questions related to competitiveness, relocation of production, impact of the EU ETS and investment decisions to determine whether carbon leakage has occurred. The disadvantage is that this limits the analysis to relatively qualitative terms. Some studies also perform a regression analysis on the survey results in order to obtain quantified results. If questions are correctly phrased, surveys are able to capture the degree the EU ETS has impacted investment and relocation decisions.

Several studies have analysed the available empirical literature conducted on the impact of the EU ETS on key elements, including competitiveness and carbon leakage (Ralph Martin, Muûls, De Preux, & Wagner, 2012; Laing et al., 2013; Reinaud, 2008; Varma et al., 2012). The synthesis studies all agree that a causal relationship between the CO_2 price and loss of international market share of the EU industry could not be clearly identified. As a possible explanation they argue that the time series used for econometrical trade analyses in the literature is too short. Respondents from surveys confirm this view (Cobb et al., 2009); any impact of the EU ETS on competitiveness has been swamped by other economic effects such as energy prices, raw material prices and changing international market structure. This is valid for all specific sectors investigated by empirical studies such as iron and steel, cement, aluminium and refineries.

Within individual analytical studies, researchers tend naturally to focus on energy intensive industries, partly because effects there will presumably be larger, and thus might be easier to measure. However, policies and contractual obligations have served to blunt the impact. The impact of carbon prices has been mitigated by the substantial free allowances available to energy-intensive industry in Phase I and II, and in the short-run the existence of electricity contracts has been a partial buffer (Varma et al., 2012, Sartor, 2012, Reinaud, 2008). Note that such contracts need not be particularly long-lasting to complicate estimations: a contract life of a year, for instance, represents a substantial share of the lifetime of the EU ETS. For example, Reinaud (2008) finds that, at the time of research, only 18 per cent of capacity in the aluminium sector[2] was exposed to higher electricity prices, with the remainder (albeit temporarily) protected. Analysis of the aluminium sector is particularly complicated by high profit margins enabling industry to at least temporarily absorb cost shocks. As noted by Sartor (2012), some aluminium smelters closed down during the first 6.5 years of the EU ETS. Although higher electricity prices could be a contributing factor, according to surveyed aluminium smelter operators (Cobb et al., 2009), this effect is probably primarily attributable to primary energy prices, rather than carbon prices. Sartor (2012) notes that this warrants a cautious approach to industry assistance, since focusing on not accelerating an industrial decline that would have occurred in any case is distinct from preventing it outright.

Other studies have similar limitations. For instance, Lacombe (2008) performed econometric analysis of the trade flows of refineries before and after implementation of the EU ETS, and found no significant changes. Again, since at the time, the margins in this sector were high, this made it difficult to observe any competitiveness impacts (Reinaud, 2008). The growing demand and shortage of capacity around the world resulted in higher prices, obscuring the impact of the CO_2 costs in the price for refinery products.

Chan, Li, & Zhang (2012) analyse panel data of the power, cement and iron and steel sectors under the EU ETS for the period 2001-2009, estimating the impact on unit material costs, employment and revenue; they find an impact on material costs and turnover due to fuel switching, but little evidence for leakage. This is in line with results from Quirion & Demailly (2008b), and Anger & Oberndorfer (2008). Abrell, Faye, & Zachmann, (2011) analyse a panel of company balance sheet data from 2005-2008 and conclude that being subject to the ETS did not significantly affect profits and added value during Phase I and the beginning of Phase II, but they find a small negative effect on employment. Conversely, using similar analysis balance sheet data for the period 2005-2007, Cummins (2012) finds that the EU ETS had a negative impact on productivity and profits, with an insignificant impact on labour and investment; they note that these results are indicative only as the period of observation is limited and they were unable to define a permit price.

Not only did none of the empirical studies observe any clear evidence that the EU ETS has caused a loss of competitiveness in Phase I and II, some studies indicated that some sectors have even profited from the EU ETS. By passing through the costs of freely allocated emissions allowances (as opportunity costs), firms may have obtained windfall profits (de Bruyn, Markowska, & Nelissen, 2010). Laing et al., (2013) provide an overview of various studies estimating the windfall profit, ranging from €1–9 billion per year depending on the assumed CO_2 price and scope. However, if passing through costs resulted in a loss of global market share, this could still lead to carbon leakage.

In conclusion, empirical evidence regarding carbon leakage to date is very limited. The challenge in interpretation is whether this is due to an absence of leakage, or whether it is due to specific market characteristics and constraints on measurement. In Table 1, the majority of the studies are concerned with leakage through the short-term competitiveness channel, and it is more difficult to measure leakage from

[2] Note that, unlike power production, in Phase I and II aluminium production was not covered by the EU ETS.

other routes. However, the consensus from this limited body of literature appears to be that there is no robust evidence that the EU ETS has caused substantial carbon leakage, at least to date.

2.5 Theoretical studies produce a range of leakage estimates for Phase III of the EU ETS

The theoretical literature spans a broad range of leakage estimates

It is worthwhile providing some specific commentary on estimates of leakage risk from the literature that focus specifically on Phase III of the EU ETS.

Based on mainly the value at stake and trade intensity, the European Commission, (2009) has determined that 176 sectors will be at risk of carbon leakage for 2013–2014. This represents 95 per cent of industrial emissions (de Bruyn, Nelissen, & Koopman, (2013)). In the methodology of the Commission, a sector's ability to pass through costs has not been included in the assessment. By including the cost pass-through rate, the value at stake becomes far less (McKinsey&Company & Ecofys, (2006); Graichen et al., (2008); Hourcade, Demailly, Neuhoff, & Sato, (2007)). This is because the impact on profit margins, which is the metric which drives investment, is the difference between the carbon cost and the revenue uplift associated with price increases. It is common for market prices to increase when a sector's production costs increase. The number of sectors that would be at risk of carbon leakage would reduce significantly if cost pass-through were taken into account.

To limit carbon leakage in Phase III, sectors deemed exposed to carbon leakage will receive 100 per cent free allocation of their benchmarked historical emissions. There will be no free allocation for electricity generation and non-carbon leakage sectors will receive a decreasing share of free allocation. Various theoretical studies have estimated the carbon leakage rate for Phase III, with estimates ranging from 0 to 39 per cent (Varma et al., (2012) Droge et al., (2009)).

Various studies have estimated leakage rates in Phase III under different distribution regimes. Using a partial equilibrium model, Droge et al., (2009) determined that leakage rates would be 10 per cent on average under full auctioning and a CO_2 price of €14/tCO_2. The authors also reported figures for individual sectors, including 20 per cent for cement, 39 per cent for steel and 21 per cent for aluminium by 2016. However, Cambridge Econometrics, (2010) used an econometric model and showed that under full auctioning the EU production in most sectors fell by less than 1.5 per cent and the leakage rates were generally below 25 per cent.

Cement receives considerable attention, owing to its high carbon intensity. Carbon leakage estimates range from -0.1 to 0.2 per cent in econometric studies (Pollitt et al., (2012)) to 17 to 100 per cent in regional partial equilibrium studies (Allevi et al., (2013)). The Boston Consulting Group, (2008) considers transport costs and cost pass-through rates, and concludes that 80 per cent of the cement industry would disappear by 2020 under a CO_2 price of €25/tCO_2 without free allocation, 100 per cent under €35/tCO_2 irrespective of cost pass-through or availability of capacity in the world.

On a qualitative note, surveys and interviews show that firms are worried about Phase III as there will be less free allocation given (Cobb et al., (2009)). Martin, Muûls, et al., (2012) interviewed more than 700 firms on how they rate their own vulnerability to carbon leakage and whether they would relocate their production. They found glass, iron and steel, and cement are the most vulnerable to carbon leakage and could lead to investment leakage in those sectors. Indeed, Laing et al., (2013) noticed from the analysis of their recent surveys that CO_2 costs have captured attention in the boardroom and could have helped to deter major carbon-intensive investments, but the impact is still small compared to factors such as energy prices and close proximity to customers, in growing emerging markets.

2.6 Conclusion

In Section 2.3.2 the range of estimates in the theoretical literature was discussed. While there is some variety in the typical estimates obtained through the theoretical approaches, at least one element of commonality is that they tend to be substantially higher than the limited empirical evidence supports.

This point of tension deserves some discussion. A partial explanation may be found in the several differences between the models and reality, some of which have been noted already:

- commonly modelled carbon costs do not always align with those found in the ETS. Real-world carbon prices under the EU ETS, or those expected under Phase III, have been substantially lower than the levels incorporated into models (de Bruyn et al., (2013));
- in Phase I and II the majority of allowances were allocated for free through grandfathering, which has not always been taken into account in models;
- some sectors may have abated some of their emissions, and therefore limited their exposure to CO_2 costs as some surveys showed;
- it has been observed that some firms have been able to pass through input price shocks, thus limiting the net carbon cost exposure;
- it might also be noted that, as argued by Reinaud (2008), and also documented in interviews with firms subject to the EU ETS (for example, see Cobb et al., 2009), other economic factors have had a much stronger influence than CO_2 prices, confounding estimates;
- the bulk of theoretical modelling involves examining equilibrium states. Given that carbon leakage is most likely to occur through long-run diversion of investment (rather than actual physical relocation of facilities), it may well be that insufficient time has passed for an equilibrium reflecting the current policy environment to be reached;
- one countervailing factor worth noting is that the models generally treat the EU ETS in isolation, when leakage may also be encouraged by other green regulation or energy taxes.

Should this interpretation of the disparities be correct, then it has several implications for policy makers with regards to Phase III of the ETS. For instance, as a new equilibrium reflecting the ETS develops, the extent of leakage would increase over time and changes in allowance distribution rules under Phase III may affect firm behaviour.

3 The modelling process

Modelling techniques allow estimation of carbon price impact for selected sectors

Section contents:

Twenty-six sectors investigated in total

The Industrial Market Models developed by Vivid Economics are intended to enable analysis of individual markets for specific goods. They are particularly suited to commoditised markets. Use of the models enables estimation of shifts in production and, consequently, carbon leakage.

The models are applied to a selection of sectors. These sectors were chosen by DECC, with input from Vivid and industry stakeholders, in a process intended to provide a reasonable cross-section of industry types, and involved listing sectors against the criteria identified by the EU as being indicative of carbon leakage risk (carbon cost- and trade-intensity).

The intention of the modelling is to provide a sense of the potential for carbon leakage risk under Phase III of the EU ETS. Estimates are produced for 2012, 2020, and 2030, under a range of carbon prices, and with a sense of potential uncertainty provided by upside and downside scenarios.

3.1 Selection of sectors for analysis

Choice of sectors was inspired by the EC's carbon leakage criteria

The intention of the sector selection process was to cover a range of industries having different carbon intensities, with a bias towards relatively carbon-intensive and trade-exposed sectors. This was balanced against practical modelling issues, such as data availability.

3.1.1 Usage of EC and modelling criteria

A goal of the overall project is to evaluate the effectiveness of the EU's criteria in identifying sectors at risk of carbon leakage and an initial step was to attempt to list all 4-digit NACE codes by their ranking against those criteria at both the UK and EU level. As discussed further in Section 5, those criteria are:

- the *carbon-intensity* of a sector, measured by the sum of carbon costs under a €30/tCO_2 carbon price as a share of sectoral GVA;
- the *trade-intensity* of a sector, measured by the sum of imports and exports, divided by the sum of domestic production plus imports.

As identified by Taylor, Juergens, Barreiro-hurlé, & Vasa, 2013, it is difficult to perfectly replicate the EC's approach, especially on an EU-wide basis. The task is somewhat simpler at the UK level, due to greater data availability.

The selection of sectors covers a range of emissions intensities and differences in intensities between UK and EU production. The selection also took into account:

- the likely availability of data, particularly for sectors targeted for investigation with the Full Industrial Market Model;
- the extent to which sectoral output can be treated as 'commodity-like', that is, to what degree production from different regions or producers is interchangeable. The closer the sector comes to such homogeneity, the greater its amenability to analysis with Vivid's industrial models.

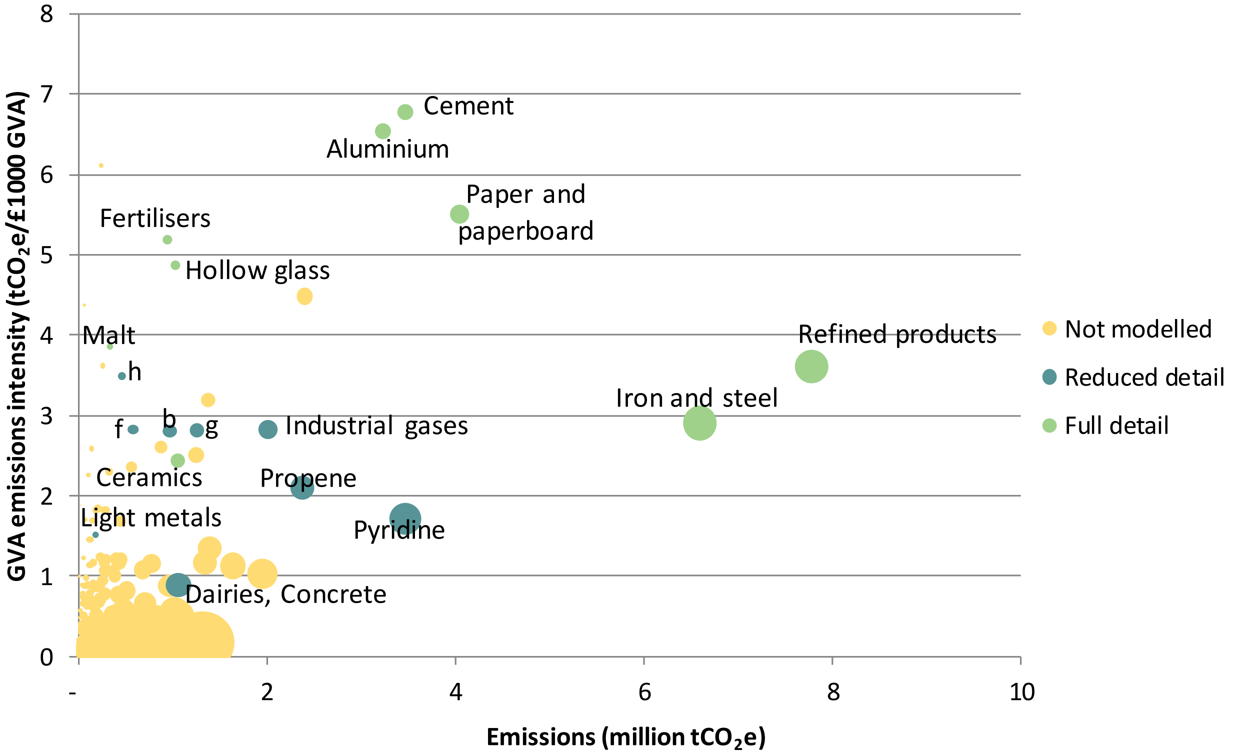
Further explanation of these factors is given in Sections 3.3 and 3.5.

3.1.2 Sector selection

Initially, it was intended that 10 sectors would be analysed in 'full' detail, using the Full Industrial Market Model (FIMM), and 10 in reduced detail, using the Reduced Industrial Market Model (RIMM) (see Section 3.3 for further discussion of these terms). However, the paper manufacturing sector, initially selected as a FIMM, proved more amenable to analysis if split into four subsectors, each of which was analysed using RIMM. One additional sector for RIMM analysis was also included, for a total of nine sectors investigated using FIMM, and 14 using RIMM. A full listing is provided in Table 3.

The direct and indirect emissions intensities of the selected sectors, compared against other manufacturing sectors, cover a range of absolute emissions and emissions intensities (Figure 5). The sectors investigated in full detail tend to be somewhat more emissions intensive than others. Sectors also span a range of trade- and emissions-intensities (Figure 6). A discussion of UK-level and EU-level modelling and criteria calculation can be found in Section 3.3.2 and Section 3.1.1.

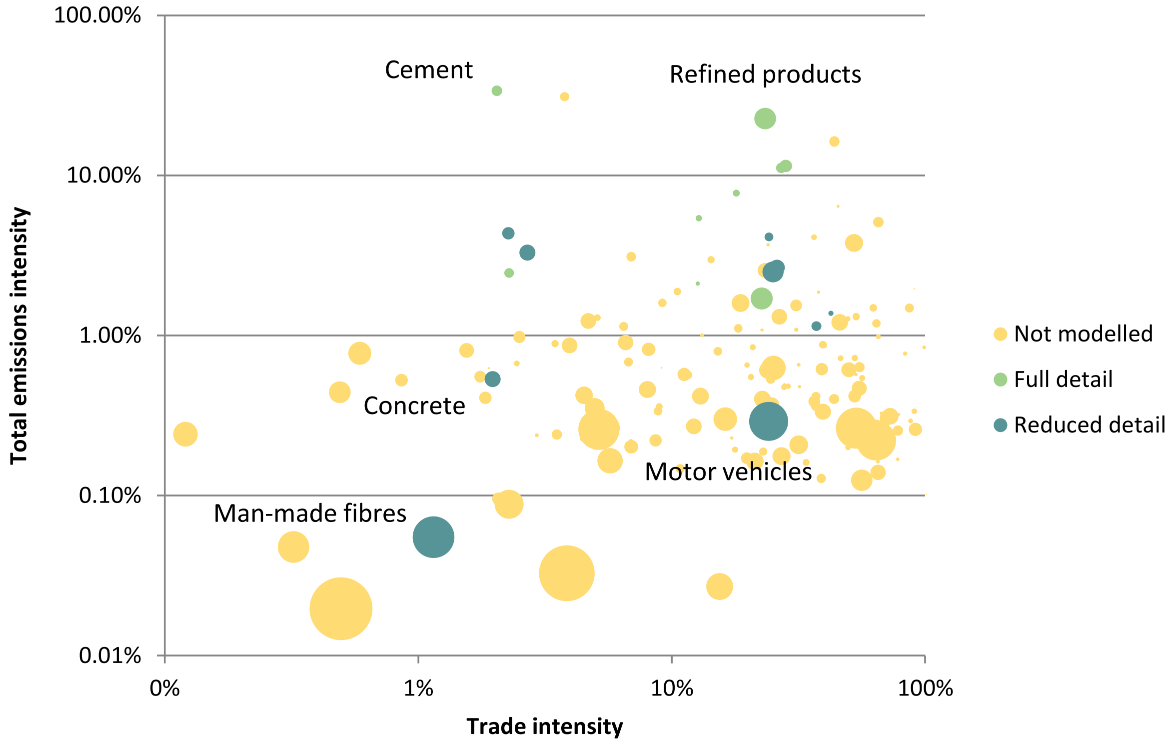
Figure 5. **The selected sectors cover a range of sizes and emissions intensities (UK-level)**



Notes: *In order to preserve legibility, some sector labels have been replaced by letters, whose code is given as follows: b: Veneer and other boards; f: Man-made fibres; g: Rubber tyres and tubes; h: Flat glass. Dairies and concrete have very similar levels of emissions intensity and so appear to overlap, thus the bubbles for dairies and concrete share a legend. GVA data is not available for flat and long steel separately. GVA data is not available for all four paper subsectors separately, so emissions and GVA data is reported for the sector 'Paper and paperboard'. GVA or emissions data for the UK for 2007 was not available at the required level of granularity for the following sectors, which are omitted from the chart: Non-dolomitic lime, Sugar and passenger vehicles.*

Source: *Vivid Economics*

Figure 6. **The selected sectors also have widely varying degrees of non-EU trade exposure (UK-level, log scale)**



Source: *Vivid Economics*

3.2 Projections, prices, and scenarios

Projections are made out to 2030, using various assumptions and incorporating upside and downside scenarios

3.2.1 Projections and prices

The immediate focus of the report is leakage risk under Phase III of the EU ETS. The potential carbon impact is estimated for both 2012 and 2020, with the former representing the most recent available data, while 2020 is the end point of Phase III. Estimates are also produced for 2030.

The key difference between projected years is the size of the sector and the growth of imports for that sector. Predictions of changes in emissions intensity are not made because it was deemed too difficult a task to produce estimates of sectoral abatement opportunities. To obtain such projections, macroeconomic growth figures for the UK produced by Cambridge Econometrics' MDM-E3 model are relied upon. MDM-E3 was originally developed as part of the Cambridge Growth Project by the University of Cambridge; it captures and represents the impacts at the macro, industrial, regional and energy system levels simultaneously within a single framework. The model is demand driven, based on post Keynesian macro-economics. It is based on the structure of the national accounts and provides a coherent, empirically validated framework for analysis, including feedback and multiplier effects and well-defined links between economic sectors.

MDM-E3 has been reviewed many times and is applied regularly by governments, the private sector and NGOs engaged in the policy debate. It was reviewed by the National Audit Office, which subsequently described the model as one of the most sophisticated macroeconomic models of the UK economy available (National Audit Office, 2007):

- the projections from MDM-E3 were calibrated so that short term growth in the UK is consistent with 2013 OBR forecasts, and that UK energy use is consistent with current DECC projections.
- MDM-E3 splits the UK economy into 86 sectors, which is a less detailed level of aggregation than that provided by 4-digit SIC codes. Sectors examined with the IMMs were thus grown at the relevant rate for the broader sector of which they are a part in MDM-E3.
- MDM-E3 focuses on the UK economy; consequently, EU sectors were grown at the rates projected for their UK equivalents, which will inevitably induce inaccuracies given the differences in developmental level of the various EU economies.

Naturally, the use of UK-level growth rates across the EU will be inaccurate; however, the drawbacks were considered tolerable, given the difficulties otherwise present in attempting to find long-range growth forecasts at the sectoral level for the EU as a whole. The growth rates used are reported in Appendix B.

Estimates of the impact of several carbon price differentials between the EU and non-EU countries were produced: €5, €15, €30, and €50/tCO_2. It was assumed that, to date, sectors have 'priced in' a carbon price of around to €6/tCO_2 to their operations. Consequently, to determine the impact of a price of €15/tCO_2, a *reduction* in production costs equivalent to of €6/tCO_2 was first applied; this then served as the counterfactual, and was used as the comparison point when a shock of €9/tCO_2 was then applied to the original data. It should be noted that, while this step was included for theoretical accuracy, it did not make a significant change to any of the results shown, compared to the alternative of simply applying a direct €15/tCO_2 cost shock to the initial inputs.

At the time of writing, prices of €15, €30, and €50/tCO_2 are all well above actual current trading prices in the EU ETS (around €4.5/tCO_2), and the higher range prices are not expected under Phase III. However, these prices were investigated in any case, as they are possible in the long-run. Indeed, the EU employs a price of €30/tCO_2 in its carbon leakage risk assessment criteria (see Section 5).

3.2.2 Scenarios

Scenario analysis is intended to provide an indication of the potential range of outcomes from a policymaker's perspective. Modelling estimates were made around three scenarios: an 'upside', 'central', and 'downside' scenario.

- the upside scenario involves EU sectoral growth being 2 per cent (so that a 2 per cent growth rate becomes 4 per cent) higher than MDM-E3 projections per annum, while natural gas prices across the EU are 10 per cent lower than DECC projections and other fossil fuel prices are held constant;
- the central scenario maintains sectoral growth at the rate projected by MDM-E3, with no change in gas prices from DECC projections and other fossil fuel prices are held constant;
- the downside scenario mirrors the upside scenario, with EU sectoral growth 2 per cent lower than in MDM-E3 (so that a 2 per cent growth rate becomes zero per cent), natural gas prices 10 per cent higher and other fossil fuel prices are held constant.

The significance of the variation in EU growth rates is that, with the growth rate in non-EU imports being kept constant, there are changes in the market share of non-EU producers. For example, the market share of non-EU producers is larger in the downside scenario, due to slower EU growth rates and the negative impact on the EU of higher gas prices. Trade intensity is consequently higher for EU producers, increasing the impact of a carbon price shock in Vivid's models.

3.3 Sectoral modelling

Industrial models allow for estimation of price shock impact

3.3.1 Introducing Vivid's Industrial Market Model

Vivid Economics has developed an in-house model for analysing interactions between rival firms and consumers within capital-intensive industries, referred to as the Industrial Market Model. The intention of the model is to depict individual economic markets and to capture the impact of changes in market structure, including the entrance or exit of individual firms, changes in the nature of demand, or, of particular relevance in the context of carbon prices, changes in production costs.

The model is well-suited to industrial sectors where firms have large fixed costs, such as energy-intensive industries. The model is based around the Cournot model of oligopoly, familiar to academic economists, and is conceptually similar to the qualitative Porter's Five Forces model, widely used in corporate strategy analysis. It is a partial equilibrium model, solved algebraically.

The model comes in two forms: the Full Industrial Market Model (FIMM), which incorporates information on individual facilities within the market, and the Reduced Industrial Market Model (RIMM), which is more aggregated. Sectors analysed using FIMM, as well as the paper sector which was analysed with four RIMMs, are referred to as those investigated in 'full' detail, while the remaining 11 sectors analysed with RIMM are referred to as those investigated in 'less' or 'reduced' detail.

3.3.2 Markets are identified before applying the models

Before either version of the model can be applied, it is necessary to define the economic market. Economic markets do not necessarily coincide with sector definitions in public statistical sources. For instance, the relevant 4-digit NACE or SIC code covering the ceramics sector is too broad: it includes speciality ceramics that have distinctly different production processes and applications than the more familiar bricks and tiles. Further, markets are defined not solely by the substitutability of their outputs, but also by geographical scope. In particular, products which are expensive to transport relative to their value are best treated as markets within a particular area.

Some sectors, such as ceramics, were narrowed down to heavy clay ceramics (that is, brick and roof tiles), for the purpose of modelling a market. Paper, another example, was split into four subsectors to ensure appropriate product scope. Each market was classed as being UK or EU. This was determined either with reference to European Commission judgments on competition cases or by examining the share of imports and exports as a proportion of the UK and EU markets. The classification is summarised in Table 3. These sectors are written up as case studies in the annex to this report.

Table 3. **Market scope by sector**

	List of sectors					
UK-level sectors (full detail):	Cement	Heavy clay ceramics	Non-dolomitic lime			
EU-level sectors (full detail):	Steel (long and flat)	Fertilisers	Container glass	Malt	Refining	
Global-level sectors (full detail):	Aluminium					
UK-level sectors (less detail):	**Sanitary paper**	Concrete products	Distilled air products	Casting of light metals	Sugar	Veneer and other boards
EU-level sectors (less detail):	**Printing & writing**	**Newsprint**	**Packaging**	Tyres and tubes	Dairy (milk)	Passenger vehicles
	Man-made fibres	Flat glass	Propene	Pyridine compounds		

Notes: Paper subsectors emboldened.

Source: Vivid Economics

3.3.3 The model accounts for a range of different possible behaviours and market structures

Traditional economic models assume that firms act to maximise profit, but in reality firms often diverge from this model. Executives may be incentivised, through their contracts, to maximise market share or sales instead. Aggressive firms may temporarily pursue market share to force competitors out of the market and create permanent competitive advantage.

While based on Cournot competition, the Industrial Market Models also encompass Bertrand competition as a special case, where, in the former, firms have market power and competition is based around production quantities, while under Bertrand competition is based on price. Real world behaviour does not necessarily align perfectly with the narrow predictions of either of these pure conceptions of market. To introduce additional flexibility, a parameter, *theta*, is introduced, which enables the model to be calibrated to the competitive outcomes observed in the sector.

Theta is adjusted until the profit margins within the model match observed values. Its value can then be interpreted, broadly speaking, as the 'aggressiveness' of competition, that is, the degree to which firms pursue maximisation of market share as against maximisation of profits.

This process and the overall structure of the model are depicted in Figure 7. The degree of competitiveness is determined as a function of gross profit margins, the price elasticity of demand, and the market share of regulated firms. The interaction between market variables is non-linear. Specifically:

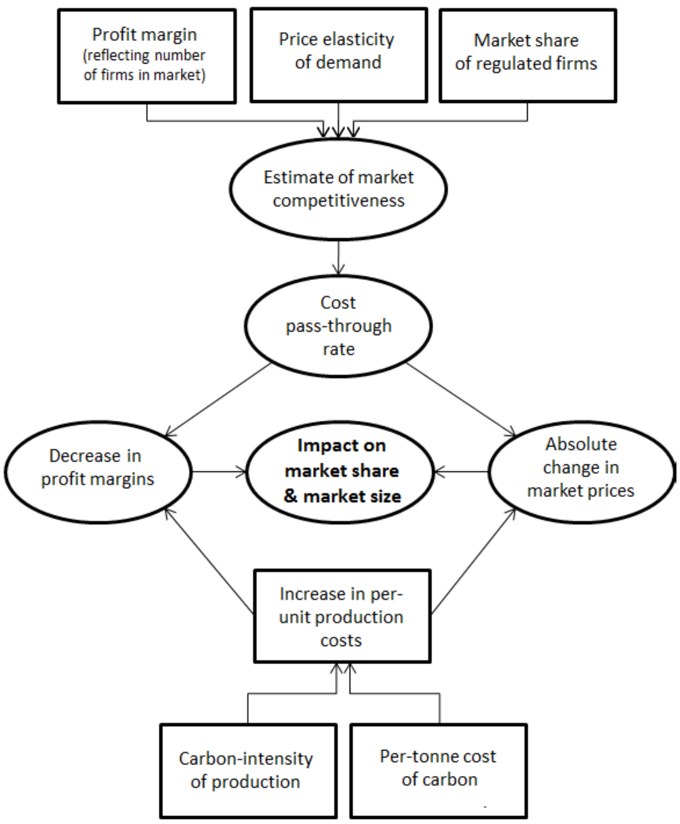
– low domestic firm market share implies that market price is influenced by the production choices of overseas firms, and that UK firms will therefore be unable to pass on higher costs;

– low margins indicate competitive markets, with firms passing cost shocks on except where they could lose out to rivals unaffected by the shock;
– the elasticity has more of an effect where firms have market power, which means that there have to be relatively few firms and relatively fat margins: in this case, high elasticity discourages firms from passing on cost increases as they wish to avoid dampening total demand, while the converse holds for cost decreases.

The degree of competitiveness in turn largely drives the resulting sectoral cost pass-through rate. Competitiveness is relative cost of production (or margin), which may be reflected in market share. In conjunction with the absolute size of the shock that the industry is subject to, the strength of competition determines the impact on quantity of production and sectoral market price. The impact on production can in turn be broken down into:
– the drop in production resulting from the decline in overall market size due to decreased demand as prices rise; and
– the loss of UK and EU market share to other producers as profit margins decrease.

Figure 7 provides a schematic of the modelling process, focusing on shifts between equilibria.

Figure 7. **Simplified depiction of Industrial Market Model structure**



Note: rectangular boxes represent inputs, ovals represent intermediate and final outputs

Source: Vivid Economics

By default, a linear demand function is used, though other specifications are possible; so long as price movements remain relatively small, the difference induced by different demand specifications is unlikely to be large. Consumer behaviour, and the slope of the demand curve, is calibrated by the incorporation of price elasticity of demand for the sector. Generally these parameters were sourced from the literature and in some cases assumptions or simplifications were made, such as, for instance, all sectors that are predominantly focused on construction materials (steel, heavy clay ceramics, and cement) face the same price elasticity of demand, see input data tables in the case study report.

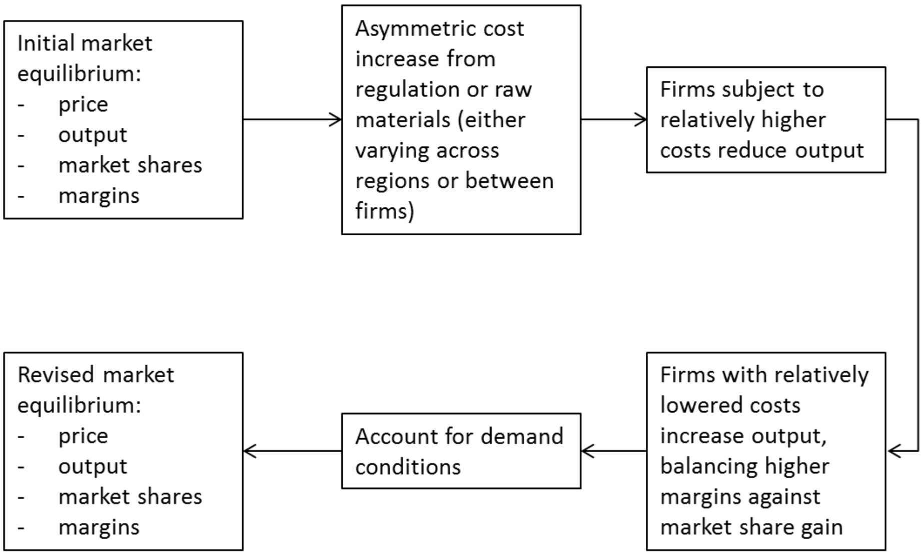
3.3.4 The FIMM incorporates detail down to the individual installation level

There are three steps to using the FIMM in the current context:

- data is compiled on market prices and quantities sold, and the market shares of individual productive installations within the market, as well as intensity of electricity usage. These data allow the estimation of marginal costs of production of each plant, which can be calibrated against quantitative or qualitative information obtained elsewhere;
- using the data on emissions intensity, an estimate can be made of the impact of carbon price changes on firms' marginal costs;
- from here, a new equilibrium is calculated, and consequent changes in market share, price, and quantity can be identified.

This process is represented in Figure 8. Some steps of the process may be simplified depending on available data.

Figure 8. **FIMM involves shifts between static equilibria; the process for RIMM is the same, but without specific reference to individual firms**



Source: Vivid Economics

3.3.5 RIMM is similar to FIMM, with simplifications

The RIMM approach enables similar estimation of the impact of carbon prices on a market with simplified data. Additional discussion of the details of RIMM analysis is contained in Appendix A and is also reviewed in Ritz (2009).

As before, firms within a market are faced with an asymmetric cost increase. Changes in the market equilibrium occur due to carbon prices affecting firms within the EU, and it is assumed that there is no carbon price outside the EU.

A key advantage of using RIMM is its lower data requirement. Under the RIMM approach, close approximations to FIMM outputs can be derived under some simplifying assumptions:

- the emissions intensity of production is the same across all firms in the EU; and
- the emissions intensity of production is the same across all firms (within the same economic market) outside the EU.

This reduces the data intensity of modelling, allowing the analysis to be extended to a much wider range of sectors.

3.3.6 The Industrial Market Models have advantages and disadvantages

To summarise the key features of the model:

- it explicitly represents firm-to-firm (in FIMM) and consumer-to-firm interactions encompassing a range of profit-maximising and sales-maximising behaviours
- it allows for changes in output within existing firms or assets as well as entry or exit (in FIMM);
- it allows consumer behaviour, whether price sensitive or insensitive, to be included;
- it considers each firm or major asset individually (in FIMM), allowing differences in unit cost or behaviour on a firm by firm basis;
- it is based upon the well understood Cournot quantity competition economic framework, with flexibility to encompass a full spectrum of competitive dynamics, including Bertrand price competition;
- it allows for cost differentials across national or administrative boundaries;
- it uses input data which is generally publicly available, which is particularly useful in public sector analysis where commercially confidential data is not available;
- it produces a wide range of output metrics which are of interest; and
- it can be calibrated, audited, and subject to sensitivity and scenario analysis.

In the context of the project at hand, the model has several key advantages:

- it finds the destination and magnitude of output and emissions leakage;
- it can integrate qualitative information gathered during expert interviews;
- it explicitly accounts for strategic interactions between firms (in FIMM) when determining cost pass-through, rather than relying on aggregate relationships.

On the other hand, the application of FIMM requires the collection of firm level data, with the consequent time costs necessitating a limitation in the number of sectors that it is applied to.

The models also assume that the market is in equilibrium before the cost shock is introduced. This implies that all firms are optimally responding to the production strategies of their competitors, and that, in the absence of a cost shock, firms would not adjust their production plans. This may not be the case; firms may be in the midst of expanding capacity, or on the verge of shutting down.

As noted, the necessity of assuming a form for the demand curve may introduce some inaccuracy, growing as the scale of the shock under investigation increases.

The model does not attempt to capture wider higher order effects of carbon prices. Key among these effects are economic ‘multipliers’. Overall demand is implicitly held constant, with consumers altering which goods and services they purchase due to changes in relative prices rather than changes in income. Yet any change in prices, quantities, and employment levels at the sector level will have consequences elsewhere in the economy, especially in the sector’s supply chain.

The analysis concentrates on the larger players within a sector. Small firms or assets are likely to produce more specialised products and will be unable to realise the economies of scale enjoyed by larger consumers. In the absence of detailed firm specific data, it is harder to take the smaller firms into account, as their inclusion may make sectors appear more competitive than, in reality, they are.

3.4 The estimation of carbon leakage

Market models allow the estimation of a variety of impacts of a cost shock

3.4.1 Carbon leakage estimates are based on output leakage estimates produced by the Industrial Market Models

In both FIMM and RIMM the key model outputs are:

- cost pass-through;
- total reduction in EU or UK sector output;
- total increase in foreign output; and
- changes in market prices.

FIMM estimates allow for some additional precision in these outputs. For instance, with regards to output leakage: within FIMM, distinct changes in production are calculated for each import partner; with RIMM, changes are only calculated at the level of aggregate imports, which then must be assigned to import partners after the modelling process. In the current research, this was done by assigning the change proportionally to each import partner's share of total sectoral imports into the UK.

The focus of analysis is on the quantity of carbon leakage, which is not a direct output of the basic form of the model, but can be produced via the model's estimated changes in regional output. The assumption in all cases is that electricity producers are able to pass through 100 per cent of the rise in their production costs due to carbon pricing; consequently, the cost increases faced by industrial sectors are in direct proportion to the total of their direct and indirect emissions.

In FIMM, estimation of carbon leakage can be split into several steps.

- first, after the application of the carbon price to all EU producers, a new set of production quantities is available for each EU member state and non-EU productive nations;
- second, to estimate leakage from changes in indirect emissions, it is necessary to obtain estimates of the indirect emission intensity in different regions:
    - unless additional information is available, it is assumed that the electro-intensity of production outside the EU is the same as the average intensity inside the EU;
    - IEA data on the carbon-intensity of electricity production, by nation and region (including individual EU member states and trading partners) is used to estimate both pre- and post cost-shock emissions resulting from electricity use (IEA, 2012);
- third, to estimate leakage resulting from direct emissions, it is again necessary to identify the direct emissions intensity by region:
    - again, unless more detailed information is available, it is assumed that process emissions per tonne of output are the same in all areas. There are several exceptions to this; for instance, for the refining sector, process emissions are available at the per-installation level;

   - direct emissions are then calculated in proportion to the changes in total production;
- finally, by adding the changes in direct and indirect emissions, the net change in global carbon emissions can then be calculated.

The estimation procedure and assumptions in RIMM are similar. However, as RIMM only breaks the market into ‘inside’ and ‘outside’ production (that is, EU producers versus non-EU importers), the emissions intensity of the two regions is a weighted average of emissions intensities with production used as weights, rather than being specific to individual nations or installations. The indirect emissions intensity applied to the whole EU reflects the indirect emission intensity of individual nations, weighted by their share of total production. A similar calculation is performed for the non-EU: the electro-intensity of production is assumed to be the same as within the EU, while regional and national data on the carbon-intensity of electricity production is used to generate a weighted average non-EU indirect emissions intensity

The differences in data availability between sectors introduces additional variation in the precision of the carbon leakage estimates. Sources of data are detailed in the case studies.

3.4.2 Caveats

One issue concerns how changes in EU carbon emissions are related to net global emissions changes. Given the EU ETS operates under a cap, it might be argued that a reduction in emissions in any individual sector would have no effect on EU emissions, given it would be offset by an increase in emissions elsewhere within the EU. However, this argument is somewhat problematic given the framework in which the analysis takes place, which involves the application of an EU-wide carbon price. For simplicity, the carbon leakage figures presented in the results are calculated *including* a reduction in EU emissions and the specific changes in EU and non-EU emissions are reported separately, that is:

sector carbon leakage rate = sector emissions increase outside EU (tonnes) / *sector emissions decrease inside* EU (tonnes)

Some of the more significant provisos that are worth taking particular note of:
- no attempt is made to account for possible reductions in emissions intensity due to technology induced abatement or changes in energy mix;
- no account is taken of emissions associated with transport;
- carbon and environmental policy in other regions of the world is assumed to be unchanged from current values;
- no attempt is made to account for decarbonisation of electricity supply over time.

Technology is likely to change incrementally over a fifteen year period and carbon intensity would fall as a result, both for inside and outside firms. The final bullet point above may be significant, given the substantial reduction in the carbon intensity of electricity production which is planned; it is an example of how uncertainties increase out to 2030. For most sectors the share of indirect (electricity based) emissions is relatively low, with the exception of aluminium, but if the UK is successful in its ambition to largely decarbonise power by 2030, it would have an impact on the sensitivity of energy-intensive sectors to carbon prices.

3.5 Data sources

Publicly available data was combined with industry liaison

3.5.1 The Full Industrial Market Model in particular is relatively data-demanding

The Industrial Market Model requires the following data for each sector analysed:

- quantity of market production;
- quantity of market trade;
- elasticity of demand across the entire market;
- average emissions intensity of UK, EU and foreign firms;
- average profit margin of UK and EU firms;
- average price per unit (tonne) of produced goods.

Further, the FIMM also requires:

- sources of imports;
- any relevant variations in emissions-intensity across installations or nations.
- total number of firms in market;
- total number of EU or UK firms in market;
- individual installation output;
- market share of EU and UK firms.

Relevant estimates have been taken from a variety of sources, including economic reports, national statistical services, industry association publications and industry association bespoke data.

Interviews with industry associations and representatives of industry firms for the sectors investigated in full detail (that is, the 9 sectors investigated using FIMM, plus paper) proved to be of considerable assistance. Interviewees were generally approached relatively early during the process, with data provided on an ongoing basis, alongside helpful review of draft inputs and outputs.

In addition to providing raw data, interviewees also assisted in identifying features of sectors that might be problematic if not given appropriate treatment in the modelling approach. In some cases, they provided qualitative information concerning the general state of their industries and the outlook for growth in coming years, and quantitative estimates of the usage of electricity. Prior to submission of the final report, some industry associations reviewed key input and output figures for the sectors investigated in full detail. This helped identify the most up to date and relevant trade figures, appropriate carbon intensity estimates and in one case, changed the methodology for estimating carbon intensity.

Where possible, an attempt was made to source data from consistent sources, but this was not always possible. For instance, no single comprehensive source exists to provide estimates of demand elasticities. Estimates of profit margins can be made consistently from IBISWorld and ONS data, but in several instances revised numbers were supplied by industry associations which were considered to be more appropriate.

Similarly the Office for National Statistics collects trade data for all sectors, but in some cases, sector associations have data which is more tailored to the market being modelled.

As a general comment, the sourcing of data from multiple sources does lead to some risk of inconsistencies in definitions. For instance, information on emissions intensity at the national level was drawn from the IEA, which may have been based on a different scope of production figures than those provided by industry associations. In aggregate, and combined with the review of inputs conducted with interviewees, it is expected that these issues do not cause significant bias.

3.5.2 Sector definition to ensure appropriate market scope

Several of the SIC 4-digit sectors selected for detailed analysis were not immediately suitable for analysis with the industrial market models due to lack of homogeneity. The issue is not necessarily whether two subsectors are direct substitutes for each other, but whether the manufacturing equipment used in one subsector can be easily altered to produce goods from another subsector. For the sectors investigated in detail, these issues arose:

- within the ceramics sector, brick production, for instance, is distinct from porcelain fixtures such as sinks, or from advanced technical ceramics which may involve substantially different levels of electricity usage;
- various major fertiliser types are produced using different chemical processes for non-overlapping (albeit complementary) purposes;
- shaping of steel is a capital-intensive process; and combined with variations in steel quality, this means that the UK's steel output as a whole cannot be seen as a single commodity;
- lime production can be seen as split into dolomitic and non-dolomitic lime, with different applications.

These issues were approached in various ways:

- the focus in the ceramics sector was narrowed to heavy-clay based products; that is, predominantly bricks. These make up well over a quarter of total ceramics sector GVA, and more than half of sectoral electricity use;
- fertilisers were narrowed down to nitrogen-based fertilisers, specifically ammonium nitrate and urea; with some small distinctions, these can be considered practical substitutes for each other, with the market price for ammonium nitrate generally tracking the urea price;
- the steel industry was split into longs and flats, each being modelled separately;
- the relatively small, albeit substantially more trade exposed, dolomitic lime production was neglected in favour of analysing non-dolomitic lime.

These distinctions should be borne in mind when interpreting the results.

Similarly, several RIMM sectors were also analysed at a level below that of the relevant NACE 4-digit code, due to the broader classification introducing too much heterogeneity. For instance, dairy production was narrowed to milk production, while automobile manufacture was narrowed to passenger vehicles.

The sector 'paper manufacturing' was originally to be modelled using the FIMM; however, in discussion with the industry association it became clear that it would be prohibitively difficult to obtain the necessary data. Consequently, paper manufacturing was split into four subsectors: packaging, newsprint, sanitary, and stationery. Together, these make up more than 95 per cent of paper production in the UK, by value or tonnage. Each subsector was then analysed separately with the RIMM, and the results aggregated to produce sector-wide estimates.

Further details on the modelling decisions made with regards to each sector are provided in individual case studies, which are included as Appendices.

The data sources are documented in the case study report. For the sectors examined in full detail, the authors approached and often obtained support from sector associations and some individual firms in supplying or checking the input data. For all data, the authors sought opportunities to cross-check figures across sources of previously published work, including previously published work by Ecofys, one of the authors, for the European Commission.

3.6 Comparison with other models

Future work could compare results across models

The discussion in this section has explained the factors which drive the results from the models and the next section will present the results. A natural further step which could be the subject of future work is to prepare a meta-analysis, comparing results from all the published studies with the benefit of an understanding of what factors are likely to drive the results to particular values.

3.7 Conclusions on interpretation of results

These are upper bound estimates

When reading the results in the next section, the following points may be borne in mind:

- comparisons with other published work show that the results given in this report represent an upper bound for estimates;
- the carbon leakage estimates are high because carbon abatement measures are not incorporated into the model as a result of reliable data not being available (the models themselves can incorporate abatement);
- the higher carbon price differentials tested with the models are not necessarily politically feasible;
- it is assumed that the carbon price is zero outside the EU;
- the models are calibrated to current market conditions;
- the market definition chosen is approximate, with local variation producing locally different effects and some specialist products not separately identified;
- not all parameter values are available for specific sectors, for example, specific price elasticities of demand for each sector's product;
- the long-run equilibrium basis of the model shows the direction in which the market will move but changes will be smaller in the short and medium term;
- the model structure shows the fundamental drivers and relationships which are likely to be important, but involves simplification and omission of other factors;
- no higher order effects in the supply chain or impacts of carbon embedded in intermediate inputs are taken into account;
- there is considerable uncertainty in the future prospects for the sectors 10 to 15 years ahead, especially in the extent of trade exposure.

4 Summary of modelling results

Carbon leakage varies substantially across sectors

Section contents:

The market structure of sectors and differences in EU and non-EU carbon intensity drive differences in extent of changes in production

In the absence of carbon leakage policy, sectoral abatement measures, or other mitigating factors, the model results suggest that carbon prices can have a significant impact on at least some of the sectors examined in full detail, with production declines in the region of 20 per cent at carbon prices of €15/tCO_2. However, for many sectors the impact is much more muted, particularly for the sectors investigated in reduced detail, which is unsurprising given they are generally less energy intensive.

The amount of sectoral carbon leakage also varies substantially. When carbon prices reach particularly high levels, substantially above those observed in the EU ETS, it becomes more likely that net global sectoral emissions increase. While there are numerous provisos to this work, the conclusion is that carbon leakage at least has the potential to be a significant risk for some of the sectors investigated.

4.1 Summary results

Extent of production declines and rate of carbon leakage varies across sectors

4.1.1 Introduction to the results

In the absence of carbon leakage policy, sectoral abatement measures, or other mitigating factors**,** the model results suggest that carbon prices can have a significant impact on at least some of the sectors examined in full detail. There is, however, substantial variation in the impact across sectors; with a carbon price differential of €15/tCO_2 in 2020, for instance, the impact ranges from negligible to, in one extreme case, production more than halving. The production changes are associated with significant absolute leakage of carbon, and in many cases high carbon leakage rates.

A literal interpretation of the modelling results would suggest that, in the absence of protective mechanisms carbon pricing represents a strong risk to many of both the UK and the EU's high emissions-intensity sectors. However, set in the context of other evidence from the literature review, and taking into account the limitations of the model, it is clear that these results deserve careful interpretation. So, alongside the results which are set out in this section, there will be considerable discussion of their interpretation. In particular, the interpretation will focus on the factors which appear to be driving the results to the levels seen here. Where comparisons can be made with the literature, they will be mainly made for the cement sector, with a brief reference to steel, since seven out of the eight previous studies using partial equilibrium models examine cement.

Within the Cournot framework of the model, the interpretation is that the relative size of the shock, as determined by the emissions intensity per tonne of production and the selling price per tonne, is strongly mitigated by the extent of cost pass-through. This in turn is jointly determined by the competitive threat from non-EU producers, broadly speaking, the non-EU trade intensity, the competitiveness of the industry, and the elasticity of demand. Expanding on these points, one can write down from the model algebra a set of word equations which describe the drivers of results. The results will show how these apply to the sectors and which are most influential. The first word equation describes cost pass-through, which is given by:

$$CPT = \left[\frac{Number\ of\ inside\ firms}{Total\ number\ of\ firms}\right]\left[\frac{Total\ number\ of\ firms}{Total\ number\ of\ firms + inverse\ competitiveness\ measure\ for\ inside\ firms}\right]$$

If firms are roughly equal-sized and the market is competitive:

$$rate\ of\ cost\ pass\ through \approx inside\ market\ share$$

Cost pass-through is related to the proportion of firms which are inside, that is, affected by the cost change, factored by a number which tends to one as the market becomes perfectly competitive and which moves closer to zero as the market becomes first oligopolistic and then collusive. This number is the ‘inverse competitiveness’. It is a parameter which describes the behaviour of firms in the market and makes the observed structure of the market (the number and size of firms) consistent with the observed margins in the model.

The rate of cost pass-through is one if there are no outside firms and the market is perfectly competitive. As inside firms are introduced, the cost pass-through rate falls. If margins are high for the number of firms present, the cost pass-through rate falls further. Less than perfect competition occurs in most markets, and may reflect a concentration of ownership of firms (many firms having the same owner, that is, being associated firms), product differentiation, or a small number of firms.

In all the sectors examined, the number of firms (installations) in the market is greater than nine. This number is sufficient to leave none of the firms individually with much pricing power, and a corollary is that if all the firms experienced an equal cost shock, almost all of that cost shock would be passed through into a change in prices. If only some of the firms are exposed to a cost shock, then the cost pass-through rate will be reduced. The effect is approximately linear, as will be seen in Figure 18. It will be seen that the proportion of supply facing the cost shock is one of the most important discriminating factors between sectors in this study, because they all have relatively large numbers of firms in the market.

The second word equation describes output change for inside firms, where inside firms means those facing the EU carbon price:

$$\%\, inside\ output\ change \approx -\left[\frac{1 - inside\ market\ share}{inside\ market\ share}\right]\left[\frac{price\ elasticity\ of\ demand}{inverse\ competitiveness}\right]\left[\frac{cost\ change}{price}\right]$$

The change in output of inside firms is a product of four elements: a term that is a function of inside market share, price elasticity of demand, inverse competitiveness and cost change as a proportion of price. The inside market share element is zero when the inside market share is 100 per cent, takes the value one when the inside market share is 50 per cent, and has higher values when the inside market share is below 50 per cent. The price elasticity of demand is generally between zero and minus 1.5, and the inverse competitiveness is often between zero and one, but can take values greater than one where margins are high. The ratio of cost change to price is between zero and one and is larger when the carbon price differential is high or carbon intensity of the sector is high. This means that the output change increases as the inside market share falls, demand becomes more price-sensitive, competition becomes more intense (firms behave more aggressively), the carbon price increases and the carbon intensity increases.

The third word equation describes the rate of carbon leakage:

$$\begin{aligned} &\mathit{carbon\ leakage\ rate} \\ &\quad = \left[\frac{\mathit{average\ outside\ emissions\ intensity}}{\mathit{average\ inside\ emissions\ intensity}}\right] \times \mathit{output\ leakage\ rate} \\ &\quad \times \left[\frac{1 + \mathit{outside\ adjustment\ factor}}{1 + \mathit{inside\ adjustment\ factor}}\right] \end{aligned}$$

The adjustment factors relate to heterogeneity among firms in terms of competitiveness and carbon intensity. For example:

- if inside adjustment factor is less than zero or outside adjustment factor is less than zero, carbon leakage declines due to intensity asymmetries;
- if inside adjustment factor is greater than zero or outside adjustment factor is greater than zero, carbon leakage rises due to intensity asymmetries.

These adjustment factors come about if the firms which give up or gain market share as a result of the carbon price shock have particularly high or low carbon intensities relative to the average. For example, if the EU firms giving up market share are particularly carbon intensive relative to the rest of EU firms, then the reduction in EU emissions will be greater and the carbon leakage rate will be lower. On the other hand, if the non-EU firms gaining most market share are particularly carbon intensive relative to other non-EU firms, then the non-EU emissions will rise faster and the carbon leakage rate will be higher. The reverse holds if the firms losing and gaining most market share have lower carbon intensity than their peers. Thus there are four possible combinations: high or low intensity of market share losers within the EU combined with high or low intensity of market share gainers outside the EU, that is high-high, high-low, low-high and low-low. The adjustments to the carbon leakage estimate due to asymmetry in carbon intensity will be greatest in the high-low and low-high cases.

Carbon leakage is the product of output leakage, the ratio of carbon intensities of inside and outside firms and adjustment factors. Since the output leakage rates are in many cases between 0.8 and 1.0, and the carbon intensities of outside firms are either similar to or higher than those of inside firms, then the carbon leakage rates are often between 0.8 and 1.25.

The output leakage rate is given by:

$$\mathit{output\ leakage\ rate} = \left[\frac{\mathit{number\ of\ outside\ firms}}{\mathit{number\ of\ outside\ firms} + \mathit{inverse\ competitiveness}}\right]$$

The output leakage rate can take any value from zero to one. Under perfect competition, inverse competitiveness is zero and the output leakage rate is 100 per cent. As market behaviour becomes less competitive, the inverse competitiveness rises to one and then larger numbers, reducing the output leakage rate. When there are large numbers of outside firms, the degree of competition in the market loses its influence and the output leakage rate becomes close to 100 per cent.

The model does not generate output leakage estimates greater than 100 per cent, but does produce estimates close to 100 per cent when there are many firms in the market, including firms competing from outside. The output leakage results span a wide range, and this is because the competitive behaviour of the market means that outside firms are positioned to take advantage of any cost increase of inside firms by expanding market share.

The competitive behaviour of the market is a function of the large number of players combined with the aggressiveness of their behaviour. The model has been calibrated to recent profit margins which results in quite aggressive behaviour. This is because, in the down part of the economic cycle, as currently being experienced, margins are low. There is spare production capacity, indicated by recent plant closures, reduced numbers of working shifts and low output per plant, and margins are squeezed. These low margins result from aggressive competition over customer orders. Another way to view it is that capital intensive plants are most profitably run at high utilisation rates and have low marginal costs. Firms with capital intensive plant will aggressively work to meet their optimal utilisation, and this will push down margins when demand is weak. This means that at times of low demand, competition is more intense. As a consequence, the output leakage rate is moved towards 100 per cent. If the model was calibrated instead to a period in mid economic cycle, the output leakage rate would be somewhat lower and so would the carbon leakage rate.

Significant caveats to the model results exist. These caveats include the following, which should be borne in mind when interpreting all model results presented in this section and in the case studies:

– the model results take place in the absence of any form of policy intended to protect against output or carbon leakage;
– in practice, emissions abatement techniques would be used by industry to lower the extent of exposure to carbon prices. The potential for this to happen varies by sector, and is discussed further in the case studies;
– carbon prices outside the EU are assumed to be zero;
– another general factor increasing the scale of the results is the models' assumption that goods are homogenous within each sector, that is, importers are providing perfect substitutes for domestic production. For several sectors this is an overstatement; current UK policy also plans on significant decarbonisation of the electricity supply out to 2050. This is not included in the models;
– the relatively large scale of the results is partly driven by the IMMs allowing for full capital adjustment; that is, the focus of the models is long term, in the order of years or decades. Thus, the suggestion is not that industries would cease operations immediately following the application of a particular carbon price in a given year, but rather would run down operations gradually;
– the lack of accounting for carbon emissions involved in transport suggests that, for the most part, it can be expected that the post-shock levels of carbon emissions are underestimated. That is, in sectors where global carbon emissions decline in association with increases in imports from non-EU producers, the extent of reductions may be overstated, insofar as transport emissions associated with non-EU producers are likely to be greater than for EU producers. Thus the benefits of carbon pricing may be overstated;
– downstream and upstream impacts of carbon pricing on a sector are not considered. That is, if universally-applied carbon prices would result in an increase in the cost of an input (besides electricity) to a sector, that is not included in the modelling. An exception is the concrete products sector, where the modelling includes the estimated increase in average cement prices under carbon pricing.

It may be of interest to discuss which of these caveats are most important and how they affect the interpretation of the results, including by comparison with the literature. First, let us consider a group of three factors: the free allowance allocation, the carbon prices of trade partners and emission abatement measures. Each of these, if accounted for explicitly, would bring down the estimated impact. The free allowance allocation and carbon prices of trade partners would lower the economic impact of the carbon price scenario, somewhat equivalent to using a lower carbon price differential in the model. It is hard to anticipate the difference it would make. At present, few other regions of the world have explicit carbon prices, though this is likely to change by 2020 and beyond.

Turning to abatement measures, the inclusion of abatement might have a great effect on the carbon leakage rate. For example, suppose there was output reduction of 10 per cent and firms outside the EU are 25 per cent more carbon intensive than those inside. In this example:

carbon leakage rate = outside increase in emissions / inside decrease in emissions
= 10 % × 1.25 / 10% × 1.0
= 125%

Compare this with a situation in which there is 10 per cent abatement (reduction in carbon intensity) among inside firms in response to the carbon price. Now the outside increase becomes:

Outside increase = 10% × 1.25 = 0.125
Inside decrease = 10% × 1.0 + 10% × 0.9 = 0.19
And the carbon leakage rate = 0.125 / 0.19 = 66%

The carbon leakage rate has halved as a result of 10 per cent abatement.

This simple illustration shows the importance of abatement when estimating carbon leakage. Unfortunately, estimates of the elasticity of carbon intensity with respect to carbon price are not available on a sectoral basis, and are very time consuming to estimate from scratch. Hence, for this report, estimates of abatement have not been included. If they become available in the future, the carbon leakage results shown in this section could easily be adjusted to show an indication of the abatement effect, even without re-running the models. Some of the comparator studies in the literature do incorporate abatement, which leads them directly to estimate lower rates of carbon leakage.

Now let us consider the assumption of homogenous goods; that is, that all firms' products within a sector are identical or perfect substitutes. To some extent this assumption is offset by the calibration of the model to observed margins or competitive behaviour. Observed margins incorporate the effect on the strength of competition from stickiness of customer-supplier relationships, product variation, local geographic restrictions, access to customers and other aspects of product heterogeneity. Nevertheless, it seems likely that the way in which the model interprets small firm size as being indicative of competitive weakness may in fact downplay such firms' strength in specialised products, niches, arising from product variety. If this is the case, then the assumption of homogeneity is likely to overstate the market share redistribution after a cost shock and thus bias output leakage estimates upwards.

Third, the long-run equilibrium which the model computes would take a number of years to be reached in the real world. Short-run results from other models in the literature are expected to be much lower estimates for this reason. It can take many years for capacity in a sector to be shaken out, for example. In some countries, state ownership of the firm, or labour laws inhibiting closure might delay exit. Whereas, in contrast, there could be circumstances in which the adoption of highly-levered financial structures precipitate rapid closure, or part of the supply chain becomes distressed and capacity adjusts quickly. Only detailed examination of the production assets, market conditions and ownership would show whether short-run behaviour will come close to the long-run position predicted by the underlying economic drivers.

Other factors are listed in the bullet points above, but those just discussed appear to be the most likely significant sources of bias for the results. This is because transport emissions and upstream and downstream carbon emissions are, in most sectors considered in this study, likely to constitute much less of the embodied carbon in the product than the direct and indirect emissions which have been modelled. Thus, although they may add to or subtract from the modelled estimates of output and carbon leakage, they are likely to be smaller than the simplifications applied to the carbon intensive sector itself.

The carbon price differential scenarios span a wide range. They include low values, capturing the impact of the current EUA price of around €5/tCO_2 with no explicit carbon prices among trade partners. They extend to €50/tCO_2, which is probably beyond the limits of political feasibility as a unilateral price within the EU in the absence of substantial carbon prices among trade partners, or in the absence of mitigating policies designed to control carbon leakage. Thus when reading the results from the higher carbon price differential scenarios, one has to bear in mind that these are for illustration only.

In summary, in introducing the model results and explaining a number of simplifications within the model, scenarios and data, a range of biases have been discussed and differences noted between the set up of these results and those reported in other studies. Most of the biases lead to higher estimates of carbon and output leakage and for this reason, it is important to treat the results as upper bound estimates. With better, more detailed data, a large part of this bias might be removed. The consequence would be that the output leakage rates estimated would move lower, away from 100 per cent, because the results in this study show that strong competition leads to output leakage rates in the range 70 to 80 per cent or higher, and this pattern is confirmed from previous work with these models. The change in carbon leakage rates could be higher where abatement measures can be included. This is the greatest of the factors causing upward bias of the carbon leakage metric.

4.1.2 Cost pass-through rates vary, as does the extent to which carbon pricing erodes margins

The impact of the shock from the perspective of producers is mitigated by the rate of cost pass-through. The greater the rate of cost pass-through, the greater the preservation of margins and hence retention of investment. By continuing to attract investment, capacity and output are both sustained. The rate of cost pass-through displayed in Figure 9 is the average figure for inside firms. In the sectors where there are specific data on individual firms, the cost pass-through rate for an individual firm may be higher or lower than the average. This reflects whether the firm has lower or higher carbon intensity than the average. Firms with lower rates of cost pass-through will experience reduced margins relative to the average, and over time they will attract less investment and will shrink.

The Industrial Market Models calculate cost pass-through rates as a function of the various parameters that describe the competitive structure of the market; that is, it is an output, rather than an input, to the model. Cost pass-through rates vary substantially over the sectors examined (Figure 9).

The lowest estimated cost pass-through rate is for aluminium. This commodity is traded in a global market, with very low transport costs relative to product price and sufficient global capacity to take any market share given up by EU producers. EU producers have little influence over the global price, supplying only 8 per cent of global output, and absorb more than 80 per cent of the cost increase.

The highest estimate rates are in distilled air and malt. Distilled air is closely integrated with steel production and much of the output of plant is supplied by pipeline locally. Transport costs are relatively high and there is little EU-non-EU trade. One hundred per cent of costs are passed through. In the malt sector, Europe has a competitive advantage and is an exporter with no or very low imports into to the EU. The absence of non-EU competitors in the supply of malt for EU consumption allows full cost pass-through.

The other sectors have estimated rates of cost pass-through of between around 50 and 100 per cent; most above 75 per cent. The estimates are driven to high levels firstly by the large number of installations present across the EU, in the majority of cases, where the market is defined as the EU region; and second, by the relatively small non-EU market share of single digit per cent in some cases.

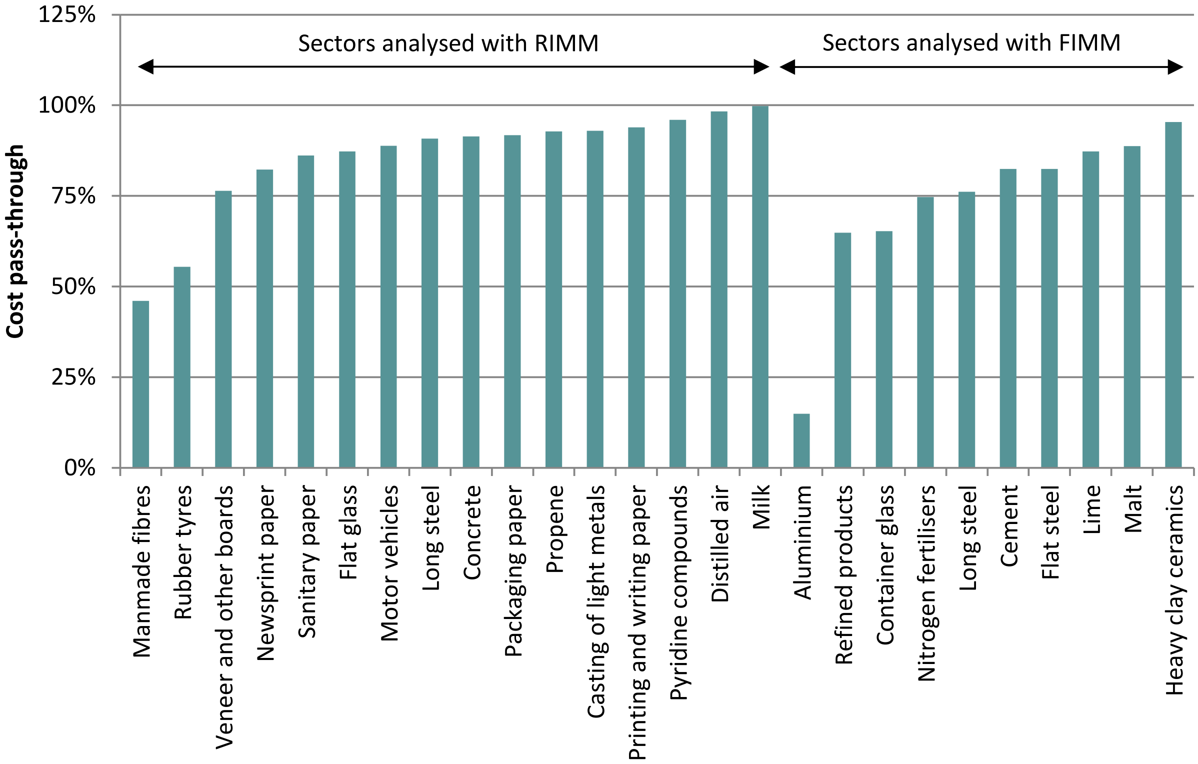
It is a simplification to treat all EU firms as if their market environment were identical. Some, for example, those on the Eastern or Southern borders are geographically close to non-EU competitors and may experience lower cost pass-through, perhaps most especially in the goods with lower prices per tonne, such as bricks and tiles or cement. In contrast, other firms might be placed well inland and centrally within the continent and face much less non-EU competition.

A higher cost pass-through rate means that the profits of firms are less eroded, though there are provisos to the interpretation of this; see Box 1. However, it can be seen that even rates of 82 per cent for cement and 65 per cent for container glass leave those sectors still facing significant cost shocks. As shown in Figure 10, a €15/tCO_2 carbon price imposes costs on several industries which constitute a significant share of their selling price. Indeed, for cement, nitrogen fertilisers, and lime, the shock is over 10 per cent of price, and substantially larger than sector average gross profit margins. Following cost pass-through, cement profit margins approximately halve, while nitrogen fertiliser margins decline by more than one-quarter.

There are other factors not incorporated into the model explicitly which may be partly built in through its calibration. These are difficult or impossible to measure directly or to quantify the importance of. One of these factors is customer-supplier relationships. These may be strong, in order to facilitate mutually beneficial investment, such as technical development, but may constitute a barrier to entry for outside firms. On the other hand, improving transport infrastructure, communications and technology transfer may result in new rivals emerging where there were none before.

Another factor which certainly plays an important role in the results is the economic cycle. During the recent times of weak consumption and investment, demand has been low and there has been surplus production capacity in many of the sectors examined. This leads to lower margins and a situation which has the characteristics of a more strongly competed market. In the model, this translates into higher rates of cost pass-through, when outside market share is low, and higher rates of output leakage, when outside market share is higher. If the model had been calibrated to a boom period, then margins would have been high, competition would have appeared to be less aggressive and the estimated rates of cost pass-through and output leakage would have been lower. Similarly, sectors experiencing protracted declining or growing demand can behave as more or less strongly competed, giving rise to different estimates even where the market structure and other attributes make them appear similar.

Figure 9. **Cost pass-through rates vary substantially across sectors investigated in reduced and full detail (2020, €15/tCO_2)**



Source: Vivid Economics

It is worth mentioning again here that the model represents changes in long-run equilibrium outcomes by treating operating and capital costs as one. The assets employed in these sectors may have working lives of several decades when well maintained, but due to the discount rate applied to investment decisions, it is the first five to seven years ahead which is most critical in investment decisions. These two facts, taken together, mean that expectations of carbon prices ten or more years ahead will have limited influence on decisions today and the results reported here may take more than a decade to emerge after a price shock has been introduced. These factors mean that the experienced impact of an anticipated future carbon price differential will be much less in the short term than the estimates presented here.

Box 1. **The meaning and interpretation of cost pass-through in the IMMs**

As with all estimates made with the IMMs, the cost pass-through rate refers to the long-run outcome, over a period of several years. Difficulties in passing on costs relating to contract lengths, or to particular (but temporary) macroeconomic conditions, should not be expected to affect the cost pass-through rate.

Within the IMMs, the cost pass-through rate is driven by:

- profit margins, where low margins are interpreted as indicating high market competitiveness and, in the long-run, high rates of cost pass-through;
- non-EU import shares, where high exposure to non-EU imports suggests that the market price is determined in a broader geographical context and price shocks within the EU will not affect the sale price;
- demand elasticity, where, if consumers are more responsive to price changes (elasticity is higher), firms will be less likely to pass on costs.

Consequently, high cost pass-through rates should not be interpreted as indicating that a sector is robust against cost shocks. Where profit margins are low, even a high cost pass-through rate for a given cost shock could still leave a firm facing a proportionally large reduction in profitability. Indeed, more generally, a high cost pass-through rate provides limited protection for a sector if the absolute size of the cost shock is large.

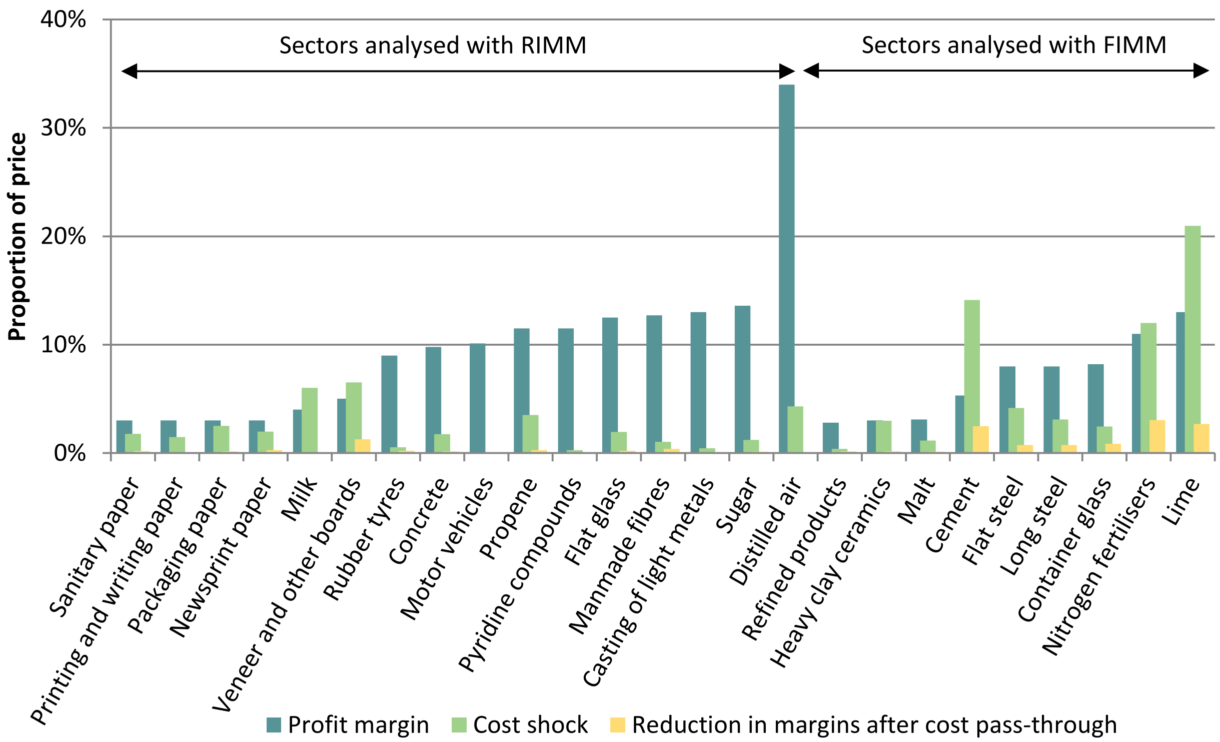
Consequently, while the cost pass-through rate is certainly of interest, it should not be the focus of attention for policy makers: it represents an intermediate step to the calculation of the variables that actually reflect the impact on the sector, such as the proportional change in production. However, it remains the case that by assuming the cost pass-through rate is zero or constant across all sectors, as is done in the EU's quantitative carbon leakage criteria, leads to sectoral distinctions being missed.

In many sectors, the impact of a €15/tCO_2 cost differential, after setting off costs passed through into price rises, is only a small fraction of the current profit margin. Malt, motor vehicles, refined products and casting of light metals are four examples shown in Figure 10. These sectors experience little change in competitiveness as a result. The same is not true of all sectors, with some others experiencing significant reductions in margin, in four examples: cement, lime and veneer and other boards, suggestive of loss of competitiveness. In the highest price differential scenarios tested, the changes in margin for some sectors are sufficient to no longer be marginal changes, and the model is less reliable in estimating the impacts of non-marginal changes. For this reason, the results for the €50/tCO_2 scenario are less reliable, for the carbon intensive sectors, than the results for the lower cost scenarios.

The EU use a threshold of 10 per cent of gross value added at €30/tCO_2 as the criterion for carbon leakage exposure. Figure 10 indicates that some sectors would experience significant margin changes at a lower carbon price differential of €15/tCO_2.

Besides reductions in margins, profits may also be eroded by reduced output, as shown next.

Figure 10. **A €15/tCO_2 carbon price differential is relatively large compared to product price, though most sectors pass the bulk of the shock to consumers**



Notes: *Gross profit margins are pre-price shock. 'Carbon price shock' refers to the tonnage of carbon dioxide emissions per tonne of production, multiplied by the assumed €15 carbon price. 'Proportion of price' refers to the scale of the carbon price shock as a share of the average selling price of sector production, by tonne. The proportion of price is* not *adjusted to reflect that, in practice, some share of the carbon price shock would be passed on to consumers. Aluminium excluded for confidentiality considerations. Note that the high profit margin shown for distilled air was reported by IBIS World (2013).*

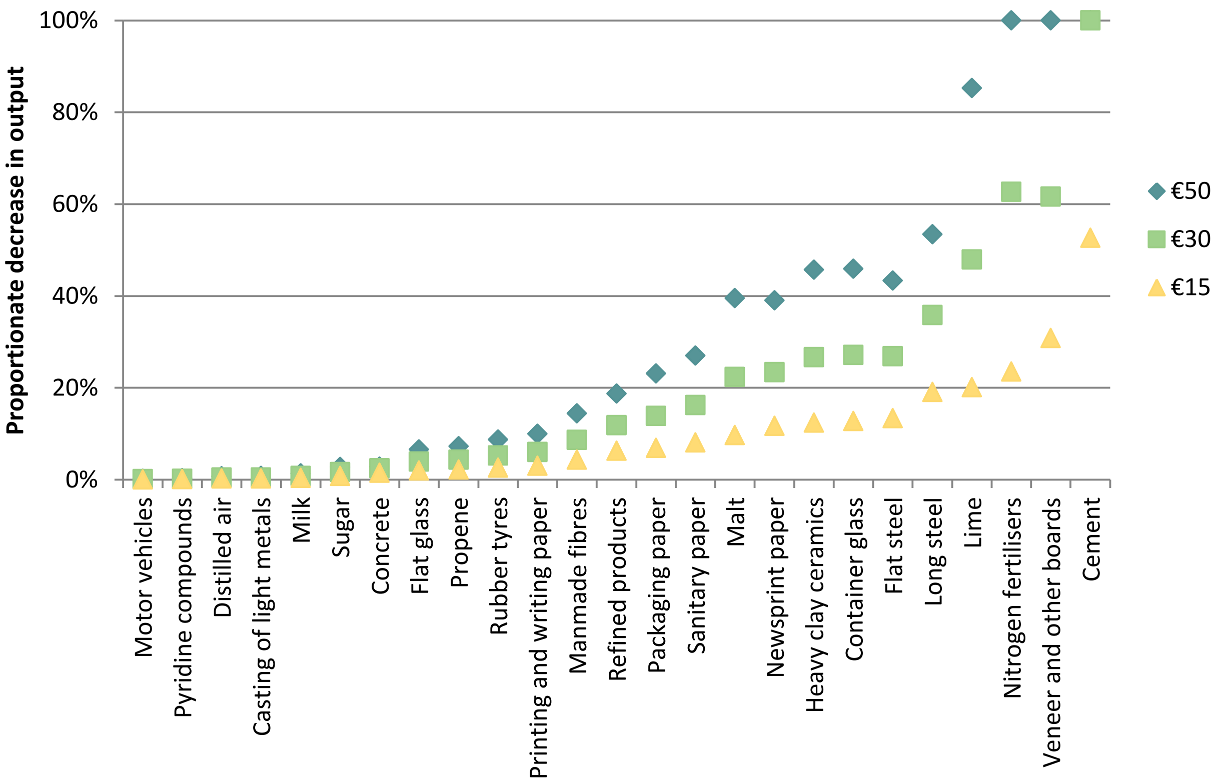
Source: *Vivid Economics*

4.1.3 High carbon prices have a strong impact on production in several sectors

Figure 11 shows the impact on UK production of the main carbon price differential scenarios on the sectors investigated using FIMM. The range of effects varies substantially; production in the distilled air and concrete products sectors reduces only slightly even under price differentials of €50/tCO_2, while the same price results in closure of the UK cement and nitrogenous fertiliser industries, noting that the model is not reliable in estimating large changes in circumstance. The effect of a €15/tCO_2 price is, naturally, less pronounced; cement still shows a decline in output of around 50 per cent, while most other UK sectors vary in their production decline between 5 and 25 per cent. Under a price of €5/tCO_2, the most strongly affected UK sector is veneer panelling, where production declines by around 9 per cent.

The Boston Consulting Group 2008 study obtain the same result for cement, that at €35/tCO_2 (in 2008 money), output falls to zero. As previously mentioned, contrasting model types based on econometrics or computable general equilibrium certainly produce much lower estimates. This being the case, let us check the credibility of the estimates shown in Figure 11 using data from Figure 10. The sense check works like this: if the margin falls to zero, the return on capital is below the cost of capital and the firms cannot invest; if the situation persists for the remaining firms, then they too will eventually close through lack of investment. This rule of thumb allows a simple test: given the cost pass-through rate, the carbon intensity and the initial margin, does a sector's margin fall to zero at any of the carbon price differentials tested? The answer for three sectors, cement and fertilisers and veneer and other boards, is that the margin does fall to zero in some scenarios; in the first case at around €30/tCO_2 and in the second and third cases at around €50/tCO_2.

Figure 11. **The impact of carbon price differentials varies considerably across sectors (2020)**



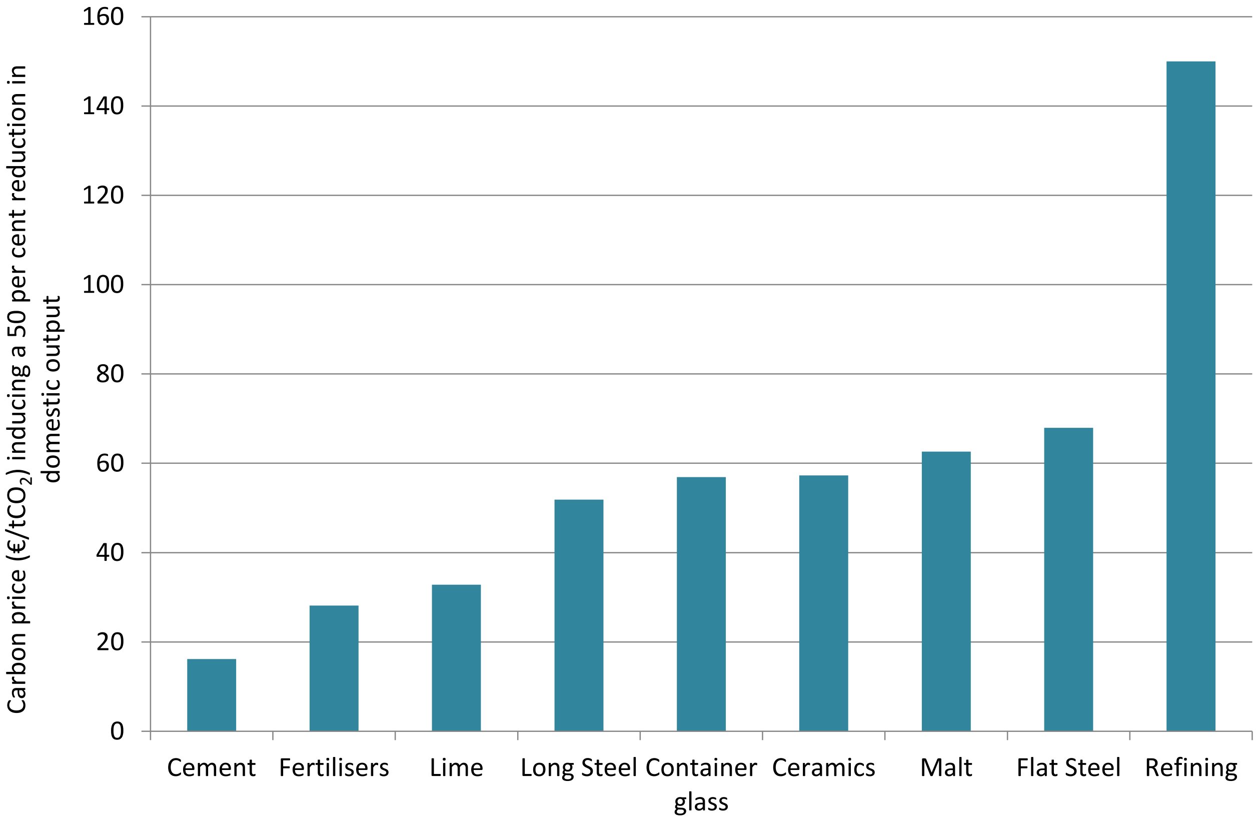
Note: *Aluminium excluded for confidentiality considerations. Results for 'UK-level sectors' refer to decreases in output at the UK-level, while for 'EU-level sectors' to the EU-level.*

Source: *Vivid Economics*

In all cases, a higher carbon price results in a bigger impact on the sector. Note that this need not necessarily be true; it would be possible, for instance, for a hypothetical UK sector to benefit from carbon pricing if it was relatively less carbon-intense that its counterparts in the remainder of the EU.

One can apply the rule of thumb in a more sophisticated manner, using the model to find the carbon price which results in a halving of production levels. This is shown in Figure 12. Again, cement appears to be the most vulnerable. Fertilisers and lime are not discussed in the literature although they are among the most vulnerable studied in detail here. As mentioned before, these estimates mark the upper limits of the probable levels of impact and reflect a scenario with no carbon leakage policies, sectoral abatement measures or other mitigating factors, so the output-halving price differentials in Figure 12 are the lowest possible prices at which output might halve in the long run.

Figure 12. **Carbon price differential (€/tCO_2) inducing 50 per cent reduction in UK output (2020 core scenario)**



Source: Vivid Economics

The effect on the sectors investigated in less detail is substantially milder, largely due to these sectors having substantially lower emissions intensities on average. It is also the result of assuming homogeneity across EU firms, so that there are no weaker firms who disproportionately reduce output when the cost differential is applied. In the more detailed analysis, part of the output reduction is focussed on weaker firms.

4.1.4 Upside, downside and central scenarios

Figure 13 shows the variation in output under the upside and downside scenarios, see Section 3.2.2 for a description. The scenarios span a range of future rates of growth in consumption and import market shares. The overall level of demand drivers the tonnes of emissions and the import market share affects sensitivity to carbon prices. In general, the larger the overall impact, the greater the range between the upside and downside. This is partly, though not entirely, a consequence of larger impacts being associated with smaller inside market share, which is amplified by the variation in inside growth rates in the scenarios.

The changes in import market shares, also called outside market share, reflect scenarios of relative competitiveness between inside and outside firms. There are many individual factors which contribute to changes in competitiveness. For example, relative costs may change due to exchange rate movements: at times when the UK or European currency is valued highly, inside producers find their costs are relatively higher than their non-UK or non-European rivals. Another macro effect is change in the cost of finance due to local inflation risk: times of higher inflation in the UK or Europe would push up the risk-free rate and make investment more expensive. This has a long-run dampening effect on the competitiveness of firms. Major disruption to the economy, as followed the recent banking crisis, can also lead to higher costs of finance and reduced investment, again undermining long-run competitiveness.

Other factors would also change competitiveness, and are intended to be covered by the scenarios. One is the adoption of technology, whereby advanced technologies, often developed in the US or Europe, diffuse to new regions and strengthen the competitive position of rivals in those regions. There may be related or independent construction of new capacity to serve local markets outside Europe, to meet growing demand, for example in the Asia-Pacific region. This new production capacity may be built to serve future demand and may in the short run use its surplus capacity to compete in Europe. A further change is in transport costs: for many years transport costs have been falling on a long-term trend as ports become more efficient and ships become larger. Further improvements in the efficiency of logistics or reductions in trade tariffs would increase levels of trade by making traded goods more competitive with locally-produced goods.

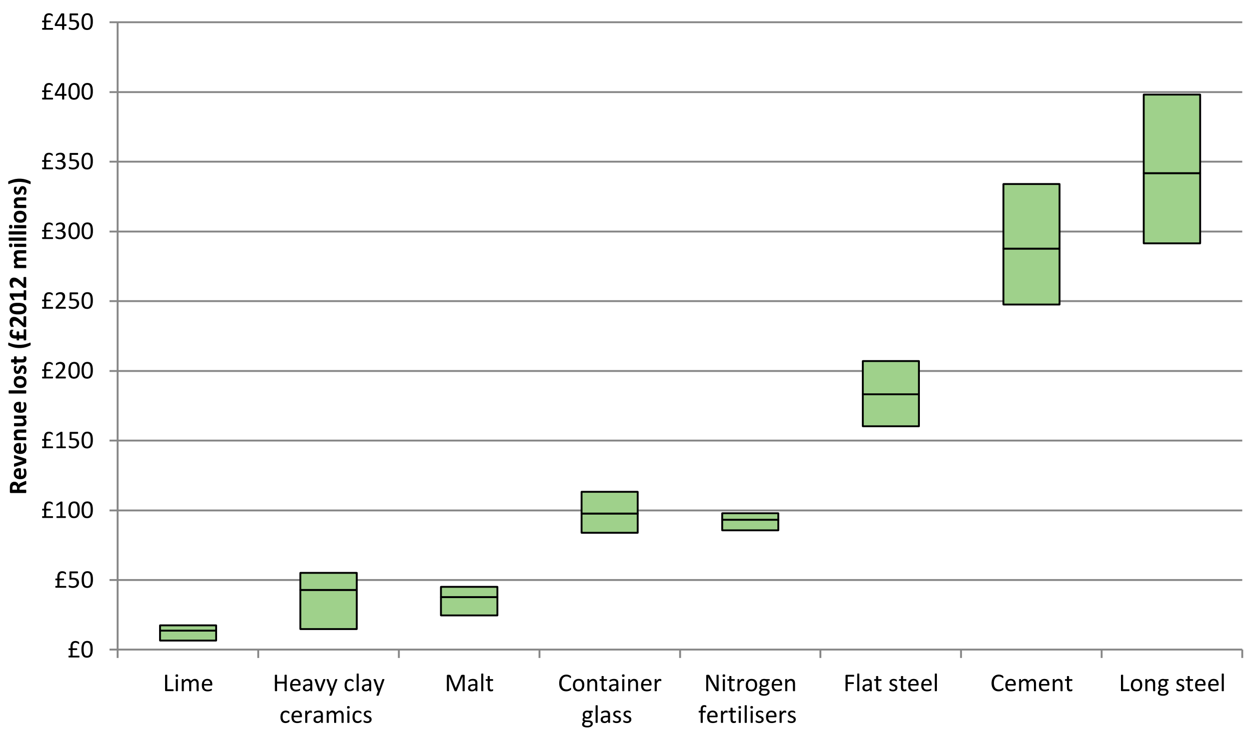
There are, of course, many more effects than those listed above, and all of these effects can change in one direction or the other, to expand or dampen trade. The purpose of the scenarios is to show how sensitive the model results are to significant aggregate changes in competitiveness through effects such as these.

In discussion with industry sectors, both sector associations and individual firms, examples of these changes have been described to the study team. For example, the opening up of new production capacity to serve new demand in Asia which then sells surplus product to Europe; or the building of new factories east of Europe's borders, taking advantage of low wages and state support, with the intention of supplying the European market; or the building of energy intensive manufacturing in the Middle East, with the intention of competing in Europe, Asia and North America. There is further discussion of recent trends in sectors in the case study appendices.

So far the discussion of results have all been normalised to show percentage changes following the introduction of a carbon cost differential. In Figure 13 and Figure 14, the presentation is of absolute changes. This shows differences in scales of activity across sectors, highlighting the large scale of paper, petrochemicals, motor vehicles, steel and cement and the smaller scale of fertilisers, container glass, heavy clay ceramics, lime and malt, for example. By far the largest revenue impact is seen in refining, followed by packaging paper, which are the only sectors to exceed £1 billion, followed by printing and writing paper, which is the only sector greater than £0.5 billion. Refining is not shown in Figure 13 and Figure 14 because it is so much larger than the other impacts.

The figures also show the sensitivity to changes in assumptions under the range of scenarios. Of all the sectors studied, propene, a petrochemical, is the most sensitive to the scenario assumptions, as revealed by the length of its bar in Figure 14. The steel sectors and cement are also relatively sensitive to the scenario assumptions, as shown in Figure 13, in contrast to fertilisers, container glass and most papers, which are less sensitive. Sensitivity is linked to competitive position. Sectors which already face some trade exposure, with between 10 and 20 per cent of the market supplied by outside firms, are the most sensitive to further changes in competitive position. Sectors with somewhat lower trade exposure, of between 5 and 10 per cent, such as container glass, have moderate sensitivity, and those with exposure of around one per cent or less, have the lowest sensitivity. In the sectors investigated in less detail, propene and motor vehicles exhibit the greatest sensitivity.

Figure 13. **The value of the reduction in UK production varies substantially across sectors investigated in full detail (2020, carbon price differential of €15/tCO_2)**



Notes: *Areas covered by boxes represent the range between 'upside', 'central', and 'downside' scenarios.*
The refining sector is excluded as it is substantially larger than any other sector shown. Changes in refining output total around £2.2b in the downside scenario, £2.6b in the core scenario, and around £3.0b in the upside scenario.

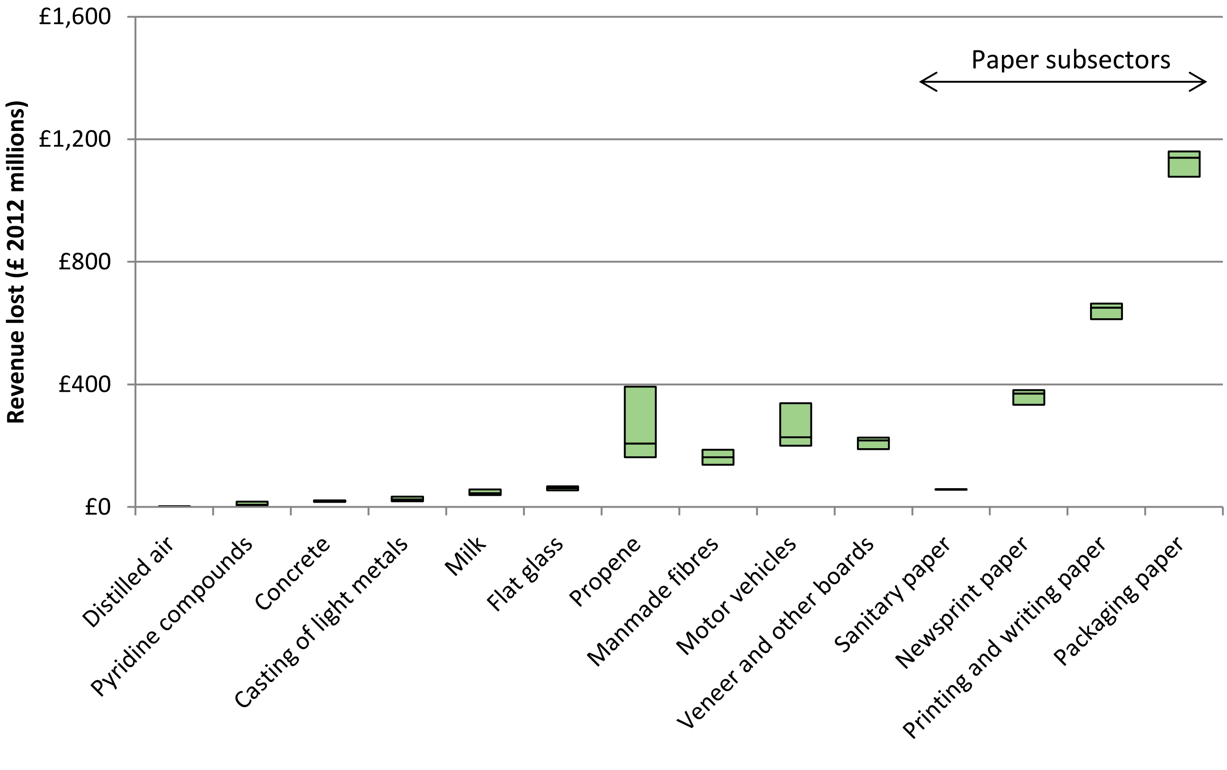
Source: *Vivid Economics*

Production losses in the paper sector vary across subsectors: sanitary paper, being less widely traded, is less exposed to competition from non-EU sources. The value of production losses in the RIMM sectors also vary significantly (Figure 14), though several RIMM sectors record substantially lower revenue losses than the

FIMM average, generally due to lower typical carbon intensity of production. The responses in the upside and downside scenarios are not symmetric; for example, the decline in the value of production in the downside scenario compared to the core scenario for 'passenger vehicles' is much greater than the difference between the core scenario and the upside scenario. This is due to non-linearities in the model's responsiveness: for instance, as EU market share changes over the scenarios, greater import exposure (and hence stronger competition) results in proportionately greater responses to carbon pricing.

As noted before, these results are all upper bounds on the likely impact, here of a €15/tCO_2 carbon price differential in 2020. Since these are long-term model estimates and 2020 is only seven years forward from the base model data, the long-run effects would not have had time to act and actual revenue impacts are likely to be lower, even if there were to be a carbon cost differential of this level in 2020.

Figure 14. **The value of reduction in UK production varies substantially across the paper sectors and the sectors investigated in reduced detail (2020, carbon price differential of €15/tCO_2)**



Notes: Areas covered by boxes represent the range between 'upside', 'central', and 'downside' scenarios.

Source: Vivid Economics

4.1.5 Carbon leakage rates under carbon price differentials

The carbon leakage rates span a wide range of values. At one end of the range, there are low values, of 10 to 30 per cent, for sectors such as malt and refining. At the other end of the range are carbon leakage rates between 75 and 125 per cent for sectors such as flat steel and cement. The high estimates all reflect levels of output leakage between 80 and 100 per cent, as discussed earlier, combined with carbon intensities for outside firms that are higher than for inside firms. For example, in fertilisers:

Output leakage rate = 93%
Ratio of carbon intensity of outside to inside firms = 119%
Carbon leakage rate = 111%
Carbon leakage rate = output leakage rate x ratio of carbon intensity of outside to inside firms
1.11 = 0.93 x 1.19

These results can be compared with results published in the literature. Again, a direct comparison can only be made with models of a similar type, where the literature offers carbon leakage estimates for cement and steel of up to 50 per cent for cement (and 88 per cent in coastal regions) and up to 75 per cent for steel. Note that some of these studies assume emissions abatement measures which reduce the carbon leakage estimates considerably.

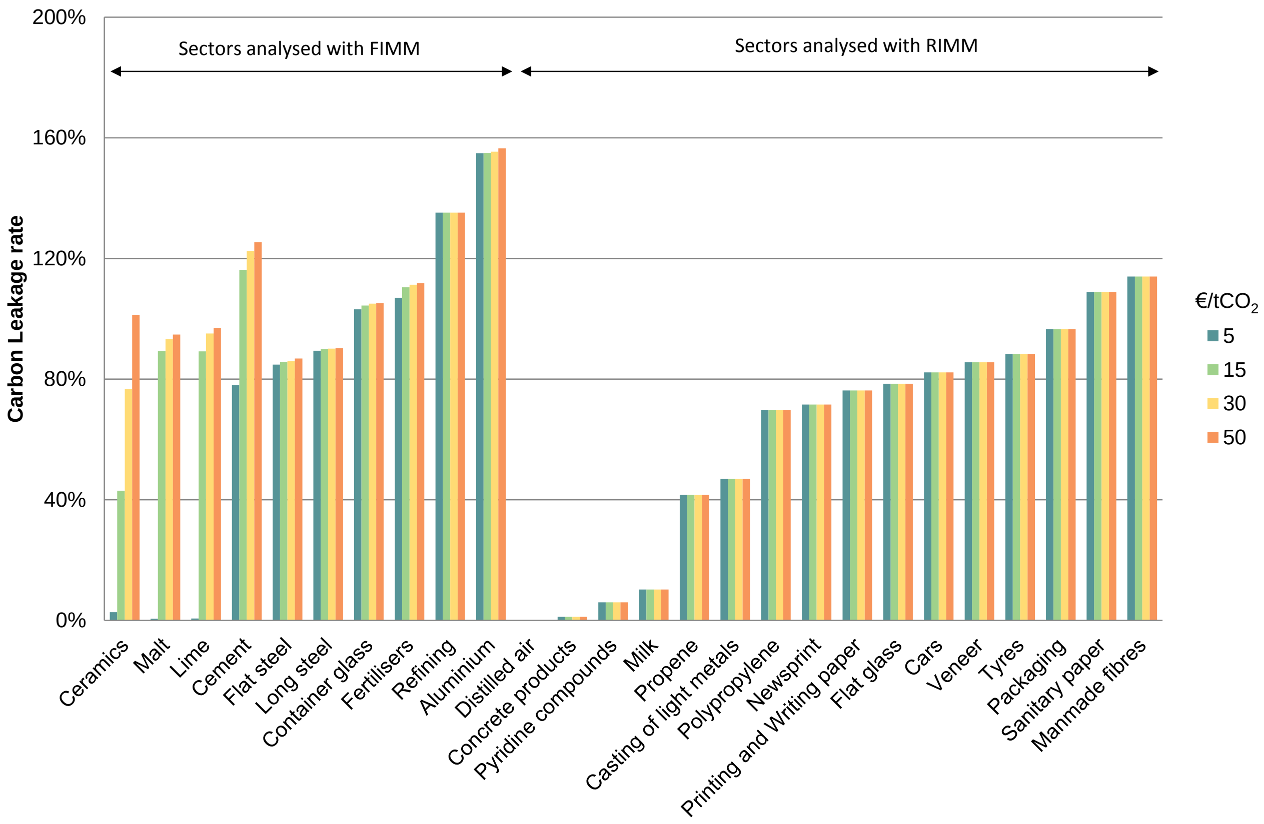
While the European Union's carbon leakage criteria take into account trade exposure, they do not take into account relative carbon intensity of EU and non-EU firms nor do they adjust for abatement opportunities. Carbon leakage is less of a concern where outside firms are clean and abatement within the EU is likely to be significant.

Carbon leakage is an important metric because it reflects the environmental effectiveness and the cost-effectiveness (efficiency) of the EU ETS in reducing global emissions. A carbon leakage rate of 50 per cent after abatement implies that the apparent cost in Euros per tonne of emissions reduction in Europe should be doubled to obtain the true unit cost of emissions reductions globally and similarly that its environmental effectiveness is half the apparent figure based on changes in emissions within Europe. Similarly, a carbon leakage rate of 90 per cent implies that the cost should be multiplied by a factor of ten.

Section 6 discusses policy instruments which might reduce carbon leakage. For the reasons just mentioned, policies which are effective in reducing leakage will increase the cost-effectiveness and environmental effectiveness of the EU ETS. It has been stated that to be effective, a policy instrument will reduce output leakage or increase inside abatement. It is not possible to control the ratio of carbon intensity of inside to outside firms in order to reduce carbon leakage, since the carbon intensity of outside firms is beyond the control of European authorities. In order to reduce output leakage a policy will have to act to reduce the effect on capacity investment of the carbon price differential between inside and outside firms. If it can do this without simultaneously reducing the carbon price acting on inside firms, then the contribution from abatement measures may increase without changing the absolute level of carbon leakage. Hence, the carbon leakage rate will be lower. The final option is to increase the abatement response of firms: the carbon price already raises the return on abatement investment, and thus the remaining lever is to reduce the cost of abatement.

In summary, there is a simple objective in improving the cost effectiveness and environmental effectiveness of the EU ETS, which is to reduce the rate of carbon leakage. The key mechanisms by which this might be achieved are by reducing the carbon price differential between inside and outside firms, by increasing the returns on investment in EU production capacity and by improving the responsiveness of inside firm abatement to carbon prices. The first of these is the easiest to measure.

Figure 15. **A variety of carbon leakage rates are estimated, often around 80 per cent (2020 core scenario)**



Note: *The RIMM, by assigning the same carbon intensities to all inside firms, produces the same carbon leakage rates in all price scenarios. In refining, all firms have been assigned the same emissions intensity, resulting in no change in carbon leakage as the carbon price differential varies. The low leakage rates for malt and heavy clay ceramics at €5/tCO$_2$ are an artefact of the construction of the counterfactual. The aluminium figures reflect large differences in carbon intensity between EU and non-EU producers.*

Source: *Vivid Economics*

4.1.6 A note on closures

As discussed, the Industrial Market Model is focused on long-run outcomes, that is, the shift from one equilibrium to another. Thus, besides the various other provisos already mentioned, results indicating sector-wide closure should not be interpreted as implying such an impact would occur immediately. Rather, the process is more likely to involve a gradual run-down of investment in domestic facilities, to the benefit of external facilities; that is, the 'investment channel', as discussed in Section 2. That is not to say that this provides a shield for the economic impact; the immediate decline in profits, for instance, would be passed to company shareholders. It is also worth noting the employment figures in each sector, as discussed in the case study, would be directly affected by production declines, though not necessarily in a linear manner. Even as the output level of a firm changes, many of the jobs involved, in operations and maintenance, may remain unchanged, with a proportion of jobs increasing or decreasing in number in response to demand.

For some sectors, the social cost of employment effects may be exacerbated by the concentration of production in particular regions. In most areas in a well-functioning economy, these effects are transitory, but in places where there is structural unemployment, they may constitute real long-term costs. The economy is typically able to absorb modest rates of change in employment in a sector, but if the sector employs a significant proportion of the workforce in a geographical area, rapid changes can result in unemployment and reduce the productivity of the economy. In areas where long-term structural unemployment is present, the loss of significant employment can result in lower long-term participation in work and hence lower output. Where jobs are highly skilled, loss of specialist roles may result in employment in less productive work generating less output.

The pathway by which capital stock adjustment occurs may also be influenced by other factors: for example, the necessity of running installations at high capacity due to inefficiencies caused by part-loading, or the extent to which a sector is comprised of many small installations versus several large ones, or financial structures. These factors may influence whether cuts in capacity are smooth or occur in steps. For example, studies of closure have found that state ownership is associated with a reluctance to reduce capacity or close and that highly geared financial structures are more vulnerable to collapse followed by closure. These features of ownership and finance can moderate the pace at which changes in output take place and whether they result in closure or a period of lower profitability and output.

4.2 Other drivers of variation

Variation is explained by market share, geographic location, and other factors

The individual stories explaining the drivers of changes in output and carbon leakage are discussed in the various case studies included as appendices. This section also provides some general descriptions of the variations in parameter values across sectors and the importance given by the models to different factors.

4.2.1 Geographic spread of industry is important

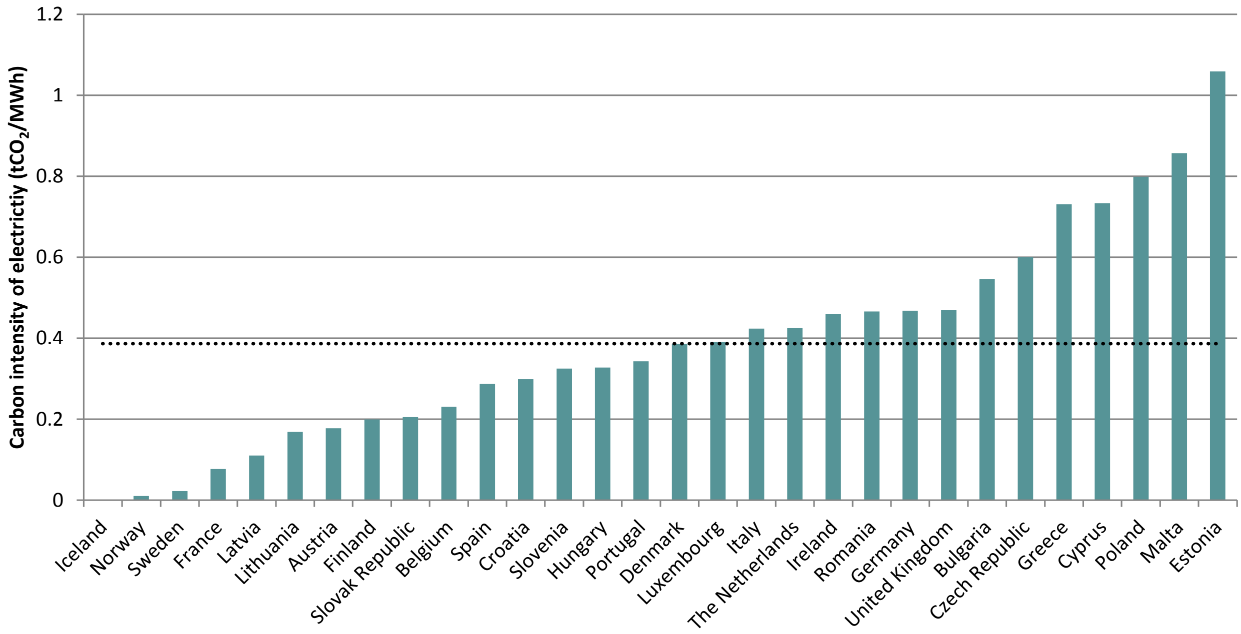
The location of industries even within Europe significantly influences how they are impacted by a carbon price. As shown in Figure 16, the average emission intensity of electricity production varies substantially across European states. Certain industries are concentrated in particular areas; for instance, malt production occurs particularly in the UK, Germany, and the Czech Republic.

The variation in indirect emissions intensity is important because it leads to differences in carbon intensity between European firms. It is likely that direct carbon intensity varies too, but the information on direct emissions is more difficult to compare across countries. This variation between European firms means that a carbon price in Europe might create redistribution of output between European firms and in due course a change in the average carbon intensity of production through this redistribution. For those countries with the highest carbon intensity of production, shown here for electricity as being Estonia, Malta, Poland, Cyprus, Greece and the Czech Republic, the level of output leakage will be higher than the EU average. For countries with the lowest carbon intensities, such as France, Norway, Sweden and Austria, the output leakage will be lower than the EU average. Note that some firms produce their own power and so these standard country values would not apply. These relative positions are likely to change over time in response to individual country programmes to decarbonise power production.

Almost certainly there will also be differences in abatement response country by country. It may be, for example, that firms in some countries are more competitive than others and have better access to abatement technology and to finance. These firms may adopt abatement measures more readily than other firms and so would have lower estimated carbon leakage figures.

These country-by-country differences are not factored into the EU free allowance eligibility criteria, which treat all sectors as being the same across Europe, so that estimates of eligibility are made on the basis of average figures, although actual allocations are made on the basis of leading benchmarks.

Figure 16. **The average carbon intensity of electricity production varies significantly across Europe, which suggests that the marginal intensity will too**



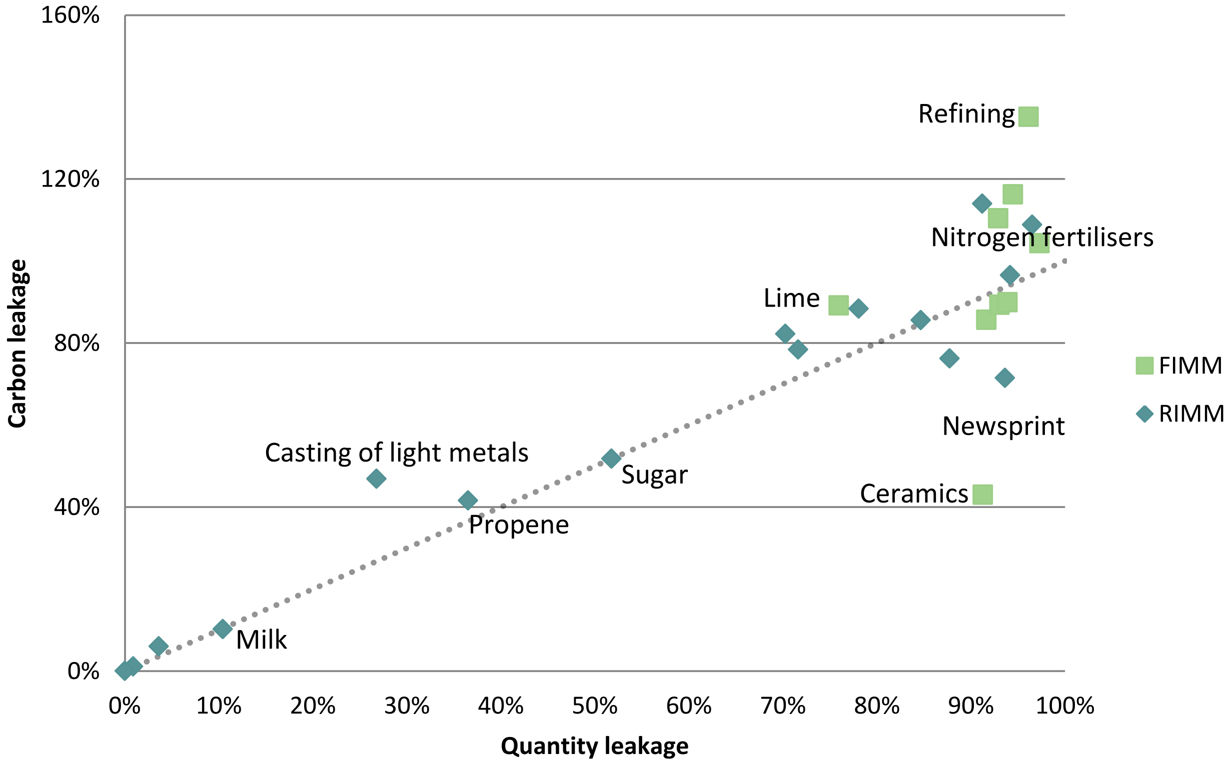
Note: The dotted line shows the EU average

Source: Vivid Economic, IEA

In addition to the size of the price shock experienced by industry, variations in emissions intensity across import sources is also an influence on the final carbon leakage rate. This is shown in Figure 17. Refining and heavy clay ceramics show carbon leakage rates well above and below the diagonal line: in the case of heavy clay ceramics, there are a few small, carbon intensive installations in the EU, which lose market share disproportionately, reducing the carbon leakage estimate. In refining, there is a tail of small, carbon intensive, non-EU refineries, which raise output and result in a higher carbon intensity of the refined product imports. Casting of light metals and lime are examples of sectors where EU producers are less carbon intensive than non-EU firms. In the other cases, such as malt, however, the differences in carbon intensity between EU and non-EU firms is not so great.

This chart, while informative, is not a complete picture because direct emissions carbon intensity estimates are not available for non-EU firms for some sectors.

Figure 17. **Higher output leakage rates tends to be associated with higher carbon leakage rates, but differences in regional emissions intensity result in the relationship not being perfectly linear (€15/tCO_2 price differential, 2020)**



Source: Vivid Economics

4.2.2 Explaining the behaviour of the model

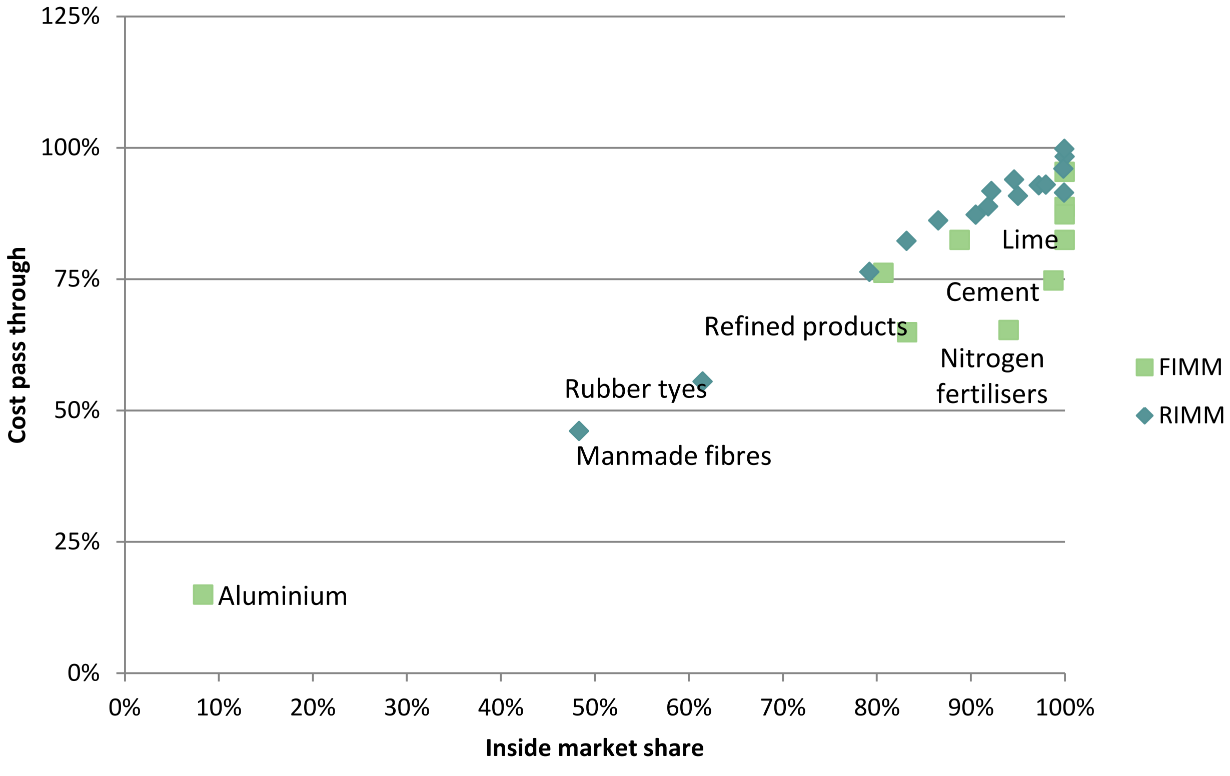
The effect on different sectors is driven by several factors besides the relative size of the cost shock. For instance, the cost pass-through rate decreases in association with greater import exposure (Figure 18).

There now follows a discussion of two key results charts, the first showing the relationship between inside market share and cost pass-through and the second between inside market share and quantity leakage. As remarked upon before, inside market share is a strong determinant of cost pass-through. In the simplified RIMM model which omits firm heterogeneity and with a large numbers of firms, the relationship is almost linear, but when firm heterogeneity is included, the relationship becomes more complex.

The word equation presented earlier explained the drivers of the cost pass-through rate and the strength of the correlation in Figure 18 shows that inside market share is an important driver. It also shows that other factors play a role, particularly in nitrogen fertilisers and cement, in pulling the relationship down from the diagonal line. The other factors act always to pull the cost pass-through rate down. Thus the inside market share is a good indicator of the maximum value which the cost pass-through rate might take, before other factors are taken into account. It is a fairly linear relationship and this means that there is no clear level at which one can separate sectors into those which are more or less able to pass on costs, but rather there is a spectrum along which each sector lies. The EU eligibility rules apply threshold values to screen for energy-intensive trade-exposed status. The cost pass-through results do not offer a threshold value which could be used in screening.

Note the clustering of results towards the high end of the cost pass-through rate. This pattern is observed for this set of sectors because each has a wide geographic area with many participating firms and many have fairly low profit margins. Both large numbers of firms in a market and low profit margins can lead to cost pass-through rates close to 100 per cent, before taking into account inside market share. Note also that in all but three cases, the inside market share is above 80 per cent, which contributes to the clustering of cost pass-through in the range 65 to 100 per cent. The outliers with cost pass-through rates below 65 per cent are aluminium (a global market), manmade fibres and rubber tyres, all of which are more widely traded than other sectors.

Figure 18. **Greater competition from non-EU producers limits the ability of EU firms to pass on costs (€15/tCO_2 price differential, 2020).**

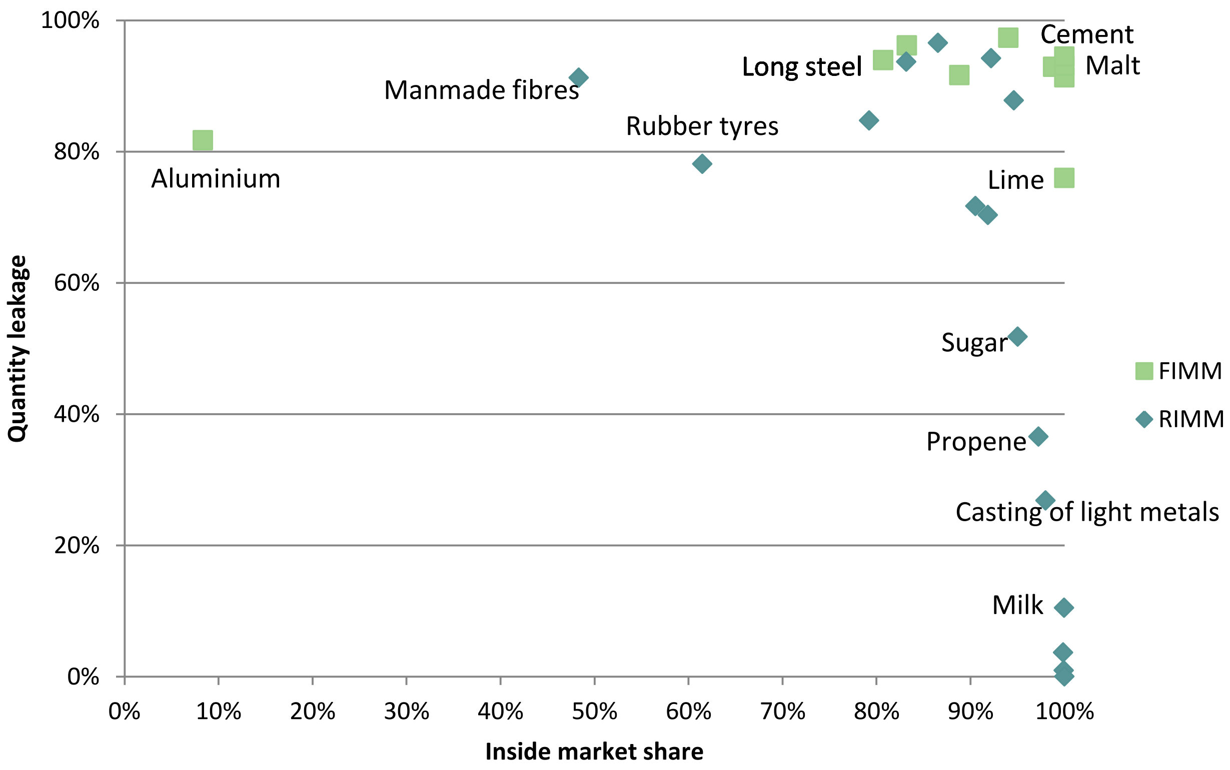


Source: Vivid Economics

The relationship of inside market share to the rate of quantity leakage is shown in Figure 19. Again, more import-exposed sectors react more strongly to carbon prices, though the relationship is less linear than the relationship with cost pass-through shown in Figure 17. Further, at levels of inside market share between 90 to 100 per cent, there is a particularly wide variance in the range of output leakage outcomes. This remaining variability is largely driven by variations in the number and size of installations and firm profit margins, which together help determine the competitive structure of each market.

Elaborating these points in more detail, quantity leakage rates are above 80 per cent for a wide range of inside market shares. Many sectors exhibit these high quantity leakage rates including aluminium, rubber tyres, long steel and manmade fibres. Lower rates of quantity leakage are only estimated where the inside market share is above 90 per cent, and then it is factors other than inside market share which drive the quantity leakage level, see discussion in Section 4.1.1.

Figure 19. **Inside market share also has a non-linear relationship with output leakage (€30/tCO_2 price differential, 2020)**



Note: All FIMM sectors not specifically labelled – refineries, cement, container glass, flat steel, heavy clay ceramics – are in the top right-hand corner.

Source: Vivid Economics

The results displayed in Figure 19 offer insights for the trade exposure criterion of the EU's free allowance eligibility test. An outside market share of more than around 10 per cent appears to be sufficient to cause high output leakage levels for supply to the domestic market. In comparison, the current criteria employs a threshold of 10 per cent, albeit defined differently, for carbon intensive sectors, see Section 5.2.2. These results suggest that the trade threshold element of the combined trade and energy intensity criteria is set at an appropriate level.

4.3 Notes on sensitivity analysis

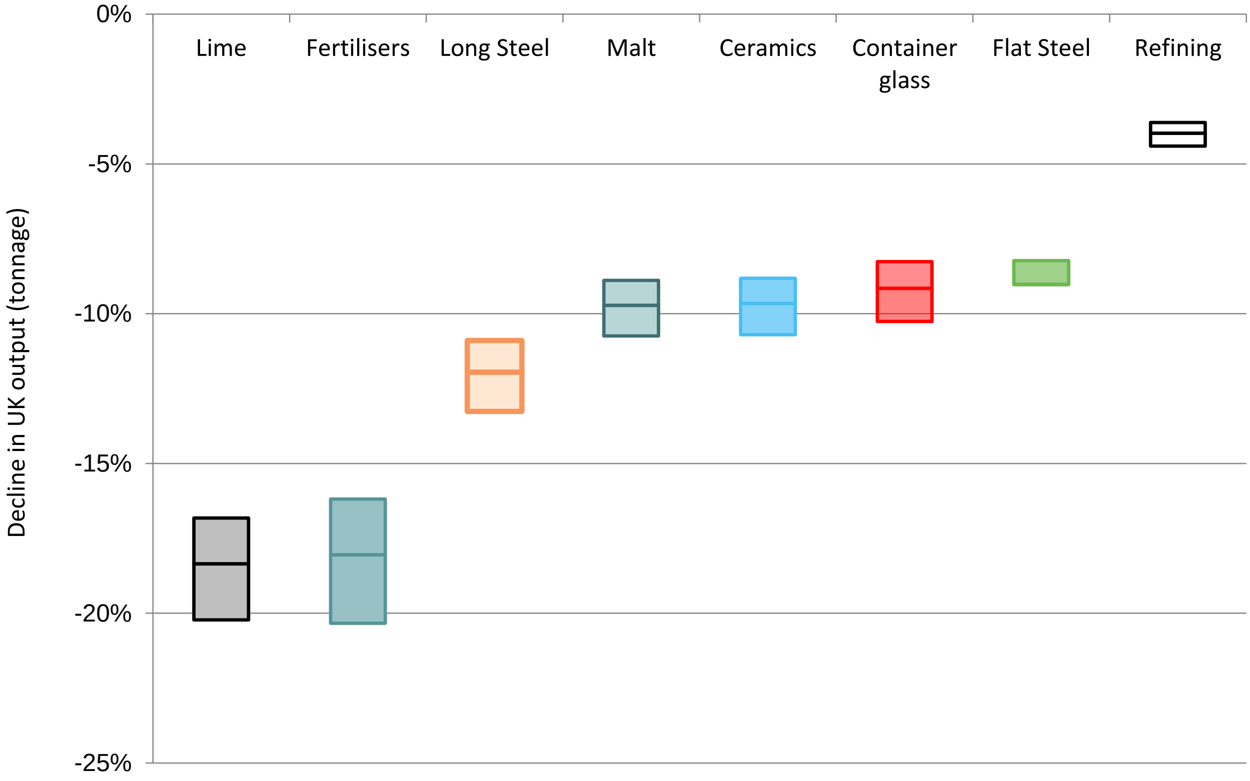
Results are generally robust to variations in demand elasticity and profit margins

As noted in Section **3**, gross profit margins and the price elasticity of demand are key inputs in determining the impact of carbon prices on a sector. Exposure to imports from non-EU sources is also a significant fact, but measures of trade tend to be more reliable than precise profit measures (which are commercially sensitive) and demand elasticity (which is innately difficult to measure). Consequently, this section presents some notes on the effect of varying these two parameters.

4.3.1 Response of output to profit margin and elasticity variations

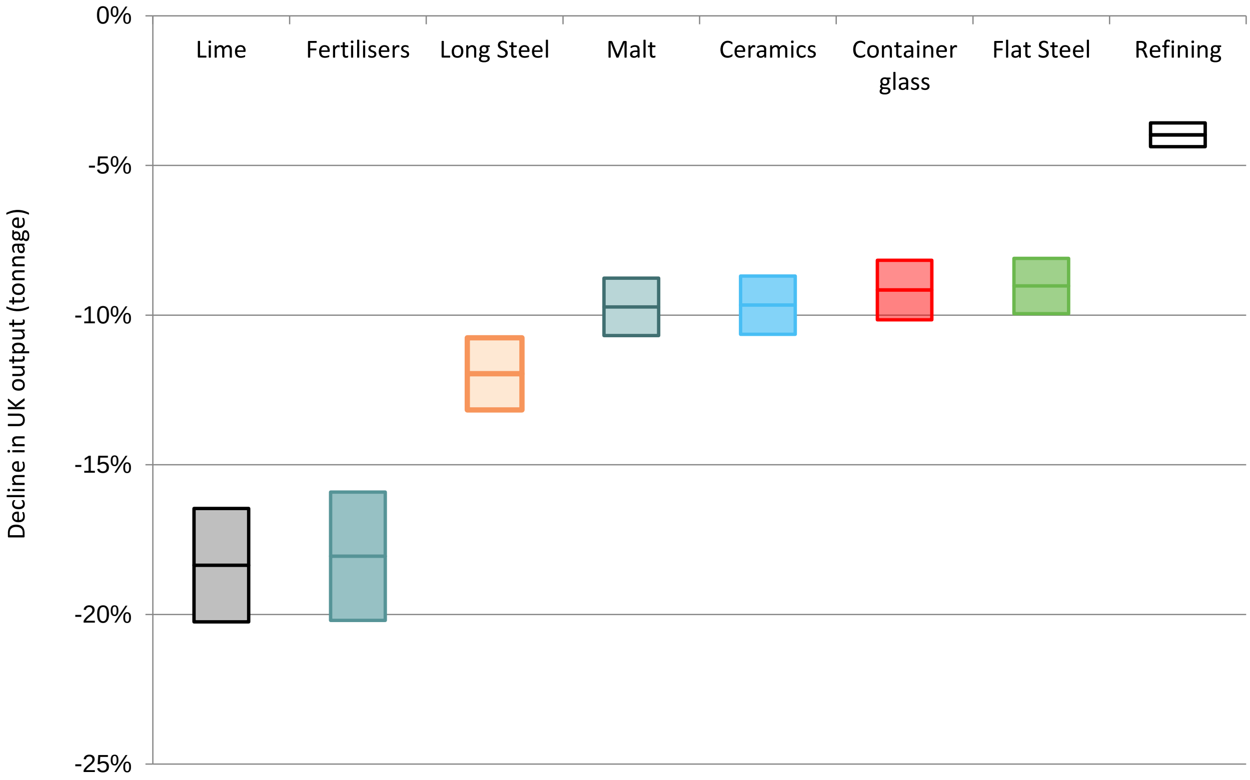
Figure 20 and Figure 21 show the percentage changes in UK output around the central estimates from varying profit margins by 10 per cent (so that, for instance, the heavy clay ceramics profit margin moves from 2.7 to 3.3 per cent around the central estimate of 3 per cent) and varying elasticity of demand by 0.1 percentage points (so that the demand elasticity of heavy clay ceramics varies from 0.2 to 0.4 around the central estimate of 0.3 per cent). The charts show similar patterns, with a moderate resulting variation in the impact on different sectors. Overall, while the uncertainty surrounding these variables could result in some reordering of the sectors in terms of relative impact, it does not change the overall narrative of the modelling results.

Figure 20. **Increasing or decreasing gross profit margins by 10 per cent has a moderate impact on output changes, with lower profit margins resulting in greater sensitivity to carbon prices (2020, €15/tCO_2 price differential)**



Source: Vivid Economics

Figure 21. **Variations in price elasticity of demand of plus or minus 10 per cent have a moderate impact on output changes, with more elastic demand resulting in greater sensitivity to carbon prices (2020, €15/tCO_2)**



Source: Vivid Economics

The effect of changing both the profit margin and the price elasticity of demand at once is likely to be approximately additive of the changes in each individually.

4.4 Results summary

Outside competition and overall strength of competition in the sector is a key driver of estimates and emissions abatement is an important omitted factor for carbon leakage

This section has presented estimates of cost pass-through, quantity leakage and carbon leakage. The estimates are upper bounds of the impacts of the EU ETS for several reasons, including the long-run nature of the model estimate, the calibration against current low margins in some sectors, and other simplifications in the model design. The carbon leakage estimate is high relative to literature values; this may be in part because it does not incorporate estimates of emissions abatement measures.

Due to the large number of firms in most sectors, the cost pass-through rates are between 80 and 100 per cent. The principal driver of cost pass-through rates to lower figures is a low inside market share, indeed the relationship between cost pass-through rate and inside market share is approximately linear, although other factors do play a significant role, notably heterogeneity in the competitiveness of inside firms.

The estimated changes in EU output can be explained by changes in profit margin. As profit margin is eroded by incomplete cost pass-through, investment returns are diminished and output capacity (and market share) will decline. Using a rough rule of thumb, a full loss of margin might indicate a decline in output to zero.

Quantity leakage is often estimated as close to 100 per cent, but with considerable variation between zero and 100 per cent where the inside market share is above 90 per cent. The quantity leakage results suggest that the EU’s criterion of trade exposure of above 10 per cent may correctly identify sectors which have high carbon leakage, but may accidentally exclude some sectors with lower trade exposure but still significant carbon leakage.

The carbon leakage rate is a product of the quantity leakage rate, the ratio of inside and outside firm carbon intensities, the level of abatement by inside firms and the intensity of competition. The evidence suggests that outside firms have higher carbon intensities than inside firms and hence carbon leakage rates can be above 100 per cent. However, if information was available about abatement measures taken at each carbon price level, the carbon leakage rate would certainly fall substantially.

5 Analysis of the EU's carbon leakage criteria

There are various shortcomings in the EU's approach to identifying at risk sectors

Section contents:

Using simple criteria to identify carbon leakage risk is an innately challenging task

The EU has based assessments on sectoral qualification for carbon leakage at-risk status around the criteria of carbon- and trade-intensity. These criteria have significant financial implications for firms, as they determine eligibility for compensation programs.

Several critiques of the criteria are possible, spanning the manner in which the criteria have been defined, the choice and justification of thresholds, the exclusion of other relevant factors, and the methods by which they were implemented. Some of the shortcomings identified are, to some extent, inevitable given the difficulty of the task at hand; others could, at least theoretically, be solved in a fairly straightforward manner.

5.1 Introduction

The scope of this assessment

5.1.1 Aim

The aim of this report is to assess how well the EU's criteria succeed in identifying sectors at relatively high risk of carbon leakage.

5.1.2 Uses of the carbon leakage criteria

In general, in Phase I and II of the EU ETS sectors received free European Union Allowances (EUAs) in amounts in proportion to historically-recorded levels of output, regardless of whether they were at risk of carbon leakage. Under Phase III, the extent of free allocation will be set with reference to industry-wide benchmarks. Sectors that meet the carbon leakage criteria receive 100 per cent of their benchmarked free allowances, corrected with a reduction factor to ensure the total allocation remains under the industry cap, in all years. Other sectors only receive 80 per cent in 2013, linearly declining to 30 per cent in 2020, with the nominal intention of reaching zero per cent in 2027, and subject to the same reduction factor. Beyond Phase III, that is, after 2020, there is no definitive decision on what policies will be used in order to combat carbon leakage. Regardless whether free allowances or other policies are used, similar criteria might be employed to identify sectors at a significant risk of carbon leakage.

The distribution of free allowances might serve one of several purposes: compensation for negative impacts on profits; mitigation of output leakage, whereby production output moves outside Europe; or mitigation of carbon leakage, whereby carbon emissions move outside Europe. The role of most interest in this report is the mitigation of carbon leakage.

Sectors can be deemed to be exposed to a significant risk of carbon leakage either on the basis of a quantitative or qualitative assessment. As of 2013, only eight sectors qualified under the qualitative criteria. The analysis here focuses on the quantitative criteria.

5.1.3 Issues addressed in this section

This report identifies the criteria used by the EU, discussing the appropriateness of the criteria themselves in broad terms; the specifics of how they were defined, including the thresholds employed; and the issues arising in their practical implementation, such as the sourcing of appropriate data.

Various questions arise as part of this process, including:

> *Do the current criteria reasonably reflect the factors that may give rise to carbon leakage risk and what is the relative importance of any factors left unconsidered?*
>
> *Do the current criteria suggest the EU's policy focus is on output leakage or carbon leakage?*

Is there an identifiable reason for the levels of the current thresholds, or the use of discrete thresholds rather than a continuous scale?

More generally, and perhaps most significantly, can it be argued that the EU's criteria could be significantly improved, and are these improvements feasible given the data available?

The criteria and data sources employed by the EU are described in Section 2, while the same are critically evaluated in Section 3. To obtain interesting cases for comparison, the criteria employed for similar purposes in other emissions trading schemes globally are discussed in Section 4.

5.2 The EU's criteria

Criteria fail to capture all leakage drivers

5.2.1 Criteria metrics

The EU applies two criteria:

- the carbon cost intensity: the sum of direct and indirect costs of carbon prices divided by sectoral Gross Value Added (GVA);
- the trade intensity: the extent to which a sector faces competition from foreign producers both from imports sold into the domestic market and domestic exports to foreign markets, defined as the sum of imports and exports divided by domestic production plus imports.

All calculations are applied to sectors on an EU-wide basis.

5.2.2 Thresholds and variable values

A sector is deemed to be significantly exposed to carbon leakage risk if any of the following three conditions are met, as illustrated in Figure 22:

- the carbon cost intensity is greater than 5 per cent and the trade intensity is greater than 10 per cent; or
- the carbon cost intensity of the sector is at least 30 per cent; or
- the trade intensity of the sector is at least 30 per cent.

A sector is usually defined at the 4-digit NACE code level. The carbon cost intensity figure for direct emissions is adjusted downwards by 75 per cent to reflect the proportion of emissions covered by free allowance allocation. Allowances are assumed to be priced at €30/tCO_2. The emissions factor for electricity production is assumed to be 0.465 tCO_2/MWh, based on PRIMES modelling by Capros et al. (2008).

5.2.3 Data sources

The data employed by the EC was mostly drawn from statistical sources and is supported by qualitative evidence (EC, 2009).

- fuel consumption and direct emissions data are drawn from CITL, the European Environment Agency's greenhouse gas inventory, and from a collation of data from individual EU member states; for confidentiality reasons, some data is anonymised;
- a matching procedure was developed to ensure that installations in CITL were classified into an appropriate NACE code;
- electricity consumption data was drawn from a survey of EU member states, in recognition of some shortcomings in the Eurostat data.
- GVA data was obtained from the Eurostat Structural Business Statistics database.

5.2.4 Omitted factors

Other variables contribute to determine the extent to which an industry is affected by carbon prices. These include, but are not limited to:

– price elasticity of demand;
– the degree of competition within the sector, and related to this, sector-wide profitability;
– carbon abatement opportunities.

These factors can change over time, for example, as a result of changes in transport costs, the appearance of new competitors or the exit of firms.

Indeed, these relationships are formalised in Vivid's Industrial Market Models, which, based on a generalized version of Cournot competition with profit-maximizing firms, describes the change in output from a sector as being approximately governed by the equation:

$$\%\ output\ change \approx \left[\frac{(1 - inside\ market\ share)}{inside\ market\ share}\right]\left[\frac{price\ elasticity\ of\ demand}{inverse\ competitivenes}\right]\left[\frac{cost\ change}{price}\right]$$

The lower the domestic market share, the higher the output leakage because there is more external competition. Thus it matters that external rivalry is correctly represented. The first quotient is related to, but not the same as, the trade exposure metric used by the EU. It is defined on an economic market basis, while the EU's trade intensity ratio is calculated on an administrative region basis. This means that the EU's ratio is always applied at the EU level, whereas economic markets may be geographically smaller, the same size as, or larger than the EU.

The more aggressively firms compete in a market, the more they will take market share from each other when one has a cost advantage over another. The second quotient, the price elasticity divided by inverse competitiveness, where inverse competitiveness is a measure of the degree of competition within the sector (the competitiveness parameter mentioned in Section 3.3), is missing from the EU's assessment. The degree of competition shows how aggressively firms compete in the market. More aggressive competition leads to lower profit margins, a pursuit of market share rather than profit and more price-based rather than quantity-based competition.

The higher the carbon cost as a proportion of price the higher the output leakage, because a given cost shock will represent a larger shock relative to market prices. The third quotient relates to the carbon cost intensity metric, replacing GVA with price. The carbon cost does not include an adjustment for free allowances in the EU ETS because free allowances are not directly linked to moderate variations in output, and it is the cost of producing output which affects competitiveness.

Note also that the theory implies that the trade exposure and cost intensity metrics interact in a multiplicative fashion, rather than as separate thresholds.

In addition, the EU's quantitative criteria do not account for the potential for technological abatement, that is, the optimising responses of firms to carbon prices.

Naturally, it is practically quite difficult to obtain consistent single measures of demand elasticity or industry competitiveness. Price elasticities can be derived econometrically, but this would be an involved exercise if many sectors were to be assessed. The practical approach is to rely upon published estimates, but these can be found only for some sectors and geographical regions, which are not always a match with EU ETS sectors. Industry competitiveness is more complex still, being a descriptor of the market environment affected by market structure, firm behaviour and market cycle. There is no standard accepted and objective methodology for assessing it, in contrast to price elasticities, carbon costs, trade statistics and other similar metrics.

The existence of factors influencing carbon leakage beyond carbon cost- and trade-intensity are part of the justification for the existence of the EU's qualitative criteria, which allow broader factors to be considered. However, as noted, qualification under these criteria is rare, and the use of qualitative factors reduces transparency.

5.3 Critique of trade intensity criterion

Definition probably sub-optimal

5.3.1 Relative carbon intensity of outside firms

Carbon leakage rates tend be higher the more that production increases in regions with high emissions factors. This is distinct from production simply increasing in trading partners generally. The use of trade intensities as defined by the EU addresses the issue of increased imports, but does not directly address the question of increased carbon emissions (Martin, 2012).

This issue might be partially addressed using weighted measures of trade, where the weights equal the relative carbon-intensity of the trading partner. Alternatively, the weights might reflect the share of trade to less-developed nations, where income functions as a proxy for level of environmental regulation.

5.3.2 Market definition

The EU defines trade intensity with respect to trade outside the coverage of the EU ETS, but firms compete in markets which may not respect administrative boundaries. In the Commission's other work on competition effects, for example in its merger control work in conjunction with the European Court of Justice, it uses economic definitions of markets, such as the small but significant increase in prices (SSNIP) test for a hypothetical monopolist. In this way, it follows closely the tradition of the US Department of Justice. This is used to define both the geographical and product scope of the market. It would be reasonable to expect that the same approach could be taken for assessing the risk of carbon leakage.

The shortcoming of the current approach can be illustrated in various ways; one problematic scenario, albeit simplified, concerns a market for products which is self-contained in Western Europe, with all production consumed locally and no trade with other regions. If another economic market for widgets also exists in Eastern Europe, consisting of the consumption of widgets imported across the eastern EU border, then the widget sector as a whole may record a significant degree of trade exposure under the EU's criteria, despite EU producers not directly competing with foreign producers.

If the economic market approach were taken, some member states may have markets which lie within Europe, while others, perhaps those on the periphery may have markets which stretch across borders. In other cases, the markets may be inter-regional or global and the competitive position in European firms can only properly be assessed in this wider context.

It is because an administrative definition of the market is used that the trade intensity metric has cross border movements as its numerator. The rationale for the denominator is unclear: it is a measure of European supply, but is neither a measure of domestic production nor consumption nor of output in any economic market. If an economic market definition were used the metric of interest would be inside and outside firm market shares. Again, the extent to which adopting an economic market based approach is practically possible is debatable; nonetheless, the failure to do so will introduce further inaccuracy into the EC's assessments.

5.3.3 Contestability

A related issue is that the trade-intensity measure is only a proxy indicator of the potential for foreign producers to make up any shortfall in EU production. Foreign producers may be capacity-constrained, or at least face rising marginal costs, which could mitigate their ability to expand in the market, which may bias the measure towards overstatement. Alternatively, current patterns of trade may not show the potential for entry by foreign firms who do not currently compete with EU firms, but will do so conditional on prices rising; that is, the contestability of the market. This may bias the measure towards understatement. Contestability is taken into account in market competition assessments, but it is not clear that it is taken into account in the leakage assessment.

5.4 Critique of carbon intensity criterion

Can GVA be improved upon?

5.4.1 Carbon intensity criterion

It is correct to consider the full direct and indirect costs of the carbon price on firms. Under an allocation method, in which free allocations are based on emissions or activity before the initiation of the trading scheme, the effective carbon price equals the market carbon price. It is not diluted by the allocation of free allowances. In the EU ETS, the allocation is based on historical output and not tied to future output, with the amount of free allocation remaining unchanged irrespective of changes in output, with some provisions to the contrary, explained below. These free allowances act as lump sum compensation and do not modify the carbon cost per unit production faced by the firm. With other types of allowance allocations, in which free allowances are tied to output, there would be an effective reduction of the carbon cost per unit of output, but with the exceptions discussed below, this is not the design of the EU ETS. This issue is discussed further in Section 6.

The denominator in the Commission's carbon cost intensity metric is Gross Value Added. However, in the medium to long-run, carbon leakage is driven by capital investment flows, and the decision makers who are boards of companies answerable to shareholders are not pursing the generation of gross value added, which spans both profit and wages, but simply profit. For example, an industry with low profitability but high labour costs would score low on the carbon intensity metric, which would understate the potential impact of carbon pricing.

In that light, the use of GVA in the denominator of carbon cost intensity is questionable: profits would be the most relevant metric, or alternatively, the cost share of carbon in all production costs. Noting that GVA is defined as profit plus wages, profit is already collected by statistics agencies as part of GVA calculations and volatility in profit measures could be averaged over time to obtain a suitable estimate. However, if there were difficulties in obtaining appropriate profit measures, simple industry revenue is an alternative to GVA as a metric. The ratio of carbon costs to revenue is used in the New Zealand scheme, see Section 5.6.

5.5 Critique of thresholds and implementation

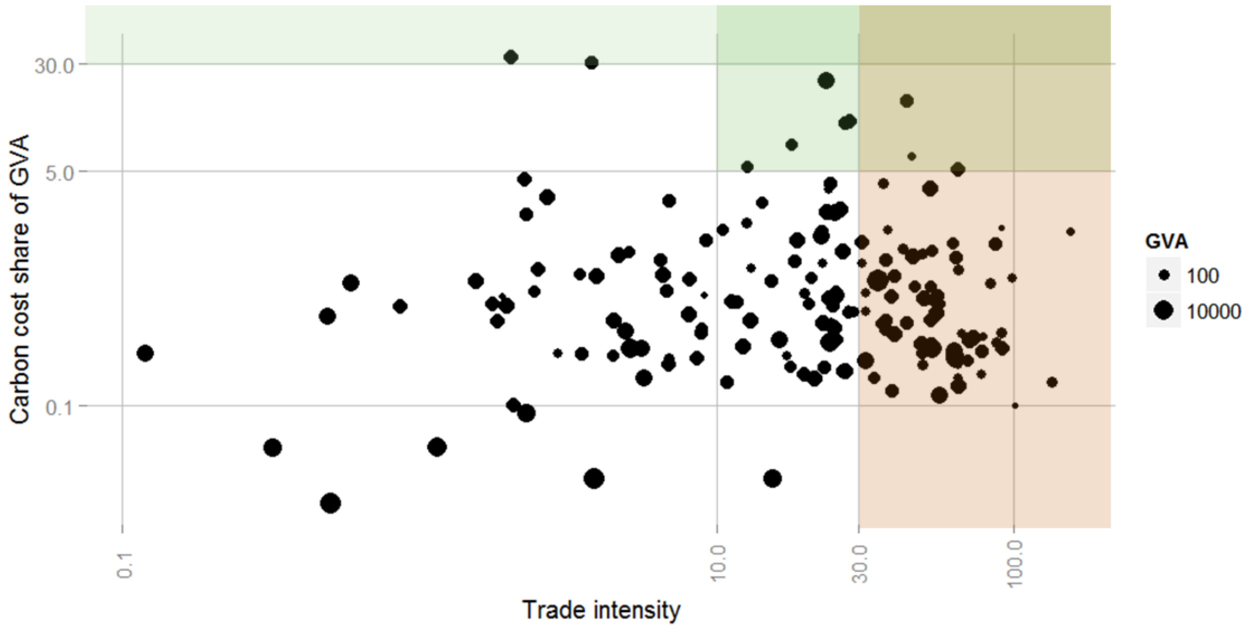
Justification of thresholds and parameter choices unclear

5.5.1 Trade intensity is by far the most common path to qualification

The EC has never been clear on how it chose the three routes to qualification and the thresholds used in each. Currently, it is possible to qualify entirely through trade-intensity, even if the industry emits zero carbon emissions (though note that such a hypothetical industry would also benefit little from free allowances, unless the industry consumes heat from ETS participants). Indeed, trade intensity is the route by which most sectors qualify: of 144 sectors at the NACE 4-digit level that qualified for quantitative reasons, 115 qualified through the trade criterion exclusively. Most UK qualifying firms use the trade exposure only route.

The pattern shown in Figure 22 for the UK is similar to that for the EU as a whole.

Figure 22. **Most UK sectors that would qualify if the test was performed at the UK level do so due to having non-EU trade exposure above 30 per cent**



Source: Vivid Economics, ONS, CITL, Eurostat (2013)

5.5.2 Separation of criteria

The impact on the competitiveness of a firm is a combination of the carbon cost intensity and the firm's ability to pass on the cost increase into prices. Only the combination of both the cost intensity, taking into account abatement opportunities, and inside-outside firm market shares, together with information on market conditions and customer price elasticity, is able to provide a full picture. This incorporates the effect of profit margins, identified in the EU ETS Directive. Although the first two of these are perhaps the most important, all four elements have a role to play. If the first two criteria alone are to be used, it may be better to apply them together, rather than separately: this is done only partially under the current set of thresholds, which distinguishes one combined set of thresholds from qualifying under each criterion separately.

5.5.3 Specific carbon price

The implementation of the criteria also raises questions. For instance, how might the use of a reference carbon price of €30/tCO_2 be justified, when the current market price is around €4/tCO_2? Instead, one could take an average of recent years' prices or a forward market price.

If the purpose of free allowances is to protect against carbon leakage, then the carbon price used in the metrics should reflect the carbon price used in firms' investment appraisals. Firms do not disclose their expectations so the figures are not known. However, firms' expectations of future carbon prices are likely to be conditioned by a combination of recent experience of low prices and their assessment of policy commitments and future targets within the EU. It is therefore appropriate to use a carbon price for the purpose of screening which takes into account future price levels above those experienced today. Given the uncertainty of future carbon prices, those values could be chosen more or less cautiously. A high level of caution might be appropriate where it is perceived that the costs of inadvertent exclusion from free allowances would be expensive, and a lower level of caution might be chosen where the same costs are perceived as being low.

5.5.4 The auctioning factor

The auctioning factor reflects the share of allowances that have to be bought from auctions if a sector does not have carbon leakage status. Since firms receive part of their allowances for free, they only need to buy a portion of the total required allowances to cover their direct emissions. The auctioning factor is not applied to indirect emission costs from electricity consumption as no free allocation is given directly to electricity producers. The European Commission estimated an auctioning factor of 75 per cent. This is multiplied by the direct emissions and carbon price to determine the actual direct carbon costs of the sector (European Commission, 2009b). This value was applied in 2013-14, but is outdated for at least after 2014 and the average auction level for the years 2015-2019 is estimated at 68 per cent (CE Delft, 2013).

Perhaps more significantly, 75 per cent understates the effective carbon cost, because free allowances do not effectively mitigate the competitiveness effect of a carbon price, as discussed further in Section 6. The argument is that free allowances can be considered a form of lump sum compensation, and will not affect firm production decisions. Assuming that the intention of free allowances is to prevent carbon leakage and not purely to compensate firms by costs incurred under the EU ETS, then the auctioning factor should be not be reduced by the full amount of the proportion of allowances received for free.

5.5.5 The electricity emission factor

The emission factor for electricity production used in the assessment is the European average electricity emission factor 0.465 tCO_2/MWh from the PRIMES model for the year 2005 (Capros et al., 2008). This number may require updating. There may also be an argument that marginal, rather than average, electricity emissions factors should be used, as that would closer approximate the price shock faced by industry. Since marginal electricity production is assumed to be produced mainly by fossil fuel plants due their place in the merit order, the marginal emission factor will be close to the emission factor of fossil fuel plants. An estimate of the marginal emission factor could be derived from the work of the European Commission on guidelines on financial compensation for electricity-intensive industries in the EU ETS (European Commission, 2012).

5.5.6 There are also some data source discrepancies

The data used in the induced carbon cost intensity calculation is from a variety of sources, raising coverage issues:

- direct emissions are primarily sourced from CITL on installation level, and do not have complete coverage of, for instance, non-ETS installations;
- the EC was not able to accurately match all CITL installations with their corresponding NACE code, leading to coverage that is too low in some sectors and wrongful inclusion of installations in others;
- the indirect emissions on sector level are supplied by member states, who do not all use the same sector definitions or may not have the information available on NACE level and also may not distinguish between ETS and non-ETS emissions;
- GVA is recorded at NACE level, which is reported per legal entity, but legal entities can operate installations under more than one NACE code and cover both ETS and non-ETS installations.

The EC has also not properly addressed the question of whether the accurate coverage for the carbon cost intensity calculation should be only ETS installations or the whole sector. This resulted in the carbon cost intensity calculations being conducted with different scopes in the numerator and denominator. The direct emissions covered only ETS installations, while the indirect emissions and GVA data in principle covered the whole sector. Sectors that did not make it on the carbon leakage list were allowed to submit data sources of better quality to substantiate their eligibility for carbon leakage compensation, but the scope for the emissions and GVA remained unchanged.

5.5.7 Other observations

National data on electricity usage, as well as other variables, are not available for all European nations, forcing the EC to place some reliance on private surveys. This results in a lack of transparency, generally considered undesirable in policies of this type. The usage of qualitative assessments is problematic for similar reasons.

Local factors may lead to different carbon- and trade-intensities across national industries. This raises the question of whether compensation levels should be tailored regionally and whether reference levels should be sector averages or benchmarks.

Compensation for direct emissions is obtained through the EU ETS in the form of free allowances, whereas compensation for indirect emissions from electricity is given in the form of state aid that is at the grace of the member states and may be more difficult to obtain. This creates an incentive for firms to favour technology that leads to direct, over indirect, emissions.

5.6 The criteria employed in other trading schemes

Four main differences emerge

Other emissions trading schemes have also confronted the issue of carbon leakage, and employed similar policies to the EU to deal with it. This section reviews the equivalent criteria employed elsewhere; critiquing these criteria thoroughly is outside of the scope of analysis, but there are interesting grounds for comparison to the EU scheme. Note there may be additional policies employed under each jurisdiction than those considered here; the discussion is limited to areas where the policies are clearly analogous.

5.6.1 California and Australia

The European Union, California and Australia all distribute free allowances with the intent of mitigating carbon leakage. The approaches to allocating amounts of free allowances are similar: an assistance factor is multiplied by an activity level and an emissions intensity benchmark, see Table 4.

The assistance factor is the rate at which free allowances are made available. The emissions intensity benchmarks in each case are calculated as follows:

- in the EU ETS, it is 100 per cent of the average of the 10 per cent of the most carbon-efficient plants;
- in California, it is 90 per cent of sectoral average emissions;
- in Australia, it is 100 per cent of sectoral average emissions.

Of the three schemes, the EU ETS is the only one where compensation is determined by reference to historical output, rather than current output.

Table 4. **Comparison of assistance factors across trading schemes**

Europe		California		Australia	
Classification	**Assistance factor:**	**Classification**	**Assistance factor**	**Classification**	**Assistance factor**
Exposed to carbon leakage risk	100%	High	100%	High	94.5%****
		Medium	100% → 50%**	Medium	66%****
Not exposed to carbon leakage risk	80% → 30%*	Low	100% → 30%***	No CL	0%

Notes: * *Linearly reducing between 2013 and 2020;*
** *100 per cent in 2013-2014; 75 per cent in 2015-2017; 50 per cent in 2018-2020;*
*** *100 per cent in 2013-2014; 50 per cent in 2015-2017; 30 per cent in 2018-2020;*
**** *Annually declining by 1.3 per cent.*

Source: Ecofys

All three jurisdictions follow the same approach to classifying sectors based on level of leakage risk:
- sector definitions based on statistical sources;
- criteria based on emissions intensity (or carbon cost-intensity) and international trade; and
- some combination of thresholds.

The thresholds for carbon leakage compensation reflect local circumstances. In California, the Air Resources Board determined that the thresholds for carbon leakage should be somewhat lower than for the Australian scheme to account for the greater level of inter-State trade and competition.

The trade criterion is similar in the EU and California. The trade criterion in Australia does not include the value of imports in the denominator, which favours high import sectors. Nowhere outside Europe is trade exposure a sole ground for exemption, meaning that sectors must have emissions intensity above a certain threshold before they are classified as exposed to a significant carbon leakage risk. In the EU, 117 out of the 258 assessed sectors meet the carbon leakage criteria solely based on the trade intensity (CE Delft, 2013). This is by far the majority of all the sectors and subsectors that qualify for carbon leakage (176 sectors and subsectors in total). However, these sectors represent only about 6 per cent of the total manufacturing industry emissions in the EU ETS (calculations based on EUTL).

Australia and California use emissions intensity as a metric instead of carbon cost intensity; this removes the need to assume a carbon price. By translating emissions intensity into carbon cost intensity, it is possible to compare the EU, Australian and Californian criteria, see Table 5. This shows that Australia has the most stringent thresholds and California the least. In Australia sectors must meet both criteria to qualify for carbon leakage compensation, implying that around 70 per cent of the sectors on the carbon leakage list in the EU would not be deemed as at a significant risk of carbon leakage in Australia, assuming the same emissions and trade intensity. In California, the carbon cost intensity criterion is less stringent than in the EU, but the trade intensity more stringent. This means that some sectors which only meet the trade criterion in the EU would meet the combined criteria in California. On the other hand, as a result of the more stringent trade criterion in combined criteria, some sectors may be excluded. Due to data confidentiality the carbon cost and trade ratio of only some sectors has been published by the European Commission, so it is difficult to quantify the number of EU sectors remaining on the carbon leakage list under the Californian criteria.

Table 5. **Comparison of criteria for maximum carbon leakage compensation**

Europe		California		Australia	
Criteria	**Thresholds**	**Criteria**	**EU ETS equivalent thresholds***	**Criteria**	**EU ETS equivalent thresholds***
Combination of trade and emissions	induced carbon cost > 5% *AND* trade > 10%	emissions > 1,000 tCO_2e/$M value added *AND* trade > 19%	Induced carbon cost > 3% *AND* trade > 19%	emissions > 6,000 tCO_2e/$M value added *OR* emissions > 2,000 tCO_2e/$M revenue AND trade > 10%	induced carbon cost > 18% *AND* trade > 10%**
Single emissions criterion	induced carbon cost > 30%	emissions >5,000 tCO_2e/$M value added	induced carbon cost > 15%	N/A	N/A
Single trade criterion	trade > 30%	N/A	N/A	N/A	N/A

*Notes: * Assuming an Auctioning Factor of 75 per cent (i.e. all emission are direct emissions); ** The trade criterion in Australia does not include the value of imports in the denominator. This is more favourable than the EU trade criterion for sectors with imports.*

Source: Ecofys (2013)

5.6.2 Switzerland and South Korea

The Swiss and Korean criteria follow the EU ETS design, adopting the same carbon leakage criteria.

5.6.3 New Zealand

Sectors are eligible for free allowances either if they would be eligible under the Australian criteria (as Australia is a key trading partner), the ‘Australia track’, or through the ‘New Zealand Track’. In the New Zealand Track, eligible sectors have to be trade exposed and are classified as:

– highly emission-intensive if emissions are greater than 1,600 tCO_2 per $1 million of revenue;
– moderately emission-intensive if emissions are equal to or greater than 800 tCO_2 per $1 million of revenue, but less than 1,600.

Highly emission-intensive industries receive a 90 per cent free allocation of the benchmarked free allowances. Moderately emission-intensive industry receives 60 per cent. The default benchmark is determined based on the average emission intensity of the sector's activity for the financial years 2006 to 2008. After 2012, the assistance decreases annually by 1 per cent. The free allocation is based on annual output and is corrected for the actual production at the end of the compliance year.

All industrial activities are considered trade exposed, unless, in the Minister's opinion, there is no international trade currently, nor likely to be any.

5.6.4 Summary of points of difference

The criteria definitions, thresholds, and methods of free allocation differ internationally in four main ways.

Firstly, the EU ETS uses carbon cost intensities while the Australian and Californian schemes use emissions intensities.

Second, in the EU ETS, there is no minimum level of emissions intensity: a sector can qualify on trade intensity alone. This is not the case in Australia and California.

Third, in California, Australia and New Zealand, sectors are classified into several categories of degree of carbon leakage exposure with different allowance allocation levels. In Europe there are only two: not exposed to a significant risk of carbon leakage and exposed to a significant risk of carbon leakage.

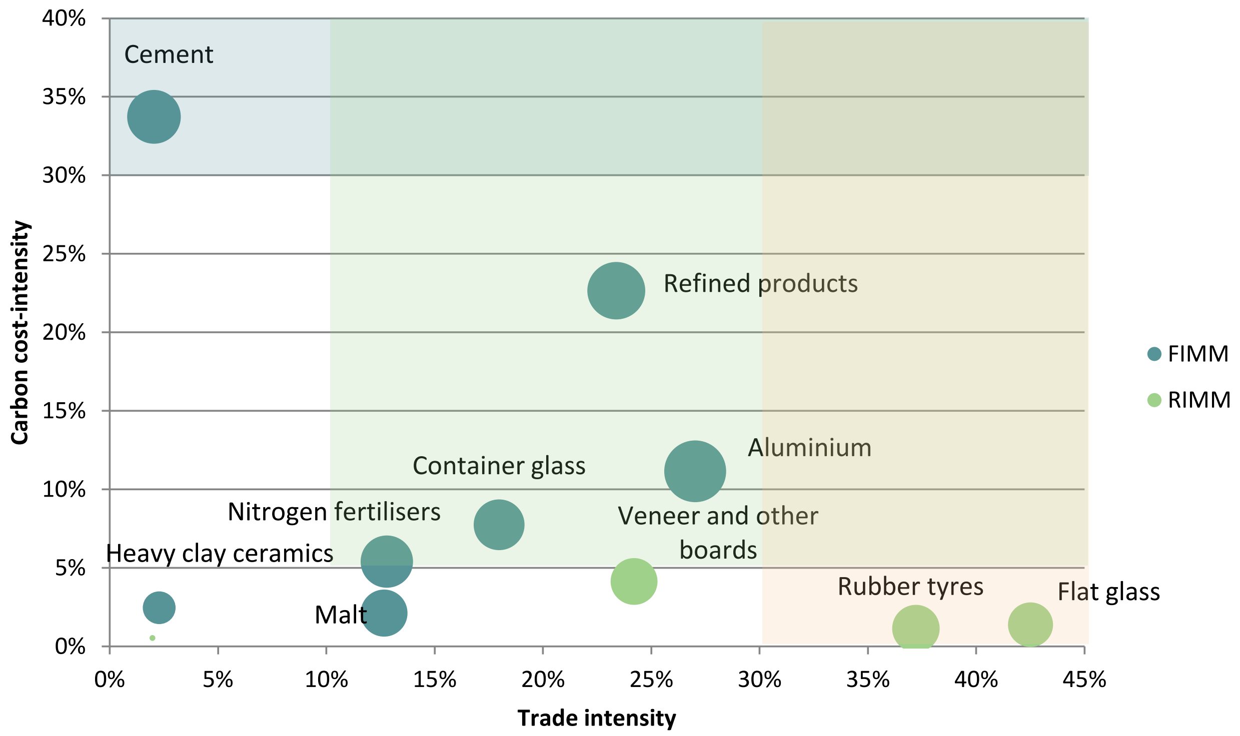
Fourth, in the EU ETS the free allocation is determined at the start of the Phase and is fixed for the remainder of the period. In California, Australia and New Zealand the quantity of free allowances is updated annually based on production levels. This approach provides certainty of the carbon costs compensated by free allowances with increased production, although it is administratively more demanding. Meanwhile, the EU system has resulted in excessive allocation of allowances during the recession, boosting firm profits.

5.7 Does the modelling support the EU's criteria?

Available evidence is not supportive but is limited in any case

A natural question concerns whether the extent to which sectors experience carbon leakage in the IMMs relates to the degree to which they satisfy the EU's criteria. The evidence is somewhat ambiguous in this regard. Figure 23 shows no clear relationship. However, the sample size is limited; even beyond the limited set of sectors investigated in the modelling, the number of sectors shown was cut down further so that only sectors which correspond to SIC 4-digit codes are shown (that is, it is not possible to construct this data for all sectors analysed with RIMM and FIMM). Further, the trade and emissions intensity calculations were performed at the UK level, rather than the EU as a whole.

Figure 23. **Carbon leakage rates compared to trade and carbon cost-intensity at the UK level. Size of bubble indicates rate of carbon leakage**



Notes: All sectors shown qualify under the EU's carbon leakage criteria.

Not all sectors are shown as not all sectors modelled correspond to 4-digit SIC codes.

Shaded areas indicated qualifying zones under the EU's criteria.

Source: Vivid Economics

The sectors with the highest carbon leakage rates are aluminium, refining, cement, nitrogen fertilisers, container glass, heavy clay, veneer and other boards, rubber tyres and flat glass. Rates of carbon leakage between 43 per cent (for heavy clay ceramics) and 155 per cent (for aluminium) can be observed across a wide range of trade intensities and emissions intensities. The conclusion is that these two metrics may allow the screening out of sectors with low rates of carbon leakage but additional information is needed to determine the rate of leakage itself. In particular, the strength of competition within the sector and the relative carbon intensity of producers within and outside the EU are influential factors.

5.8 Conclusions

Current eligibility criteria offer some scope for improvement

5.8.1 Points of critique

The EU's quantitative criteria only partially identify carbon leakage risk. Their limitations include:

- omission of carbon policies outside the EU ETS, except to a limited degree (for example, accounting for regions such as Australia which may operate linked schemes). This results in the criteria being more focussed on output leakage than carbon leakage;
- absence of rationale for the current thresholds and methods of criteria construction, particularly for eligibility based on trade exposure alone;
- absence of accounting for abatement options, demand elasticity, market structure and the mismatch between GVA data (which includes non-ETS activity) and emissions data (which excludes non-ETS activity). The use of qualitative criteria partially addresses some of these issues, but at the cost of transparency;
- the definitions of the carbon cost and trade intensity metrics could be improved and applied to a geographic scope based on markets rather than administrative boundaries.

5.8.2 Recommendations

Several possible avenues for improvement to the criteria are discussed below. The first group of remedies reduce systematic errors of false eligibility for free allowances. The second group, if implemented, would change the current focus on output leakage to carbon leakage. The third group generally improve the robustness of the eligibility criteria.

Removing systematic errors of false eligibility

The most important single remedy is to repeal the trade-only criterion. This currently allows sectors which have low carbon intensity to qualify for free allowances, even though the risk of carbon leakage in these sectors is small. By restricting eligibility to carbon-intensive sectors, the number of eligible sectors would be dramatically cut, without a detrimental increase in the total amount of carbon leakage. This might be politically and administratively feasible to implement because it introduces no new administrative burden and the rationale for change is strong and simple.

Second, a carbon price which fairly reflects reasonable expectations of EUA prices, or actual levels which are updated regularly, should be used as the basis for carbon intensity calculations. Whenever a price is used which does not reflect market conditions, it biases the eligibility test and when that divergence is large, as it is currently, it reduces the credibility of the whole free allowance scheme. Further, the current use of an auctioning factor both complicates the definition of carbon cost intensity, and raises conflicts with economic theory concerning how firms can be expected to treat carbon costs. One means of addressing these concerns would be to change the criterion into an emissions intensity criterion, as is the case in the California and

Australia. The rationale for change is strong but there is likely to be resistance from firms who would lose out from the change and they may mount a legal challenge.

Third, change the trade intensity denominator to 'inside market share', meaning the output share in the economic market of firms within the EU ETS. The rationale for the current denominator is unclear: it is a measure of European supply, but is neither a measure of domestic production nor consumption nor of output in any economic market. Economic theory tells us that what matters is the proportion of output within the EU ETS and the proportion competing from outside it. This change would make the test more efficient in identifying sectors at risk of leakage. The rationale is more subtle and thus difficult to make, but administratively it is no more complex than the current criterion.

Fourth, instead of using GVA in the measure of carbon cost intensity, change the metric to profit or consider revenue and exclude data for production outside the EU ETS. GVA encompasses both wages costs and profits whereas carbon leakage concerns the relocation of production, and the location of production is driven by pursuit of profit or perhaps as a second best, revenue, not wages costs. This is likely to entail a simultaneous adjustment of the threshold level, which will create losers who will oppose the change. It is administratively no more complicated than the current definition.

Accounting for carbon rather than output leakage

As they stand, the EU's criteria are likely better at identifying sectors at risk of output leakage. The difference between output leakage and carbon leakage is the relative carbon intensity of inside and outside firms, yet this factor is not considered in the European scheme, at least it is not considered for the 2013-2014 carbon leakage list. As is understood from the ETS Directive Art 10a (18(b)) the emissions intensities of installations in non-EU countries should be taken into account in determining the carbon leakage list, where the relevant data are available.

There are two changes that could be made which would convert the current criteria into a test for carbon leakage. In the first change, the emissions intensities of non-EU trade partners are factored into the analysis. Extra weight is placed on trade with carbon-intensive non-EU trade partners. In this way, the free allowance allocation can be focused on protecting against leakage to the dirtiest producers. In the second, the great variation in indirect (power generation) emissions intensity across Europe would be taken into account. This would help ensure that sectors which have high carbon intensity due to their local power supply are protected from carbon leakage while those who are not exposed in the same way are not over-compensated.

The study that the Öko Institute and Ecofys carried out for the Commission in 2013 to prepare the carbon leakage list for 2015-2019 suggested that data on industrial greenhouse gas intensities that could be used for cross-country comparisons appears to be very limited (Graichen et al., 2013), which would make the first of these two options more difficult. In the first change, third party countries may engage in the selection of estimates, making the decision more political. In the second change, countries with less emissions-intensive power sectors may oppose the change and it may involve difficult legal argument about the single market within the EU.

Improving robustness

The first recommendation to improve robustness is to take into account significant imminent abatement improvements. In some sectors there are significant economically viable changes to operations and assets which can be taken to reduce carbon emissions. Some of these will be required by law through the application of Best Available Techniques. Meanwhile, other sectors will not have the same opportunities. By taking into account these opportunities, the allocation of free allowances may raise awareness of carbon efficiency and award compensation on the basis of the most efficient plant only. The current approach, incorporating benchmarking, achieves some aspects of this recommendation already. This new approach could be especially helpful where it is known major abatement improvements are expected within a forthcoming phase of the ETS. Firms are likely to argue against this approach, instead asking for credits for early action.

The second recommendation to improve robustness is to apply the eligibility criteria to ‘economic’ markets, making the trade criterion much more accurate, but more complex to assess. This would allow the assessment to reflect more closely the market experience of EU firms. It would introduce important distinctions between goods which are traded globally, those traded regionally and those traded nationally. It might, in doing this, help to address the higher trade exposure which some peripheral member states experience for some types of product. It is likely to be feasible to make this change for sectors whose economic markets are broader than the EU. However, sub-division of the EU into sub-regional markets is unlikely to be a feasible basis for allowance allocation, and may face legal challenge on the grounds that it goes against the principles of operating the EU as a single market.

6 Assessing the policy options for mitigating leakage

No option combines effectiveness at tackling leakage with ease of implementation

Section contents:

The policy options available all have some weaknesses

Methods of mitigating leakage can be divided into four main categories:
- provision of financial compensation to firms;
- provision of free allowances to firms;
- excision of economic sectors from the trading scheme;
- application of levies and subsidies at points of trade in relation to embodied carbon, that is, Border Carbon Adjustment

There are numerous possible variations in design within these categories, with some of the most significant concerning how financial compensation or free allowances are allocated to firms. All policy options face significant problems however, ranging from failing to contain leakage, failure to address the overarching goal of mitigating carbon emissions, or large hurdles in implementation. An ideally-designed Border Carbon Adjustment scheme is likely the preferred option in theory, but such a scheme has yet to be proven through practical application.

6.1 Approach

An exploration of four types of policy instrument

6.1.1 Aims and approach

The aims of this task are to identify and to assess policy options which could correct, mitigate or compensate for carbon leakage.

The policy options and their effects emerge from a review of the literature and Vivid Economics' analysis, while the assessment framework draws upon standard practice by examining the four areas of efficiency, effectiveness, feasibility and administrative cost, tailored for this application.

The report structure is as follows:
- this section introduces the candidate policies;
- Section 6.2 sets out the assessment framework;
- Section 6.3 and Figure 28 present and discuss the assessment results and conclusions.

6.1.2 Typology of policies and mechanisms of effect

Typology of policy action

Carbon leakage can occur when a carbon price, or a policy with a similar effect, affects some but not all producers within an economic market.

For brevity, let us call those firms who are subject to the policy 'inside', and those firms who lie beyond its jurisdiction 'outside'. The relationships between inside and outside firms we can call horizontal effects, but the impact of carbon pricing may be transmitted up and down a supply chain, which we can call vertical effects, and thus affect other economic markets.

Mechanisms by which carbon leakage can occur include:
- firms close plants 'inside', while the same or other firms open replacement plants 'outside' the jurisdiction of the carbon price;
- firms in a growing market choose to open new plant 'outside' instead of 'inside';
- firms reduce production at plants 'inside', while the same or other firms increase production 'outside'.

The first type is the most dramatic, but the second and third types are most common and problematic. The first and second types relate to the 'investment channel', identified in Section 2, while the third type relates more to the 'short term competitiveness channel'.

There are four main ways in which policies can address carbon leakage, namely by:
- diluting the carbon price (either at the margin or infra-margin) so that the impact is diminished;
- lump sum payments tied to keeping plant open which can partially reduce leakage without reducing the carbon price at the margin;

– expanding the coverage such that more firms are brought inside, making the scheme more universal;
– exemptions, rolling back the coverage such that fewer firms are left inside, removing sectors which are more exposed or vulnerable from the scheme altogether.

All the policy options which change leakage levels act in one of these ways, though, as discussed below, it is possible to have policies that fit into one of these categories that have minimal practical impact on leakage.

For clarity, note that the policies addressed in this section are not limited to those concerned with addressing the leakage *rate*, but with reducing the overall absolute value of leakage. This is what allows rolling back the coverage of the scheme or diluting the carbon price to be considered as policy options.

Box 2. **The economics of firm decision-making and carbon leakage mitigation policy**

There are two ways in which carbon leakage and carbon leakage mitigation policies can affect firms: by changing their relative competitiveness, or by changing their endowment of allowances. Competitiveness refers to the relative profitability of firms, which is a combination of their relative costs and the prices they receive for their products. In markets in which buyers do not distinguish between the goods produced by different firms, competitiveness is a matter of the unit cost of production alone. In the short run, this is the variable cost of production. In the long run, it is the average cost of production. The short run is differentiated from the long run by the life of the assets used in production. In the energy intensive sectors of interest here, the long run is typically 20 years or more. Changes in competitiveness encompass dramatic plant closures or relocations and the attrition or piecemeal reallocation of production and investment internationally, which gradually erodes the standing of some plant and builds the strength of others.

The endowment is the set of assets which the firm has. In addition to the production assets it owns, this includes any entitlements to emit carbon dioxide or to receive allowances (at below market price) to emit greenhouse gases. The endowment affects the wealth of the firm and thus of its owners, but does not affect its marginal (or short-run) production costs. It may, in narrow circumstances, affect long run costs if it changes a firm’s credit-worthiness and hence its cost of finance. Otherwise, however, alterations in endowment alone are unlikely to change a firm’s long-run decision-making.

Recognising this, free allowance distribution within the EU ETS does incorporate some requirements regarding minimum levels of firm production. However, tying compensation too closely to ongoing production levels reduces the incentive to alter production patterns in the first place.

Some policy options, by addressing the cost of production, also benefit firms upstream and downstream in the supply chain. Other policy options pay compensation to the obligated firms and change their endowment, with no consequent trickle up or trickle-down effect.

6.1.3 Candidate policies

The complete set of policy options for mitigating carbon leakage can be grouped in pairs under the four types of policy previously mentioned (reducing the effective carbon price, compensation, levelling the playing field, exemptions), see also Neuhoff's discussion of options (Neuhoff, 2008). These have all been either implemented or discussed as candidates for implementation within the last decade.

Reducing the effective carbon price

There are two broad ways in which the carbon price, from firms' perspective, can be diluted:

- increase the number of allowances issued, that is, reduce the tightness of the cap;
- allocate free allowances as a function of produced output.

The first of these policies causes a reduction in the market price of carbon. Whether by accident or design, this has been an outcome within the EU ETS, resulting in carbon prices below €10/tCO_2 in recent years, which in turn has contributed to the lack of evidence of carbon leakage (as discussed in Section 2). It is also evident in cap and trade schemes introduced in Australia, New Zealand and California, where there is an ambition to compensate firms for the impact of the carbon price in order to avoid carbon leakage effects.

The second of these policies rewards production with receipt of a free allowance, equivalent to a production subsidy. It counteracts the increase in variable cost of production, which erodes competitiveness, with an offsetting benefit, which enhances competitiveness.

Free allowances may also play a role in implementing border carbon adjustments which aim to ensure that inside and outside firms compete in each jurisdiction on a level playing field. This has two elements. First, imports from outside firms must be subject to a compensating charge (discussed below). Second, exports from inside firms are granted a compensating subsidy.

Compensation

Compensation comes in two forms and neither relates to production. If compensation is a function of production, it is a dilution of the carbon price. The two forms are:

- lump sum cash compensation, which may alternatively be delivered as a tax credit (note the specifics of how the tax credit might be delivered, and any accounting complexities which might result, are not addressed in this report);
- allocation of free allowances.

Lump sum cash compensation is a payment made with the intent of restoring some of the income forgone by the firm's owner through the imposition of carbon policy. It would be usual to think of the compensation as justified recompense for the revocation of a right to pollute the atmosphere freely, which is arguably a usufruct, or right established through past use.

An allocation of free allowances, if not tied to output, can have the same effect, differing solely in its denomination in tonnes of carbon rather than in euros and perhaps also differing in the way it is currently recorded in public accounts.

In practice, free allowance distribution schemes do have some relation to output even if they are based on fixed quantities; for instance, by reducing allowance distribution to zero if output ceases or drops below a certain level. Note, however, that basing allowances on historical levels of production fixes the allocation independent of current or future output, unless it is explicitly updated in some way in reference to current output.

Levelling the playing field

The carbon price can be expanded to cover outside firms who compete with inside firms via imports in two ways. One is the first element of the border carbon adjustment, discussed above. Importers may be required to purchase emissions allowances, or instead to pay an equivalent charge permitting a public authority to purchase allowances, or, instead to pay an equivalent tax.

Multilateral sector agreements are the second option. These are international agreements which act within a sector and are intended to introduce an equivalent carbon price or equivalent effective mitigation action in a third country which competes through imports to the inside home market or with inside firms' exports.

Exemptions

Finally, it is possible to reduce the scope of the carbon price by exempting activities from the scheme. These exemptions come in two forms. One is a plain exemption, an example being small emitters within the EU emissions trading scheme. The other is an exemption with conditions, where a contract is drawn up and the exemption is granted under terms and conditions using specifying mitigation action to be taken by the exempt firms. An example is Climate Change Agreements, which are exemption contracts associated with the Climate Change Levy in the UK.

6.2 Assessment criteria

Main criteria and various sub-criteria

6.2.1 Introducing the assessment framework

The assessment framework uses a set of five criteria which between them cover economic, legal, institutional and political aspects of a policy's performance. These criteria are:

- carbon leakage;
- environmental effectiveness;
- efficiency;
- feasibility; and
- administrative cost.

The criteria are discussed further below. Strong performance against all of them individually would be the characteristic of an ideal policy. In practice, some degree of trade-off in determining the ideal policy is appropriate. The assessment criteria are not weighted equally in this regard: for instance, a complete lack of effectiveness might be sufficient on its own to rule a policy out, but relatively high administrative cost on its own might not be.

Where relevant, the counterfactual for comparison purposes is a hypothetical ETS with a given cap and full auctioning – that is, effectively the current EU ETS without free allowance provisions. Rankings against criteria are chosen in a manner intended to make the relative performance of the different policies clear.

6.2.2 Carbon leakage

As all policies are nominally intended to reduce the level of carbon leakage, the absolute level of their effectiveness at achieving this goal is a key issue in assessment. Note, however, that preventing carbon leakage can also be consistent with, for instance, failing to reduce overall emissions, an issue addressed by the 'Environmental effectiveness' criterion.

6.2.3 Environmental effectiveness

Effectiveness should take into account both short and long term reactions from firms and consumers, in particular the influence of the policy on investment decisions, in which policy risk is a factor. Policy risk exists in many policies because of the limited means by which governments can commit future administrations and because of the counteracting incentives which they sometimes face. These are developed under the feasibility criterion.

The key issue from an environmental perspective is whether a policy is consistent with the overarching goal of the EU ETS, that is, to reduce the global level of emissions. Thus a higher rating implies lower net emissions globally.

6.2.4 Efficiency

Efficiency is measured as the effect of the policy relative to its cost. In this case, the effect is the amount of carbon leakage which is prevented, measured in tonnes of CO_2. The costs measured are welfare costs, which means that they take into account the effects on consumers (consumer surplus) as well as on firm owners (profits).

The emissions can be counted on three bases:

– UK/European produced emissions (excluding imports);
– UK/European consumption emissions (excluding exports);
– global emissions.

Of these, the first maps onto the international liabilities of nations which are denominated in nation-produced emissions. The second has no current currency but could reflect a moral responsibility for consumption and has been proposed as an appropriate measurement basis in (Helm, Smale, & Phillips, 2007). The third is of interest in identifying the globally preferred option.

The costs can similarly be measured using different bases, which define the assessment categories under the efficiency criterion:

– UK/European producers, consumers and, for some policies, taxpayers;
– global producers and consumers.

The narrower scope of costs is usually used in impact assessments which have a national relevance, although considerations of international acceptability may dictate that analysis has also to be conducted on a global basis in order to acknowledge the impacts on third parties. In both cases, a high rating implies a large reduction in leakage per unit of cost.

6.2.5 Feasibility

The distributional impact of a policy can affect its acceptability and make it institutionally feasible or infeasible to introduce. Generally policies that impose costs on the powerful are more difficult to implement. For instance, the ability of affected parties to lobby or change the assessment calculus by changing the costs of the scheme, relates to feasibility. This is key to international impacts where third party governments may find it in their interests to attempt to respond punitively to the introduction of a scheme.

Feasibility concerning the impact on domestic income distributions

The impacts of policy options on domestic feasibility occur through differential impacts on:

– consumers through product prices;
– capital owners, through the impacts on inside firm profits;
– (organised) labour, through employment impact related to output;
– the state, through fiscal liabilities or assets.

Based on lobbying power and visibility of impacts, the feasibility of the policy may be most likely to be affected by the impacts on capital owners and state finances.

Feasibility concerning international relations

The impacts of policy options on international relations occur through impacts on:

– international institutions, which often have difficult politics, lack of experience in handling assets or payments, and slow, consensual decision-making processes;
– fiscal balance in other countries;
– capital owners, through the impacts on outside firm profits and competitiveness;

– employment, through effects on output;
– cultural fit with third party national policy.

In general, financial impacts which benefit the competitiveness of inside firms will disadvantage outside firms and so provide grounds for international opposition. Opposition is likely to be stronger if there is a poor cultural fit with third country policies or if the policy does not provide opportunity for a fiscal benefit.

Feasibility concerning institutional implementation

Certain policies may be difficult to implement due to the incentives or conflicting goals faced by governments and other key institutional players. As a simple example, larger operating costs tend to reduce institutional feasibility, given that governments face some requirements to justify spending. Other policies may be hard to implement due to the weighting given to different interest groups in the policy process.

In all cases, higher ratings imply greater feasibility.

6.2.6 Administrative cost

The administrative cost is just one part of the cost of the scheme and so is inherent within the cost-effectiveness criterion, but it deserves individual attention because of its considerable influence on policy choices. The administrative cost on the government purse is of particular relevance, since policies are generally required not to place excessive demands on institutional budgets, but costs imposed on regulated parties are also included under this criterion.

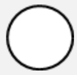
High ratings imply relatively lower administrative cost.

6.2.7 Graphical representation

The figures produced in this report use a “Harvey Ball” representation of a five point Likert scale. To evaluate different aspects of policy options, Vivid and Ecofys (with the advice of associated experts) provided responses on a scale from one to five corresponding to very poor, poor, fair, good and very good. The extent to which each policy option fulfils each of the 13 criteria is represented by a Harvey ball. The empty circle represents very poor and a full circle represents very good. Results shown are the consensus of Vivid and Ecofys.

It is worth emphasising that it is not considered appropriate to evaluate policies simply by averaging their scores across the assessment criteria. Indeed, the use of a graphical, rather than numerical, means of presenting individual scores is partly intended to underline this point.

Figure 24. **Harvey ball presentation of fulfilment of criteria**

Complete fulfilment of the criterion	
Greater fulfilment of the criterion than the counterfactual	
No better nor worse than the counterfactual	
Lesser fulfilment of the criterion than the counterfactual	
No fulfilment of the criterion	

Source: Vivid Economics

6.3 Assessment results and discussion

The performance of four options against assessment criteria

6.3.1 Free allowances

Discussion of free allowances

Free allowances are a common component of emissions trading schemes, appearing within the European, Californian, Australian, New Zealand and Chinese schemes. The free allowances within the EU ETS are specifically intended to benefit firms that are most at risk of moving production abroad (Hallegate, Hourcade, & Dumas, 2007).

6.3.2 Design options

There are a number of design variants for free allocations. They can be based on emissions over a historic period (grandfathering) or based on output multiplied by a carbon intensity factor. In both cases, they can be tied to the operation of the plant, so that it ceases when a plant closes, or so that it varies as a plant's output varies. For output-based allocations there are three further options: to use actual emissions, benchmarks derived from sectoral emissions, or technology standards. These options are all listed in Table 6.

The EU ETS updates its allocations based on output, but only very intermittently compared to the Australian and Californian schemes. For Phase III, the allocation takes output in 2005-2008 or 2009-2010, whichever gives the highest median value, applying a benchmark at the top (most efficient) decile of emissions intensity for the sector. The output base year has been changed between Phases I, II and III to reflect more recent output. In principle, output levels for allocation in Phase III are fixed for 8 years, with potential for adjustments explained in Section 6.3.3.

In the US, both the Lieberman-Warner and Waxman-Markey bills proposed output-based allocation to quell leakage. In fact, for sectors considered at risk of leakage under Waxman-Markey, a rebate of 85 per cent of direct emissions and 100 per cent of indirect emissions was offered (Wooders, Cosbey, & Stephenson, 2009).

Having determined a level of output as the basis for allocation, the number of allowances to be given is found by multiplying output by carbon intensity. The carbon intensity is generally drawn from a benchmark, which may be periodically updated. Some benchmarks may be fixed for a period of time and intermittently updated, whereas other dynamic benchmarks are adjusted annually. Australia, California and New Zealand use annual updating. The EU ETS currently applies a benchmark of the top (best) decile of emissions intensity, based on a recent period (European Commission, 2011).

Table 6. **The basis of free allowance allocations**

Aspect of design	Options				
Eligible plant	all currently operating plant		all plant operating on historic date		
Basis	emissions over historic period		output × benchmark		
Output-link		historic output	recent plant-level output	projected future sector output	
Carbon intensity benchmarks		technology standard	sectoral fixed historic	sectoral updated	sectoral projected

Notes: The vertical arrangement shows how the aspects of design can be combined. Those which overlap vertically can be combined together. The current basis of free allowance allocation is indicated by shading. In the third row, the allocation is first based on historic activity levels in 2005-2008 or 2009-2010, but it is changed if (a) there is a 'significant capacity change', that is, a 10 per cent increase or decrease of activity levels in combination with a technical modification, or (b) a partial cessation, that is, a drop of output below 50 per cent of initial output.

Source: Vivid Economics

6.3.3 Assessment

Carbon leakage and efficiency

An output-based allocation is a production subsidy and 'sacrifices some of the efficiencies of market-based policies' (Carolyn Fischer, 2001). Firms 'no longer minimise their abatement costs but also take into account the profits they could obtain by receiving a larger allocation in the next period' (Hahn & Stavins, 2012). An output-based allocation increases the carbon price needed to achieve a given level of emissions reduction by diluting the effective carbon price signal facing some consumers. This means the consumers not entitled to output-based allocations face a different effective price from those who to receive them. The more responsive consumers are to price signals, the greater is the cost imposed by output-based allocation.

A free allocation tied to a historic output level would rapidly become out of date, but it would not impose the efficiency costs described above (Matthes, 2008) since it does not link free allocations to output and thus the allocation does not change the marginal cost of production. However, allocations based on recent output levels have the effect of linking free allocation with output, effectively diluting the carbon price because the marginal cost of production is reduced.

In the EU ETS, allocations are tied to historical operation of plant and are updated periodically. For Phase III, for example, for incumbent installations, 'Member States shall determine historical activity levels of each installation for the baseline period from 1 January 2005 to 31 December 2008, or, where they are higher, for the baseline period from 1 January 2009 to 31 December 2010' and this will be the basis of the allocation (European Commission, 2011). This is an output-based approach, where the relevant output level is updated only if (a) there is a 'significant capacity change', that is, a 10 per cent increase or decrease of activity levels in combination with a technical modification, or (b) a partial cessation, that is, a drop of output below 50 per cent of initial output.

Thus the EU ETS gives some protection against carbon leakage because the free allocation is tied to historical output and to some extent continued operations, but lesser leakage protection (and more environmental effect) than a fully updating output-based scheme would offer. It seems likely that the current approach offers low protection against carbon leakage while it could offer reasonable environmental effectiveness (and would do so if the EU ETS cap were tighter).

Effectiveness at reducing global emissions

Free allowances have no or little effect on carbon leakage unless they are tied to output, which they are in all existing emissions trading schemes and in the previously-proposed US schemes. In all these cases, the link to output dilutes the effective carbon price for the recipient firms and diminishes the emissions abatement which those firms undertake. This makes output-based free allocation environmentally less effective. So, while an output-based allowance allocation may reduce leakage, it does not perform well on environmental criteria.

Modelling using computable general equilibrium models offers insights into the performance of output-based allocations, auctioning and grandfathering. When comparing macroeconomic impacts, leakage and competitiveness, research suggests that output-based allocation combined with auctions perform the best (Takeda, Arimura, Tamechika, Fischer, & Fox, 2011). However, output-based allocation is not as effective in reducing emissions when compared with auctioning or auctioning with BCAs (Quirion & Demailly, 2008a). These two pieces of research support the arguments made above.

Feasibility

Free allowances can compensate for forgone profits if set at an appropriate level. Indeed, they can have such a large positive effect on inside firm profits that the firms can make larger profits with the emissions trading scheme than they did without it, so-called ‘windfall’ profits (Smale et al, 2006; Hepburn, Quah and Ritz, 2013). This makes them attractive to industry.

Free allowances impose an equal and opposite cost on the government through forgone revenues from auctioning. This is invisible since it is not reported as an expenditure in government accounts. They have no impact on third countries.

The high feasibility of free allowances is proven by their introduction in emissions trading schemes in four continents, but there is political effort expended in deciding the level of free allocations in which firms push for higher allocations and governments push for lower allocations. The pattern has been that firms have argued that the emissions trading scheme has significant adverse impact and have demanded free allowances, often on an output basis. This demand diminishes the environmental effectiveness of the scheme, protects against carbon leakage and reduces fiscal revenues.

Administrative cost

The administrative cost of free allowances is substantial because of the work involved in constructing benchmarks. This cost is lower than the cost of administering a BCA, however, since its scope only extends to production inside the scheme, and may or may not require such frequent updating (benchmarks are only updated at the start of each Phase under current rules). Output-based allocations carry some of the same problems of defining products and outputs that are encountered for compensation and BCAs. They also involve ongoing administrative costs.

Figure 25. **Free allowances tied to current output score highly on carbon leakage control and feasibility but poorly on economic criteria**

Leakage	Carbon leakage	Leakage is avoided because inside firms no longer face full carbon price	●
Environmental effectiveness	Global emissions	Reduced global emissions because of lower imports if EU ETS cap remains unchanged	◑
Efficiency	Cost to Europe	Inefficient because abatement target has to be met from narrower scope within the economy	◔
	Cost global	Higher costs within the EU to meet the target and thus higher total global costs of controlling warming	◔
Feasibility	Domestic	In operation: proven feasibility	●
	International	Requires no overseas cooperation except in aviation and shipping	◕
	Institutional	In operation: proven feasibility	◕
Administrative cost	Admin cost	Costly lobbying and benchmarking activities	◑

Source: Vivid Economics

6.3.4 Firm compensation

Discussion of firm compensation

An alternative to free allowances as a means of redress is financial compensation. This can take the form of tax credits or cash payments. Tax credits are, by definition, only accessible to firms who have tax liabilities to offset.

The compensation can be made on any of the same bases as free allowances, that is historic, current or projected output coupled with a variety of benchmarks. In addition, there is the option of compensating forgone profits, but this option is likely to be more open to dispute, more discretionary and thus more difficult to implement.

Where the level of compensation is tied to allowance prices it becomes, in economic terms, very similar to the granting of free allowances, even though the accounting procedures may retain an important difference. It could, however, be set in a way which smoothes allowance prices or even fully independently of allowance prices, in which case it would perhaps strictly cease to be classified as compensation.

Assessment of firm compensation

Carbon leakage

Compensation payments have a similar effect as free allowances, when made on the same basis. When tied to output on an updating basis, they protect against carbon leakage, reducing imports and reducing the emissions associated with imports. When tied to output on an historic basis, they are much less effective at maintaining competitiveness, and offer little protection against carbon leakage. In the assessment table below, they are presented as if the compensation is paid on an historic output basis.

Environmental effectiveness

The effect of compensation on global emissions depends on the way it is administered. If it is administered on a purely historic emissions or output basis, then it does not redress carbon leakage but maintains the integrity of carbon prices, and hence environmental effectiveness, within the trading scheme. If it is administered on an updating output basis, then future output generates entitlement for compensation, and this diminishes the effective carbon price, reducing the environmental effectiveness of the trading scheme.

Efficiency

Compensation on a historic activity basis, like free allowances made on this basis, does not change future production costs and thus leaves all prices unchanged. There is no correction to competitiveness and no impact on consumers. The administrative cost would be similar to that for free allowances.

Feasibility

Where compensation is made on the same basis as free allowances, that is, in compensation for the cost of purchasing allowances, the assessment is the same, although it is less domestically feasible because, although the impact on the fiscal balance may be the same, it is less discreet. Capital tax allowances and free emissions allowances are discreet because they do not appear as expenditure in national accounts, but there may be a low limit to the level of assistance which can be channelled through this route where capital allowances are already offered or investment is low.

Administrative cost

If modelled on a free allowance allocation scheme, the administrative costs will be similar to the costs of administering free allowances, as discussed earlier.

Figure 26. **Compensation scores poorly across all criteria, although capital allowances offer reasonable domestic feasibility**

Leakage	Carbon leakage	Does not reduce carbon leakage when made on historic output basis (as assumed here)
Environmental effectiveness	Global emissions	No change in emissions because the incentive of the trading scheme carbon price remains fully effective, when compensation is made on an historic output basis (as assumed here)
Efficiency	Cost to Europe	Costs of leakage remains, fiscal cost of paying compensation is similar to fiscal cost of free allowances
	Cost global	No additional costs above those for Europe above
Feasibility	Domestic	No track record of use, except in form of capital allowances. Fiscal burden
	International	May have to be implemented nationally due to national fiscal sovereignty within Europe. Could face opposition from other countries on trade grounds
	Institutional	Payments to firms unusual and may contravene State Aid rules in Europe
Administrative cost	Admin cost	Costly lobbying and benchmarking activities. Fiscal burden

Source: Vivid Economics

6.3.5 Exemptions: rolling back coverage

Discussion of rolling back coverage

Exemptions have two forms. The first is the complete exemption of some categories of emissions, examples being household fossil fuel heating, transport, non-CO_2 emissions and small emitters. The second is a partial exemption through the discounting of emissions. This reduces the emitter's liability to a fraction of their total emissions. It reduces the effective carbon price. An example is Climate Change Agreements which discount the Climate Change Levy rate.

Exemptions may be tied to the promise of alternative action through the vehicle of a negotiated agreement, similar to the UK's Climate Change Agreements. There is experience of writing negotiated agreements. They take substantial effort and suffer from information asymmetry which gives firms a negotiating advantage over governments and leads to uncertainty in their effectiveness. Their effectiveness depends upon whether they are genuinely binding, dynamically adjusting and enforceable through bilateral contracts rather than collective agreements. Dynamic adjustment allows the agreement to maintain its bite as circumstances change over time and bilateral contracts make the agreement easier to enforce than collective agreements where liabilities are spread diffusely.

Assessment of rolling back coverage

Carbon leakage

Carbon leakage risk is reduced, broadly speaking, in proportion to the extent of rollback. Thus exemptions can be considered an effective means of reducing leakage risk.

Environmental effectiveness

Exemptions have low environmental effectiveness. In most cases, they result in a narrower emissions trading scheme and thus a reduced coverage of emissions pricing in the economy. Carbon emissions increase, unless effectively controlled through a negotiated agreement, and the output effect from carbon costs embodied in product prices is lost (that is, customers are not exposed to the cost of carbon embodied in products), benefiting customers but further reducing effectiveness. Carbon leakage ceases.

Furthermore, negotiated agreements are difficult to monitor and evaluate because unless they are conducted with an experimental control, which is unlikely to be feasible, it is difficult to define the counterfactual, that is, what would have happened in the absence of the agreement.

Efficiency

If they are well targeted on sectors where carbon leakage is severe, then exemptions can improve the efficiency of an emissions trading scheme. Exemptions for other sectors reduce efficiency by introducing variety in the levels of carbon prices across the economy and thus distort the allocation of effort to reduce carbon emissions. Bohringer & Rutherford (1997) use evidence from Germany to suggest that by protecting the competitiveness of carbon intensive industries an exemption policy narrows the tax base requiring a higher marginal tax rate and therefore increasing the costs of achieving emission reductions.

Feasibility

Feasibility is quite high: exemptions are widely used, though they erode the reputation of the emissions trading scheme and signal weak commitment. Exemptions are already employed for transport, small emitters, households and some non-CO_2 gases, though these exemptions have been given for reasons not related to carbon leakage.

Exemptions have a high fiscal cost in terms of foregone revenue from allowance sales, but this is not visible in accounts because it is not counted as a public asset.

In the current international policy context, exemptions do not create any adverse impacts on third parties because European trade partners do not themselves operate strong carbon pricing schemes which would cause them to object to a relaxation of European carbon policy on grounds of unfair competition. It is possible that exemptions could become a source of tension in international relations if they cause carbon leakage in third countries or act as a brake on those countries raising carbon prices domestically.

Administrative cost

Figure 27. **Negotiated agreements are costly and difficult to monitor but exemptions may sometimes be justified**

Leakage	Carbon leakage	Reduces leakage in approximate proportion to the extent of rollback (full rollback eliminates leakage)	
Environmental effectiveness	Global emissions	Increased global emissions because of lower coverage of EU ETS	
Efficiency	Cost to Europe	Inefficient because abatement target has to be met from narrower scope within the economy	
	Cost global	Higher costs within the EU	
Feasibility	Domestic	In operation: proven feasibility	
	International	Requires no overseas cooperation	
	Institutional	In operation: proven feasibility	
Administrative cost	Admin cost	High cost to implement	

Source: Vivid Economics

6.3.6 Border carbon adjustments

Discussion of Border Carbon Adjustments

Border carbon adjustment (BCA) targets the underlying cause of leakage, the unequal carbon price, in an environmentally effective way. However, there are reasons why it is not part of any current emissions trading scheme despite having longstanding theoretical appeal (Markusen, 1975) and (Hoel, 1991). Given the complexity of BCAs and the diversity of design options, the discussion of this option is more extensive than has been provided for other options.

The BCA imposes a tax, a charge or an obligation to purchase allowances on imports. The distinctions between these forms are not crucial for the purposes of discussion here, relating more to how the BCA is accounted for in relation to government revenue and the number of issued allowances:

– in the form of a charge, it funds the purchase of allowances to cover emissions embedded in imports;

- in the form of a tax or charge, payment of a sum is exchanged for a waiver on allowances for emissions embedded in exports.

A symmetrical arrangement can operate for exports, where allowances are bought back from exporting firms (Vivid Economics, 2012). In practice, this can operate through a subsidy paid to firms, accompanied by a parallel purchase of allowances in secondary markets. This is analogous to 'duty draw-back' in free trade agreements (Cadot, Carrere, Melo, & Tumurchudur, 2006).

Since the aim of the adjustment is to reflect differences in carbon prices between jurisdictions, the adjustment might take into account the strength of carbon policies in third party countries on a carbon price or equivalent basis for policies which do not use carbon prices directly. The emissions embodied in the product can be treated as specific to an installation, a country of origin or made general to a sector, making use of data supplied by participants, national governments or gathered for the purpose of benchmarking emissions within the EU ETS.

It is likely that rules of origin would have to be developed defining how to calculate the embodied emissions and country of origin of products in the common situation where intermediate inputs embodied in the product have themselves been traded across borders. These arrangements have the potential to become complex, to account for components of a product with embodied emissions arising from different places. Compromises in the accuracy of the adjustment are likely to be in order, to avoid the complexity that may otherwise arise. However, the complexity might not be too extensive: some have suggested that the proportion of GDP which would be covered by BCAs is around one per cent (Holmes, Reilly, & Rollo, 2011).

A further design consideration is whether the border carbon adjustment for EU imports is imposed by the producing country exporting to the EU or by the EU itself, that is, whether it is an adjustment at origin or destination. A related question is whether, under a destination model, the revenue raised from applying the BCA to imported goods should be kept by EU governments or returned to exporting country governments. Where the revenue is returned to the government of the country of origin, it creates a hybrid in which the administration of the scheme is destination-based but the fiscal distribution is origin-based (D. Helm, Hepburn, & Ruta, 2012).

A summary of the design options introduced above is set out in Table 7.

Table 7. **Summary of BCA design options**

Aspect of design	**Options**			
Trade flow	Imports only	Imports and exports		
Currency	Tax payment	Allowance purchase		
Emissions price	Spot price on date of entry/exit	Time-averaged price	Price on periodic fixed calendar date	
Origin/destination country price adjustment	None	Equivalent carbon price		
Emissions intensity	Installation level	Country and sector	Sector	
Aggregation level	Installation	Narrow sector	Broad sector	
Rules of origin	Proportion of embodied carbon	Proportion of value added	Number of process steps	Change in industrial class
Scope of inclusion	Energy intensive	Energy intensive and trade exposed		
Administrative authority	Europe	Country of origin		
Jurisdiction receiving import revenues	Europe	Country of origin		

Source: Vivid Economics

There are methods which can be employed to work out the carbon price equivalent basis of policy programmes in trading countries (OECD, 2013; Productivity Commission, 2011; Vivid Economics, 2011). Where pure market based instruments are employed, the prevailing price may be used, but in most cases the shadow price of other policy types will also or instead have to be taken into account (Metcalf & Weisbach, 2010).

The BCA could be applied to carbon-intensive and trade-intensive products only since its administrative costs would otherwise outweigh its benefits, although it is likely there would be lobbying from excluded firms to extend its application to their sectors. The design could either be complex and precise, or simple and approximate, with the latter likely to be able to remedy most of the leakage effect at lower administrative cost. Each product category and third country combination would be given a carbon adjustment value in tCO_2 per unit of product and the allowance price would be applied to this value to give a charge or payment. There are significant administrative challenges in implementing this which are discussed below.

The payments system could operate in parallel with Value Added Tax and thus keep administrative costs down. The VAT system is much simpler than a BCA, however, since VAT operates on the product value, whereas BCAs operate on the nature of the product and its provenance (Holmes, Reilly, & Rollo, 2010; Holmes et al., 2011).

Assessment of Border Carbon Adjustments

Efficiency

BCAs can be designed to remove the distortion caused by borders because they can reduce the differential in carbon prices applied to goods consumed in the European economy: this makes them efficient.

There is dispute within the body of existing work examining BCAs as to how effective they are in addressing carbon leakage and in large part this can be attributed to differences in results between the main classes of models used in estimating leakage. The literature review discusses the origin of these differences and concludes that it is not appropriate to rely on extrapolations of historical observations of leakage at low carbon prices to future high-price regimes, a conclusion supported by Aldy and Pizer (J E Aldy & Pizer, 2009). Within this literature there are discussions of models and their interpretation by various multi-lateral agencies including the OECD, European Commission and World Bank (J.-M. Burniaux & Chateau, 2008; European Commission, 2010; Mattoo, Subramanian, van der Mensbrugghe, & He, 2009).

Although if perfect information were available, the efficiency of BCAs would be high, inevitable simplifications and inaccuracies in data make the border carbon price corrections approximate. Iron and steel exemplifies some of the worst difficulties. In this sector, it is impossible to tell by inspection what type of production process has been used to make a piece of steel, yet the carbon embodied in steel varies greatly by production method, from 0.1tCO_2/tonne steel for electric arc furnace recycled steel to 1.8tCO_2/tonne steel for virgin blast oxygen furnace steel (Holmes et al., 2010). The use of an average carbon intensity figure will overburden some sources and under-burden others. Similar issues would apply to other sectors, though in some, such as cement, the range of intensities is likely to be narrower.

Having considered the challenges of estimating the carbon content of goods, let us turn to the carbon price. The use of allowance prices would appear more accurate and thus more efficient than the use of an administratively-determined tax rate. The most transparent way to implement this would be to require importers to surrender allowances (Stéphanie Monjon & Quirion, 2010).

In the long run, BCAs can encourage third countries to adopt carbon policies of their own whereas without BCAs they are discouraged from doing so, as by adopting such policies their exporters will no longer be subject to BCA charges. The use of BCAs protects domestic industry on the international stage and shifts the burden of abatement from abating countries to non-abating countries (Böhringer, Carbone, & Rutherford, 2011). This may encourage greater collective action.

In summary, ideal BCAs are efficient because they correct cross-border distortions. In practice, BCAs are not ideal: they involve administrative and political compromises. The extent of the compromises determines their final efficiency. Their administrative and feasibility characteristics are discussed further below.

Effectiveness

BCAs may allow high carbon prices without leakage, with substantial carbon-saving effect. They may be most effective in correcting carbon price differences across borders where the goods traded are simple and homogenous and least effective where the goods are complex and heterogeneous.

In simulations done by the Energy Modelling Forum study across a large number of models (Böhringer, Balistreri, & Rutherford, 2012), BCAs reduce the loss of output in abating countries by around two thirds. It is noteworthy that of the 13 models tested in this study, the PACE model relied upon by the European Commission produced the smallest changes in output from energy intensive industries.

The results of investigations of the effectiveness of BCAs using economic models have advanced understanding, but have not led to consensus. For example, some experiments with general equilibrium models found that these models typically may under-estimate the effectiveness of BCAs and it has been suggested that this is because they work with aggregated sector data from the GTAP database (Caron, 2012b). Disaggregated models generate higher carbon leakage estimates. Furthermore, most general equilibrium models specify trade effects using one approach, Armington elasticities, but an alternative more recent specification gives higher estimates of leakage and competitiveness effects (Balistreri & Rutherford, 2012).

Pragmatically, it seems likely that BCAs might be applied uniformly to imports using a benchmark emissions intensity. This leaves no incentive on importers to reduce their emissions intensity and, in this formulation, makes the scheme ineffective at stimulating abatement within third country firms.

Administrative cost

The administrative costs of BCAs have not been studied in detail here or in the literature, but there is some initial work, for example concerning using international standards as a way of lowering costs (Evans, 2003).

The BCAs would require regular, perhaps annual, updating. Administrative costs are likely to be higher than for free allowance allocation.

An indication of the administrative costs of BCAs can be obtained from the costs of existing free trade or preferred trading party agreements such as the PANEURO and NAFTA systems. This is an appropriate analogy because similar rules of origin may have to be employed to identify originating from non-originating designations. NAFTA compliance costs are estimated at around 6 per cent of the cost of the value of the traded goods, which, considering the cost of carbon embodied in the goods, represents a significant proportion of the cost of carbon for some combinations of product and carbon prices (Anson et al., 2005). This estimate is large, and if BCAs were to be similarly costly to administer, they would only be worthwhile introducing for the most energy intensive, trade exposed and simple-to-administer goods and only when carbon prices had risen to levels where competitiveness effects were beginning to bite.

Feasibility

BCAs are likely to face international political opposition and threats even though they may be permitted under international law. This is because the introduction of carbon prices sufficient to address climate change will create losers (J. E. Aldy & Stavins, 2012). Some parties oppose carbon prices because of an absence of trust: concerns that carbon pricing may be used as a cover to introduce trade policies. For either reason, BCAs are likely to face legal challenge. Firms in some sectors, perhaps those where there is great variation in emissions intensity by production method, may find BCAs unpalatable because they fear unfair treatment. This may lead them to resist their introduction strongly.

An agreement has been the object of UNFCCC negotiations but has not yet been achieved. Even so, without an international agreement, there is some evidence that trade measures such as a BCA used solely to protect the environment may be admissible (Cosbey, 2007; Houser et al., 2008). For instance, the principles of such a measure have been confirmed in a judgement in the Asian countries versus US Shrimp-Turtle case of 1998.

Meanwhile, the US has presented draft climate policy legislation twice to Congress and both times it has included provision for import allowance requirements (a BCA). First, there was the Lieberman-Warner Climate Security Act in 2008, next came the Waxman-Markey American Clean Energy and Security Act 2009, which passed the House of Representatives but was rejected by the Senate. It would have enabled BCAs from 2025 under its ‘international reserve allowance programme’ (U.S. Congress, 2009).

However, it is likely that there would be a challenge at the WTO if either Europe or the US were to introduce BCAs (Zhong, 2012). Two major powers, India and China, are opposed. From previous threats of trade action and attempts to block BCAs from within multi-lateral negotiations, the risk that third countries would oppose BCAs through legal challenge and threat of retaliatory trade action appears to be real. It is an entirely expected position. These countries expect significant advantage from avoiding BCAs, as the World Bank’s modelling has shown (Mattoo et al., 2009). A range of other models indicate that without BCAs, third party countries bear about 25 per cent of the cost of a unilateral carbon policy, and with BCAs, that figure increases to around 50 per cent (Böhringer et al., 2012).

It would not be correct to conclude that the risk of retaliatory action by third countries would be sufficient to deter developed countries such as the US and Europe from introducing BCAs. Two studies have independently tested the policy game by examining the payoffs for countries from a variety of strategies and find that the BCAs strategy is credible (Bohringer, Carbone, & Rutherford, 2013; D. Helm et al., 2012). This evidence suggests that acknowledging the political difficulties and the real cost of retaliation, developed countries may still be better off with BCAs than without them.

From a global perspective, it is desirable to move towards universal efforts to mitigate carbon emissions, and thus incentives to cooperate are important. The option of returning carbon revenues to countries of origin could allow gains to be shifted from developed to developing country governments. This has not yet been tested within multi-lateral negotiations but may yet prove helpful.

Figure 28. **Border carbon adjustments perform well on economic criteria but weakly on feasibility**

Leakage	Carbon leakage	Carbon leakage is reduced to low level for main products which are exposed to leakage	
Environmental effectiveness	Global emissions	Reduces global emissions by bringing net imports within the scope of regulation	
Efficiency	Cost to Europe	Lower costs of achieving cap by wider scope of emissions abatement action	
	Cost global	Lower costs in Europe, higher costs outside Europe, overall position unclear	
Feasibility	Domestic	Potential objections to approximate adjustments	
	International	Threat of retaliation is real, but could be mitigated by returning receipts to countries of origin	
	Institutional	New detailed arrangements would be needed	
Administrative cost	Admin cost	High costs because of complexity, and remaining question about the number of sectors to be covered	

Source: *Vivid Economics*

6.4 Conclusions

6.4.1 All policy options face difficulties; BCAs tackle leakage while maintaining environmental effectiveness, but free allowances are more feasible

Border carbon adjustments appear to be the sole policy option of those investigated with the theoretical potential to outperform free allowances. However, there remain important questions about the feasibility of BCAs and their administrative costs. Some argue that the threat of retaliation is too great to risk, while others argue that it is a risk worth taking.

Meanwhile, the design of free allowances which is most effective in mitigating carbon leakage is the output-linked design. The disadvantage of output-linking is that it compromises the effectiveness of carbon prices in stimulating emissions abatement, and the general disadvantage of free allowances is the cost to the Exchequer.

On balance, while these two instruments are the most promising of the four examined, neither is straightforward. It is easier to implement free allowances unilaterally, and administratively simpler, and this is perhaps why they have been preferred to date.

If carbon prices rise, border carbon adjustments may become relatively more effective in addressing the competitiveness problems caused by unilateral carbon prices. They are unlikely to offer a perfectly accurate correction, but the evidence suggests that even an approximate correction may be quite effective and become more effective than the alternative policies as carbon prices rise. It is less clear whether the corrections can be designed sufficiently well for this conclusion to hold true for all sectors, steel being an example which may be problematic. In the steel sector, there is a great range in carbon intensity as a result of the variety of processes available for making it, and therefore the application of a generic benchmark carbon intensity might be quite inefficient. This would make BCAs less accurate in adjusting for competiveness effects in steel production.

In comparison, free allowances can only address the production cost differentials which are the cause of carbon leakage, if allocations are made on an updating output basis, and unfortunately this reduces their environmental effectiveness. So, while free allowances can be effective in controlling carbon leakage, and can be applied more broadly than BCAs due to the administrative costs of the latter, they cannot at the same time be environmentally effective.

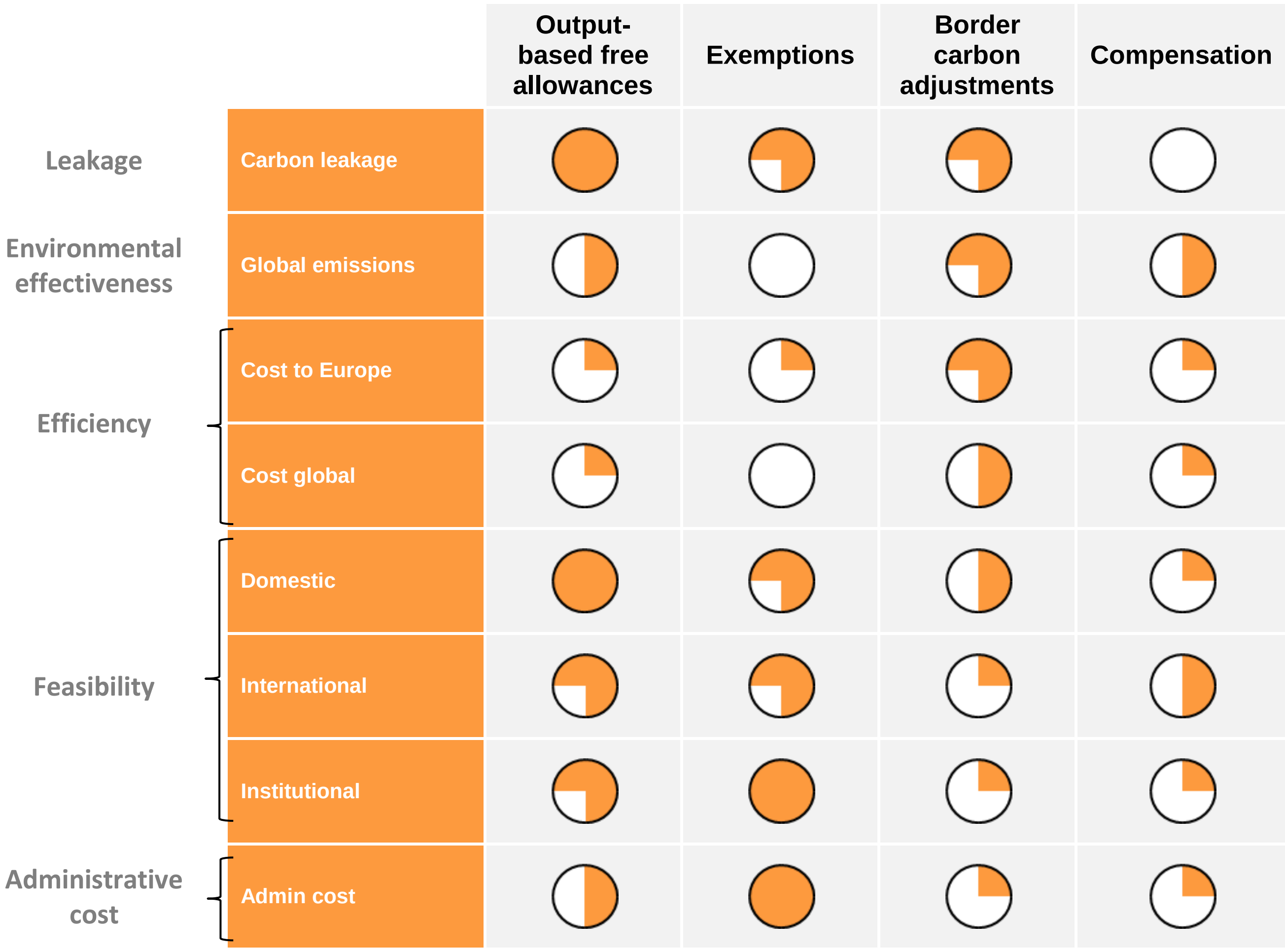
Direct compensation through subsidies or tax allowances would be a sovereign fiscal matter and thus extremely difficult to implement on an EU-wide regional basis. Nor would it be effective at controlling carbon leakage. For this reason compensation is likely to be ineffective at addressing competitiveness.

Exemptions are widely used: around 50 per cent of emissions are exempt under the EU ETS, albeit not due to carbon leakage risk. However, they are ineffective in controlling carbon emissions and so cannot be considered a preferred solution to carbon leakage. They could be used as an interim measure in a few specific cases where the costs of carbon leakage are judged to be particularly high. As effort to mitigate greenhouse gas emissions becomes stronger over time, as is expected, carbon prices will rise.

There are two strategic arguments relating to BCAs: one is that BCAs offer incentives to pursue multilateral agreements while free allowances do not, and the other is that BCAs may erode goodwill between negotiating parties and make it more difficult to reach multilateral agreement. BCA offers a fiscal incentive for government to maintain the scheme (with high carbon prices) while free allowances do not. On the other hand, the BCA is likely to trigger trade retaliation and may be opposed by some domestic producers. Hence there are arguments that BCAs assist in building a credible long-term commitment to emissions trading and that they may disrupt cooperative action.

Two design elements may help improve third country acceptability of BCAs: the recognition of third country carbon policies in the design; and allowing third countries to operate the border adjustments themselves or returning import revenues to them.

Figure 29. **Border carbon adjustments are most efficient at addressing leakage while maintaining environmental effectiveness, but output-based free allowances are most feasible**



Source: *Vivid Economics*

6.4.2 As carbon prices rise, the relative feasibility of different options may change

As the carbon price increases, the administrative costs of border carbon adjustments, which will be higher than those for free allowances, will become of declining importance. As carbon prices rise, the signals throughout the economy to become a low carbon economy become more important. This stimulates substitutions within the supply side of the economy, such as replacement of coal-fired power generation with gas and renewables, and substitutions in the demand side of the economy, such as use of recycled steel in favour of virgin steel. It increases expenditure on commerce and services at the expense of manufactures. As carbon prices rise, the importance of efficient abatement and correctly-priced trade activity rises in its value relative to the administrative costs of correcting those costs embodied in traded goods.

As the substitution costs increase, it becomes more important to have a broad coverage of the carbon price within the economy, and the costs of using exemption policies rise. This rules them out as a long term option. As output leakage rises, the effectiveness of the policy in controlling leakage becomes more important.

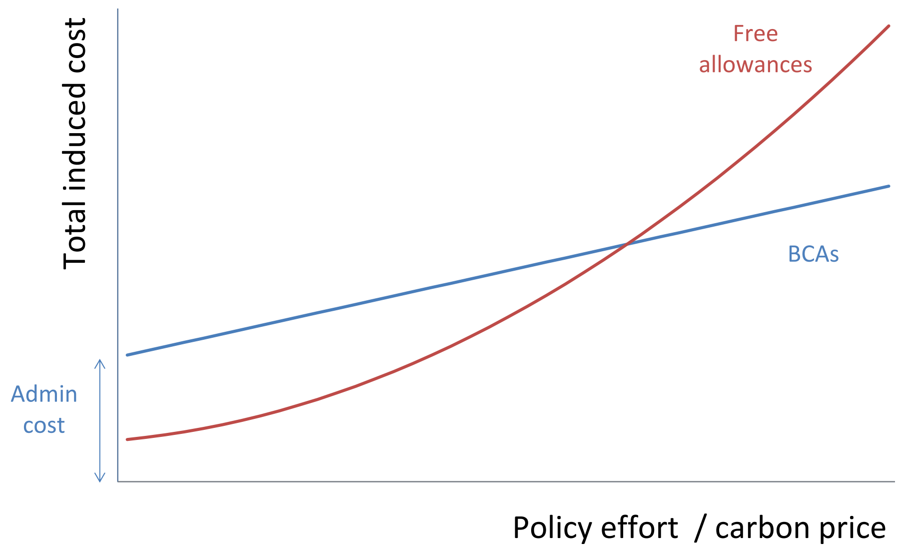
Although the trends described above need not wash away any international or domestic political opposition to BCAs, the relative feasibility of BCAs and free allowances may change over time. However, if China or the US, or both, decided to introduce BCAs themselves, then this option in the EU might become feasible.

When comparing the two prime candidate policy options, free allowances and border carbon adjustments, one can see in Figure 30 that free allowances may have low administrative costs when effort and carbon prices are low, but as effort increases, the cost of free allowances to the exchequer and to sectors experiencing carbon leakage grows. In theory, border carbon adjustments may become the more cost-effective policy but the outstanding question remains their feasibility.

The discussion above raises various points that could be the subject of further discussion, of which two are highlighted here:

- how effective is free allocation in the EU ETS at mitigating carbon leakage?
- how feasible is the introduction of BCAs by Europe or by other major regions?

Figure 30. **As leakage costs rise, at some level of effort BCAs might become the cheapest option**



Source: Vivid Economics

7 Conclusion

In the long-term, pursuit of abatement targets may require innovative policy

Section contents:

Improvements to the current policy framework may provide leakage protection in the medium term

The modelling prepared for this report suggests high rates of carbon leakage, with broad economic implications, but the actual leakage rate is likely to be much lower, drawing upon evidence from the literature and understanding how to interpret the model results. In the medium-term, carbon leakage risk can be mitigated by the current policy framework, through free allowances. The use of energy intensity and trade exposure to identify eligible sectors captures two of the most important aspects but could be refined further.

Long-term emissions mitigation is expected to include substantially higher carbon prices than those currently prevailing in the EU ETS. While it is unlikely that the EU would maintain high domestic carbon prices in the absence of global action, a period where such differentials exist may occur, leading to increased carbon leakage pressure. In these circumstances, the prevention of carbon leakage may warrant more substantial policy reforms, including consideration of alternative leakage mitigation measures, such as border carbon adjustment, though this currently seems politically infeasible.

7.1 The overall risk of leakage under Phase III of the EU ETS

Section 2 of this report investigated the academic and grey literature to assess the evidence for changes in investment patterns or relocation of production from the EU to the rest of the world as a result of the EU ETS. This could potentially lead to an increase in emissions.

This literature is sufficiently well developed to offer a range of estimates of carbon leakage. The studies encompass two broad methodological categories: those using statistical (econometric) methods in an attempt to identify the scale of past changes, and those using theory-based models to explore scenarios of future changes. Some studies attempt to identify how effective unilateral emissions controls such as the EU ETS have been in reducing global emissions, and so concentrate on carbon leakage. Others explore the degree of competitive disadvantage imposed upon firms inside a scheme, and so focus on output leakage. Both environmental and productive impacts are of interest to policymakers.

Although the differences in focus and method generate a range of estimates, there is a strong consensus that carbon leakage is a real effect, that it varies between sectors, and that it increases with carbon prices. However, the evidence from empirical studies concerning carbon leakage in the EU ETS to date is limited; the available data suggest that a small amount of leakage has occurred. Conversely, theoretical estimates suggest that there is a risk of significant adverse impacts on industrial production in at least some energy-intensive sectors in Europe, though note that this requires significantly higher carbon prices than those currently observed in the EU ETS. The provisos to Vivid Economics' own modelling noted below may also apply to many of these theoretical studies.

The simple ratio of the level of costs relative to profits suggests that, in the absence of some form of compensation policy or other mitigating actions, it is possible for even moderate carbon prices of around €15/tCO_2 to have a significant impact on production and profitability in some sectors, even if others are more robust. Higher carbon price differentials without carbon leakage mitigation measures could lead to a loss of industrial output for some sectors and an increasing share of European emissions being embedded in imports: that is, it would encourage the import of goods which we would otherwise produce domestically.

The evidence suggests that the quite wide range of estimates reported by a range of models will not be resolved easily. Nor would it be appropriate to wait in the hope that empirical evidence of sector impacts will emerge before taking policy action. The theoretical work is indicative of significant upper bounds on potential economic consequences at modest carbon price differentials.

7.2 The risk of leakage by sector over a range of carbon prices

While the results presented in this study indicate that carbon prices can impact the production of energy-intensive goods in the UK and more widely in Europe, they are subject to significant provisos, in particular:

- they contain no data on abatement measures which firms might take, meanwhile the sectoral case studies indicate that many sectors will have at least some ability to reduce their carbon intensity;
- they assume no decarbonisation of the UK or EU electricity supply, when substantial decarbonisation is planned;
- they assume no increase in carbon mitigation efforts amongst the EU's major trading partners, even though that is a strong possibility;
- they allow for no compensating policy action by governments, including no free allocations or other forms of compensation for EU ETS costs, whereas in practice some protective measures are currently being taken and are likely to be in the future.

Nonetheless, the modelling results indicate at least the potential for carbon prices to become a factor in the location of investment in sectors that combine high carbon intensity with trade exposure, elastic consumer demand and strong competition. The findings lie at the range of findings from other research, albeit at the higher end of previous estimates. They can be interpreted as upper bound estimates.

It has not been found that there will be tipping points at which carbon leakage suddenly accelerates. The theoretical work suggests that so long as there are a handful of outside firms and strong competition, the rate of output leakage could be high, and if the carbon price and carbon intensity were both high, the economic impacts would be significant. Although the empirical evidence suggests that the response is small, a cautious approach would deal with this uncertainty in the evidence by putting an effective response in place, through: the design of policies to protect exposed sectors; the adoption of abatement measures by firms; international cooperation to increase mitigation effort outside the EU; and, cost-effective power sector decarbonisation.

This is a useful finding, because it is clear from other work, such as that prepared by the Committee on Climate Change, that carbon prices will need to rise in order to stimulate the abatement needed to achieve a low carbon economy and to stabilise the level of greenhouse gases in the atmosphere.

These findings have environmental as well as economic implications. The evidence suggests that it is currently common to find that energy intensive goods imported into Europe have higher embodied carbon than their equivalents produced in Europe. This means that one consequence of carbon prices in Europe, in the absence of mitigation measures, is that the carbon embodied in some energy intensive products would rise as import shares go up: two examples are aluminium and refining.

The sectors most exposed to output and carbon leakage are those where non-EU imported goods have already achieved significant market share, for example, above 15 or 20 per cent. In all the examples where this threshold has been passed, the estimated carbon leakage rate is high. In sectors where the import market share is low, such as malt, milk and distilled air, leakage rates may be low.

Transport costs play a role. In some sectors, cost pass-through rates are high because the cost of transport from outside the EU is high relative to the value of the product. Imports might reach the periphery of the EU but not penetrate its central areas. This can mean that production in some peripheral areas could be at risk of carbon leakage while central areas are not at risk.

Product diversity is also important. Wherever products do not compete with one another, and are not complementary, they constitute a separate market. Thus some markets have to be treated at a disaggregated level in order to obtain an accurate understanding of their carbon leakage response. Furthermore, product differentiation in some sectors is a possible protection against carbon leakage, but in other sectors, where products are highly commoditised and homogenous, this defence is not present and carbon leakage risk is higher. For example, steel comes in a variety of grades, forms and applications whereas cement and lime are much more homogenous. The level of profit margins, taken across an economic cycle, can be an indication of the strength of competition in a sector; and when margins are relatively low and trade is significant, it is an indication of vulnerability to leakage. This is illustrated by the pattern of low margins and closure of capacity in heavy clay ceramics seen during the recession in the UK, followed by increased demand accompanied with increases in imports as the recovery has begun.

The rate at which carbon costs are passed through to customers varies by sector and by firm. There is a wide range of estimated cost pass-through rates in energy intensive sectors, from 11 to over 100 per cent. The theory tells us that cost pass-through is a fairly linear function of the proportion of market-wide production which is covered by the EU ETS. The effect of border carbon adjustments is effectively to bring more firms into the EU ETS, pushing up the cost pass-through rate. Free allowances do not have such a direct effect.

In all cases, vulnerability is driven by the carbon cost which is absorbed after costs are passed through to customers, compared to profitability, since, by this route, investment is affected. Although it would be ambitious to attempt to estimate the impact on investment directly, the estimated changing market shares associated with carbon leakage reflect underlying reallocation of investment flows.

In those sectors where there is output leakage or reduced customer demand, the installations feeling economic stress first are those with higher costs, that is, those which are less competitive. Generally, smaller installations will have higher costs and will be more likely to exit than larger installations This general rule will not apply in every case, because some small installations produce specialist products for niche markets, or benefit from vertical integration in the supply chain which gives them some protection. Reduced activity in one link in the supply chain is likely to affect the value added by other links in the chain, first by increasing costs faced by downstream customers and secondly because of the effect of price increases on final consumption. Thus there will be wider economic impacts of carbon leakage beyond the energy intensive activities examined in this study.

To sum up the various determinants of carbon leakage, consider the factors that would make a highly exposed sector. A highly exposed sector will face aggressive rivals from outside the EU and the carbon costs will represent a substantial share of firm profits. Thus, cost increases cannot be passed on, because of aggressive external competition, and so profits will be significantly eroded, resulting in reduced investment and long-term decline in capacity. Those external rivals will already have costs low enough to allow them to secure a substantial market share in the EU, indicating their capability to take more market share if the opportunity arises. Fortunately for the rivals and unfortunately for the EU firms, the product is homogenous and customers are unable to distinguish between goods made within and outside the EU. To compound the problem in this hypothetical most exposed sector, consumers are price sensitive, making it harder for firms to pass costs through to them. In this case, the output leakage rate is high. If the external firms have higher carbon intensity than the internal firms, the carbon leakage rate will be even higher.

In contrast, consider the factors that would make a sector well protected. A well protected sector will face few rivals from outside the EU and those that it does encounter will have low market shares, reflecting their poor competitiveness in selling to EU consumers. The protected sector will sell little of its output outside the EU and thus overall encounter little extra-EU competition. This hypothetical sector will further benefit from consumers who are quite insensitive to price increases, allowing a greater proportion of costs to be passed through into prices. However, those cost increases will be small because the sector has low carbon intensity. To make the firms' situation even more secure, the product is also bespoke, enabling EU firms to make many varieties and to establish customer loyalty and niches, which diminish the effective strength of competition. In this case, the output leakage rate is low, see Table 8.

As noted, this study has not examined costs of abatement nor factored them into carbon leakage estimates, but the foundations have been laid for those estimates to be prepared. This will make it easier to develop value for money assessments of policy options for mitigating carbon leakage.

Table 8. **Characteristics of sectors with high and low rates of carbon leakage**

Characteristic	Indicative of high carbon leakage	Indicative of low carbon leakage
Non-EU rival behaviour	aggressive	passive
Non-EU rivals	numerous	few
Cost of carbon relative to profits	high	low
Abatement opportunities	low	high
Customers	price sensitive	price insensitive
Goods	homogenous, indistinguishable	differentiated, niches, brand value

Source: Vivid Economics

7.3 Performance of EU sector eligibility criteria

The European scheme criteria cover two important factors, carbon intensity and trade, but omit harder-to-measure influences from price elasticity, the competitive environment and abatement options. Further, the European Commission and European legislation define the carbon cost and trade intensity metrics in a manner which may be sub-optimal, and do not apply it to market scope in sense of economic geography. There is no account given for the thresholds, and particularly no rationale given for eligibility based on trade exposure alone. As a consequence of these limitations, it is likely that too many sectors are currently awarded energy intensive trade exposed status.

The possible improvements in the criteria are:

- remove the trade-only criterion, which would cut the number of eligible sectors without affecting the total amount of carbon leakage. This would dramatically cut the number of eligible sectors without a detrimental increase in the total amount of carbon leakage. It creates no new administrative burden and the rationale is strong and simple;
- use a carbon price which reflects reasonable expectations, or use actual levels and adjust the carbon price regularly. The current high value biases the test and reduces the credibility of the scheme. One solution is to change the criterion into an emissions intensity criterion, as used in the California and Australia schemes;
- apply all criteria to ‘economic’ markets, thereby making the trade criterion much more accurate, but more complex to assess;
- change the trade criterion to a combination of ‘inside market share’ and EU exports. The rationale for the current denominator is unclear and theory tells us that what matters is the proportion of output covered by the EU ETS;
- switch from GVA in the measure of carbon cost intensity to profit or revenue and include data for EU ETS production only. This will exclude wages from the calculation. Wages are not relevant to the competitiveness impact on firms and it would be an administratively straightforward change;
- account for the great variation in indirect (power generation) emissions intensity across Europe, since this means some firms and countries are more exposed to leakage risk than others.

The EU might also continue considering how to estimate the emission intensities of non-EU trade partners.

7.4 Merits and demerits of policy options to mitigate leakage

Several policy measures are available to address the problem that carbon prices increase the costs of production. The first policy type compensates firms for losses. An example is the grant of free allowances. This cannot mitigate carbon leakage directly unless the allocation is output-based, but it may, even so, have an indirect effect. The second type exempts emissions from carbon pricing. Around half of EU carbon dioxide emissions are exempt from the EU ETS. In this case, the EU ETS has neither a carbon leakage nor an environmental effect. The third type extends carbon pricing to all products consumed in Europe and could also introduce effective exemption for exports from Europe. The only example of this type is border carbon adjustment. A fourth type, global harmonised carbon pricing is outside the control of European government.

Of the types available to European government, only a few directly address the competitiveness and therefore output and carbon leakage effects of carbon pricing: updating output-based free allocation, exemption and border carbon adjustment. Only one of them directly addresses competitiveness while remaining environmentally effective: border carbon adjustment, but it is less administratively and politically feasible than free allocation.

Border carbon adjustment is not proven as a feasible option, but if carbon prices increase its appeal may increase and it has the potential to outperform free allocations in terms of carbon leakage mitigation and environmental effectiveness. Although there are models in analogous fiscal instruments, such as Value Added Tax, which offer a template for its introduction (albeit with greater complexity), there are a number of significant difficulties which have yet to be resolved, namely:

- international political opposition of the type seen over the inclusion of aviation in the EU ETS;
- the evasion of carbon prices through carousel trade of goods through high carbon price third countries; and
- administrative cost and complexity.

Considering the potential future importance of carbon leakage, both continued free allocations and border carbon adjustments deserve to receive further effort in their evaluation, design and assessment.

7.5 Closing remarks

In recent years, carbon prices under the EU ETS have been low enough that the effectiveness of free allowance allocations in mitigating carbon leakage has not been a priority policy concern. Looking ahead, the instrument of higher carbon prices might become a mainstay of the policy approach. The economic and environmental risks of carbon leakage with high carbon price differentials are real and policy options to deal with it are imperfect. This constitutes a significant public policy problem.

While understanding of this problem has advanced over the last five or so years, the economic evidence remains incomplete and inconclusive. The empirical estimates of small impacts appear to offer comfort, while theory tells us where the risks might lie and suggests that they may be significant. There are some candidate next steps in policy development.

In the medium term, the cost-effectiveness of the free allowance allocations could be improved by making revisions to the eligibility criteria which the European Commission uses. In the longer term, the problem of carbon leakage may have to be addressed more directly, by solving the problem of differential marginal costs of production rather than relying on compensation through free allowances. It does not appear that free allocations can resolve these differences in production cost while being environmentally effective, because by resolving them through allocation in proportion to output, they reduce the effective carbon price. Border carbon adjustments may be an economically and environmentally effective option, but its political and administrative feasibility is currently poor, or at best uncertain.

References

Abrell, J., Faye, A. N., & Zachmann, G. (2011). Documents de travail. *Bueau d'economique Theorique etAppliquee (BETA)*, *15*.

Abrell, J., Zachmann, G., & Ndoye, A. (2011). Assessing the impact of the EU ETS using firm level data. *Bruegel Working Paper*, *2011/08*.

Aichele, R., & Felbermayr, G. (2010). Kyoto and the carbon content of trade. *CESifo Resource and Environment Economics Series Working Paper*, *3661*.

Aldy, J E, & Pizer, W. A. (2009). The Competitiveness Impacts of Climate Change Mitigation Policies.

Aldy, J. E., & Stavins, R. N. (2012). The Promise and Problems of Pricing Carbon: Theory and Experience. *The Journal of Environment & Development*, *21*(2), 152–180. doi:10.1177/1070496512442508

Allevi, E., Oggioni, G., Riccardi, R., & Rocco, M. (2013). A spatial competitive analysis: the carbon leakage effect on the cement industry under the European Emissions Trading Scheme. *Banca D'Italia Working Paper*.

Anger, N., & Oberndorfer, U. (2008). Firm performance and employment in the EU emissions trading scheme: an empirical assessment for Germany. *Energy Policy*, *36*(1), 12–22.

Anson, J., Cadot, O., Estevadeordal, A., Melo, J. De, Suwa-Eisenmann, A., & Tumurchudur, B. (2005). Rules of Origin in North-South Preferential Trading Arrangements with an Application to NAFTA. *Review of International Economics*, *13*(3), 501–517. doi:10.1111/j.1467-9396.2005.00520.x

Balistreri, E. J., & Rutherford, T. F. (2012). Subglobal carbon policy and the competitive selection of heterogeneous firms. *Energy Economics*, *34 (S2)*, S190–S197.

Barker, T., Junankar, S., Pollitt, H., & Summerton, P. (2007a). Carbon leakage from unilateral Environmental Tax Reforms in Europe, 1995–2005. *Energy Policy*, *35*(12), 6281–6292. doi:10.1016/j.enpol.2007.06.021

Barker, T., Junankar, S., Pollitt, H., & Summerton, P. (2007b). Carbon leakage from unilateral environmental tax reforms in Europe, 1995–2005. *Energy Policy*, *35*(12), 6281–6292. doi:10.1016/j.enpol.2007.06.021

Böhringer, C., Balistreri, E. J., & Rutherford, T. F. (2012). The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29). *Energy Economics*, *34*, S97–S110. doi:10.1016/j.eneco.2012.10.003

Böhringer, C., Carbone, J., & Rutherford, T. (2011, September). Embodied carbon tariffs. *Oldenburg Discussion Papers in Economics*.

Bohringer, C., Carbone, J., & Rutherford, T. F. (2013). The Strategic Value of Embodied Carbon Tariffs.

Bohringer, C., & Rutherford, T. F. (1997). Carbon Taxes with Exemptions in an Open Economy: A General Equilibrium Analysis of the German Tax Initiative. *Journal of Environmental Economics and*

Management, *32*(2), 189–203. Retrieved from http://ideas.repec.org/a/eee/jeeman/v32y1997i2p189-203.html

Burniaux, J., & Martins, J. O. (2000). Carbon emission leakages: a general equilibrium view. *Organisation for Economic Cooperation and Development Economics Department Working Paper*, (242).

Burniaux, J.-M., & Chateau, J. (2008). An Overview of the OECD ENV-Linkages Model.

Cadot, O., Carrere, C., Melo, J. De, & Tumurchudur, B. (2006). Product Specific Rules of Origin in EU and US Preferential Trading Arrangements: An Assessment. *World Trade Review*, *5*(2), 199–224.

Cambridge Econometrics. (2010). *Assessment of the degree of carbon leakage in light of an international agreement on climate change Department of Energy and Climate Change*.

Carbone, J. (2013). Linking Numerical and Analytical Models of Carbon Leakage. *American Economic Review: Papers and Proceedings*, *103*(2).

Caron, J. (2012a). Estimating carbon leakage and the efficiency of border adjustments in general equilibrium - does sectoral aggregation matter? *Centre for Energy Policy and Economics, ETH Zurich*.

Caron, J. (2012b). Estimating Carbon Leakage and the Efficiency of Border Adjustments in General Equilibrium - Does Sectoral Aggregation Matter? *Centre for Energy Policy and Economics, ETH Zurich*.

Chan, H. S., Li, S., & Zhang, F. (2012). Firm competitiveness and the European Union Emissions Trading Scheme. *World Bank Working Paper*.

Cobb, M., Kenber, M., & Haugen, O. (2009). *The effects of EU climate legislation on business competitiveness : a survey and analysis*. *The Climate Group, Climate and Energy Paper Series* (Vol. 9).

Cosbey, A. (2007). Unpacking the wonder tool: border charges in support of climate change. Retrieved from http://www.iisd.org/pdf/2008/unpacking_wonder_tool.pdf

Cummins, M. (2012). EU ETS market interactions: a multiple hypothesis testing approach. *Mimeo, Dublin City University Business School*.

De Bruyn, S., Markowska, A., & Nelissen, D. (2010). Will the energy-intensive industry profit from EU ETS under Phase 3? *CE Delft Report*.

De Bruyn, S., Nelissen, D., & Koopman, M. (2013). *Carbon leakage and the future of the EU ETS market*. Retrieved from http://www.cedelft.eu/art/uploads/CE_Delft_7917_Carbon_leakage_future_EU_ETS_market_Final.pdf

Dechezleprêtre, A., & Calel, R. (2012). Environmental policy and directed technological change: evidence from the European carbon market. *Centre for Economic Performance, Working Paper LSE*, *dp1141*.

Demailly, D., & Quirion, P. (2006a). CO2 abatement, competitiveness and leakage in the European cement industry under the EU ETS: grandfathering versus output-based allocation. *Climate Policy*, *6*(1), 93–113. doi:10.3763/cpol.2006.0606

Demailly, D., & Quirion, P. (2006b). CO2 abatement, competitiveness and leakage in the European cement industry under the EU ETS: grandfathering versus output-based allocation. *Climate Policy*, *6*(1), 93–113. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/14693062.2006.9685590

Demailly, D., & Quirion, P. (2009). Leakage from climate policies and border tax adjustment: lessons from a geographic model of the cement industry. In R. Guesnerie & H. Tulkens (Eds.), *The design of Climate Policy*. Boston: MIT Press.

Droege, S. (2009). Tackling leakage in a world of unequal carbon prices,. *Climate Strategies Working Paper*.

Droge, S., Grubb, M., & Counsell, T. (2009). Tackling carbon leakage Sector-specific solutions for a world of unequal carbon prices. *Carbon Trust Working Paper*.

Ellerman, A. D., Convery, F. J., & Perthuis, C. De. (2010). *Pricing Carbon: The European Union Emissions Trading Scheme*. Cambridge University Press.

European Commission. (2009a). *Impact assessment: Accompanying document to Commission decision determining a list of sectors and subsectors which are deemed to be at significant risk of carbon leakage pursuant to Article 10a (13) of Directive 2003/87/EC*.

European Commission. (2009b). *Impact assessment: Accompanying document to Commission decision determining a list of sectors and subsectors which are deemed to be at significant risk of carbon leakage pursuant to Article 10a (13) of Directive 2003/87/EC*.

European Commission. (2010). *Commission Staff Working Document on Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage*.

European Commission. Commission decision of 27 April 2011 determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council. , Pub. L. No. 2011/278/EU (2011). Official Journal of the European Union L 130/1.

European Commission. (2012). *Guidelines on certain State aid measures in the context of the greenhouse gas emission allowance trading scheme post 2012* (pp. 4–22).

Evans, C. (2003). *Studying the Studies: An overview of recent research into taxation operating costs*. ATAX, University of New South Wales. Retrieved from http://econpapers.repec.org/RePEc:nsw:discus:54

Fischer, C., & Fox, A. K. (2009a). Combining Rebates with Carbon Taxes: Optimal Strategies for Coping with Emissions Leakage and Tax Interactions. *Resources for the Future Discussion Paper 09-12*.

Fischer, C., & Fox, A. K. (2009b). Comparing Policies to Combat Emissions Leakage: Border Tax Adjustments versus Rebates. *Resources for the Future Discussion Paper*, *09-02*(February).

Fischer, Carolyn. (2001). Rebating Environmental Policy Revenues : Output-Based Allocations and Tradable Performance Standards. Washington D.C.

Fowlie, M. (2009). Incomplete Environmental Regulation , Imperfect Competition , and Emissions Leakage. *Mimeo, Ford School of Public Policy and Department of Economics, University of Michigan*.

Gerlagh, R., & Kuik, O. (2007). Carbon leakage with international technology spillovers. *Fondazione Eni Enrico Mattei Note di Lavoro, Nota di Lavoro 33.2007*, (March). Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=979915

Graichen, V., Schumacher, D. K., Healy, S., Hermann, H., Harthan, R., Stork, M., … Lam, L. (2013). *Support to the Commission for the determination of the list of sectors and subsectors deemed to be exposed to a significant risk of carbon leakage for the years 2015-19 (EU Emission Trading System)*.

Graichen, V., Schumacher, K., Matthes, F. C., Mohr, L., Duscha, V., Schleich, J., & Diekmann, J. (2008). *Impacts of the EU Emissions Trading Scheme on the industrial competitiveness in Germany: final draft report prepared under the UFOPLAN*. Berlin.

Hahn, R. W., & Stavins, R. N. (2012). The Effect of Allowance Allocations on Cap-and-Trade System Performance.

Hallegate, S., Hourcade, J.-C., & Dumas, P. (2007). Why economic dynamics matter in assessing climate change damages: illustration on extreme events. *Ecological Economics*, *62*, 330 – 340.

Healy, S., Quirion, P., & Schumacher, K. (2012). Modelling the allowance allocation method of the EU ETS: an application to the cement industry. *Climate Strategies Working Paper*, (05796323).

Helm, D., Hepburn, C., & Ruta, G. (2012). Trade, climate change, and the political game theory of border carbon adjustments. *Oxford Review of Economic Policy*, *28*(2), 368–394. doi:10.1093/oxrep/grs013

Helm, Dieter, Smale, R., & Phillips, J. (2007). Too Good To Be True? The UK's Climate Change Record. *Vivid Economics*.

Ho, M. S., Morgenstern, R., & Shih, J. S. (2008). Impact of Carbon Price Policies on U.S. Industry. *SSRN Electronic Journal*. doi:10.2139/ssrn.1320201

Hoel, M. (1991). Global environmental problems: The effects of unilateral actions taken by one country. *Journal of Environmental Economics and Management*, *20*(1), 55–70. Retrieved from http://ideas.repec.org/a/eee/jeeman/v20y1991i1p55-70.html

Holmes, P., Reilly, T., & Rollo, J. (2010). Border Carbon Adjustments and the Potential for Protectionism. *University of Sussex Economics Department Working Paper Series*.

Holmes, P., Reilly, T., & Rollo, J. (2011). Border carbon adjustments and the potential for protectionism. *Climate Policy*, *11*(2), 883–900.

Hourcade, J.-C., Demailly, D., Neuhoff, K., & Sato, M. (2007). *Differentiation and Dynamics of EU ETS Industrial competitiveness Impact*.

Houser, T., Bradley, R., Childs, B., Werksman, J., & Heilmayr, R. (2008). *Leveling the Carbon Playing Field*. *Environmental Law*.

IEA. (2012). IEA Data Services. Retrieved March 15, 2012, from http://data.iea.org/IEASTORE/DEFAULT.ASP

Kuik, O., & Gerlagh, R. (2003). Trade liberalisation and carbon leakage. *The Energy Journal*, *24*(3).

Kuik, O., & Hofkes, M. (2010a). Border adjustment for European emissions trading: Competitiveness and carbon leakage. *Energy Policy*, *38*(4), 1741–1748. doi:10.1016/j.enpol.2009.11.048

Kuik, O., & Hofkes, M. (2010b). Border adjustment for European emissions trading: Competitiveness and carbon leakage. *Energy Policy*, *38*(4), 1741–1748. doi:10.1016/j.enpol.2009.11.048

Lacombe, R. H. (2008). Economic Impact of the European Union Emission Trading Scheme : Evidence from the Refining Sector. *Thesis for the degree of MTech, Massachussetts Institute of Technology*.

Laing, T., Sato, M., Grubb, M., & Comberti, C. (2013). Assessing the effectiveness of the EU Emissions Trading System. *Centre for Climate Change Economics and Policy, Grantham Research Institute Report*.

Linares, P., & Santamaria, A. (2012). *The effects of carbon prices and anti-leakage policies on selected industrial sectors*.

Markusen, J. R. (1975). International externalities and optimal tax structures. *Journal of International Economics*, *5*(1), 15–29.

Martin, R., Muûls, M., & Wagner, U. (2011). *Climate Change , Investment and Carbon Markets and Prices – Evidence from Manager Interviews Carbon Pricing for Low-Carbon Investment Project*. *Climate Policy Initiative Report*.

Martin, Ralf, Muuls, M., de Preux, L. B., & Wagner, U. J. (2012). Industry Compensation Under Relocation Risk : A Firm-Level Analysis of the EU Emissions Trading Scheme. *Centre for Economic Performance Working Paper*, (1150).

Martin, Ralf, Muûls, M., & Wagner, U. (2011). Climate Change , Investment and Carbon Markets and Prices – Evidence from Manager Interviews Carbon Pricing for Low-Carbon Investment Project. *Climate Policy Initiative Report*, (January).

Martin, Ralf, Muûls, M., & Wagner, U. (2012). An evidence review of the EU Emissions Trading System , focussing on effectiveness of the system in driving industrial abatement. *Department of Energy and Climate Change Report*, 1–70.

Matthes, F. (2008). *What role for benchmarking and alternatives to auctioning?*

Mattoo, A., Subramanian, A., van der Mensbrugghe, D., & He, J. (2009). Reconciling Climate Change and Trade Policy. *The World Bank Policy Research Working Paper*, *5123*.

McKibbin, W. J., & Wilcoxen, P. J. (2009). The Economic and Environmental Effects of Border Tax Adjustments for Climate Policy. In I. Sorkin & L. Brainard (Eds.), *Climate Change, Trade, and Competitiveness: Is a Collision Inevitable?* Brookings Institution Press.

McKinsey&Company, & Ecofys. (2006). *EU ETS REVIEW Report on International Competitiveness*.

Metcalf, G. E., & Weisbach, D. (2010). Linking Policies When Tastes Differ: Global Climate Policy in a Heterogeneous World, (July).

Monjon, Stephanie, & Quirion, P. (2011). Addressing leakage in the EU ETS: border adjustment or output-based allocation? *Ecological Economics*, *70*(11), 1957–1971.

Monjon, Stéphanie, & Quirion, P. (2010). How to design a border adjustment for the European Union Emissions Trading System? *Energy Policy*, *38*(9), 5199–5207.

Monjon, Stéphanie, Quirion, P. (2009). Addresing leakage in the EU ETS: results from the CASE II model. *Climate Strategies Working Paper*, *3*.

National Audit Office. (2007). *The Climate Change Levy and Climate Change Agreements*.

Neuhoff, K. (2008). *Tackling Carbon - How to price Carbon for climate policy*.

OECD. (2013). *Taxing energy use: a graphical analysis* (Vol. January).

Pollitt, H., Summerton, P., & Thoung, C. (2012). *Modelling the impact of policy interventions on carbon leakage*.

Ponssard, J. P., & Walker, N. (2008). EU Emissions Trading and the Cement Sector: a Spatial Competition Analysis. *Climate Policy*, *5*, 467–493.

Productivity Commission. (2011). *Emissions reductions policies in key economies*.

Quirion, P., & Demailly, D. (2008a). Changing the allocation rules in the EU ETS: impact on competitiveness and economic efficiency. *Fondazione Eni Enrico Mattei Nota di Lavoro, No. 89*.

Quirion, P., & Demailly, D. (2008b). European Emission Trading Scheme and competitiveness: a case study on the iron and steel industry. *Energy Policy*, *30*(4), 2009–2027.

Reinaud, J. (2008). Issues behind Competitiveness and Carbon Leakage: Focus on Heavy Industry. *International Energy Agency Information Paper*, (October).

Ritz, R. A. (2009). Carbon leakage under incomplete environmental regulation : An industry-level approach. *University of Oxford, Department of Economics, Discussion Paper Series*, (461).

Sartor, O. (2012). Carbon leakage in the primary aluminium sector: what evidence after 6 ½ years of the EU ETS? *CDC Climate Research Working Paper 2012-12.*

Sartor, Oliver. (2013). An Empirical Assessment of the Risk of Carbon Leakage in Poland, (June).

Sijm, J., Chen, Y., & Hobbs, B. F. (2009). The impact of power market structure on the pass-through of CO 2 emissions trading costs to electricity prices – A theoretical approach. *EARE Working Paper*.

Smale, R., Hartley, M., Hepburn, C., Ward, J., & Grubb, M. (2006). The impact of CO_2 emissions trading on firm profits and market prices. *Climate Policy*, *6*, 29–48.

Szabó, L., Hidalgo, I., Ciscar, J. C., & Soria, A. (2006). CO_2 emission trading within the European Union and Annex B countries: the cement industry case. *Energy Policy*, *34*(1), 72–87. doi:10.1016/j.enpol.2004.06.003

Takeda, S., Arimura, T. H., Tamechika, H., Fischer, C., & Fox, A. K. (2011). Output-Based Allocation of Emissions Permits for Mitigating the Leakage and Competitiveness Issues for the Japanese Economy.

Taylor, P., Juergens, I., Barreiro-hurlé, J., & Vasa, A. (2013). Identifying carbon leakage sectors in the EU ETS and implications of results. *Climate Policy*, *13*(1), 89–109.

The Boston Consulting Group. (2008). *Assessment of impact of 2013-2020 ETS Proposal on the European Cement Industry Methodology and assumptions*.

U.S. Congress. The American Clean Energy and Security Act of 2009 (H.R. 2454) (2009). Washington D.C.: US House of Representative.

Varma, A., Milnes, R., Miller, K., Williams, E., de Bruyn, S., & Brinke, L. (2012). Cumulative impacts of energy and climate change policies on carbon leakage. *CE- Delft Report*, (February).

Vivid Economics. (2011). *Approaches to quantifying the cost of low-carbon policies*.

Vivid Economics. (2012). Carbon taxation and fiscal consolidation: The potential of carbon pricing to reduce Europe's fiscal deficits. Report prepared for the European Climate Foundation and Green Budget Europe.

Wooders, P., Cosbey, A., & Stephenson, J. (2009). *Border carbon adjustment and free allowances: responding to competitiveness and leakage concerns* (Vol. 33).

Zhong, Z. (2012). Competitiveness and Leakage Concerns and Border Carbon Adjustments.

Appendix A The economics of the industrial market models

The IMMs depend on economic theory concerning optimising behaviour

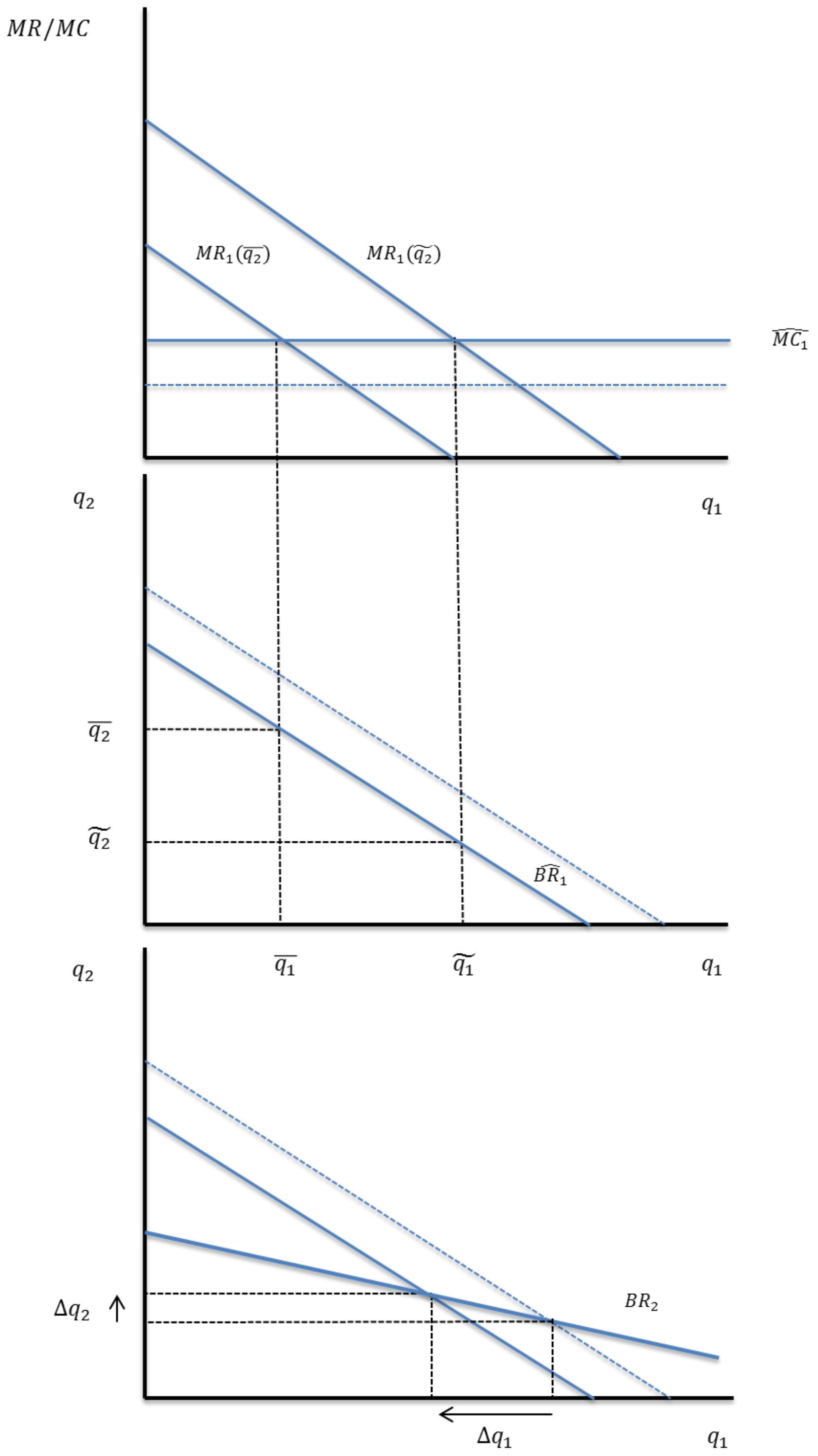
Underling the industrial market models are various assumptions regarding optimising firm behaviour, largely based around Cournot competition. Some insight can thus be obtained by considering a simplified two-firm, pure Cournot model, where the analysis would proceed as follows:

- a best response curve for each firm is derived as the intersection of the firm's marginal revenue and marginal cost curves at different levels of production for their opponent;
- the initial equilibrium is defined by the intersection of the firms' best response curves;
- the marginal cost of one of the firms is increased. This results in an inward shift of their best response curve;
- a new equilibrium is derived. Production in the new equilibrium is higher for the firm whose marginal cost remains unchanged and lower for the firm whose marginal cost has increased.

This process is depicted in Figure 31. The first chart shows how optimal production levels (q_1) for Firm 1 changes as Firm 2 varies its production quantity (q_2). This allows the derivation of the best response curve shown in the second chart. The first and second charts also show how Firm 1's best response curve shifts in response to a change in marginal costs.

The third chart then depicts both the best response curve of Firm 1, and the best response curve of Firm 2. Where these curves intersect, that is, where each firm's output is the best response to the other firm's output, defines an equilibrium. When Firm 1's best response curve moves inwards in response to a change in production costs, q_1 falls and q_2 rises.

Figure 31. **An asymmetric cost increase in a two-firm Cournot model**



Source: Vivid Economics

Analysis under the FIMM approach proceeds in a broadly analogous manner, but with several additions:

– integrates a broad array of competitive strategies beyond Cournot (quantity) competition, including price competition;

- extends the analysis to a large number of firms;
- models each firm as having a unique cost function; and
- includes market exit, removing firms that are unable to earn positive margins in the new equilibrium.

However, the equilibrium can still be understood as determined by the intersection of each firm's best response curve. The model constructs the best response curve for each firm using sector and firm specific data on market demand, average cost and market shares. The response curves of all firms are then perturbed to reflect the change in cost resulting from carbon prices. This allows the new equilibrium to be derived. Finally, the new and old equilibria are compared to determine the effect of policy.

As further explication of the industrial market modelling approach, Table 9 provides an indication of some of the calculations that can be performed when conducting RIMM analysis.

Table 9. **Indicative selection of calculations that can be performed as part of RIMM analysis**

Metrics of interest	Value	Relevant calculations
Increase in electricity price due to CfD support costs	*a* £/MWh	
Sectoral electricity intensity of production	*b* MWh/t	
Increase in production cost	*c* £/t	$a\ £/\mathrm{t} * b\,\mathrm{MWh/t} = c\ £/\mathrm{t}$
Total sectoral production in UK	*d* tonnes	
Apparent cost to the industry	£ *e*	$c\ £/t * d\ \mathrm{t} = £\ e$
Margin for UK firms	*f* %	
Cost pass-through rate	*g* %	Derived from Cournot model based on: – number of firms supplying market; – number of firms affected by cost increase; – market share of firms affected by cost increase; and – price elasticity of demand.
Industry output following cost increase	*h* tonnes	Derived from Cournot model based on the factors driving cost pass-through plus: - cost increase; and - average profit margin in sector for UK firms.
Reduction in size of UK sector	*i* %	The reduction in size of industry is: $h\ \mathrm{t}\ /\ d\ \mathrm{t} = i\ \%$
Costs absorbed by firms	£ *j*	$(100\% - g\%) * c\,£/\mathrm{t} * h\ \mathrm{t} = £\,j$
Loss of profit to UK industry	£ *o*	Pre-CfD price was £k/ t, unit cost was £l/t. Former profits were: $(k\,£/\mathrm{t} - l\ £/t) * d\ \mathrm{t} = £\,m$ New profit is: $(k\ £/\mathrm{t} * g\ \% - l\ £/\mathrm{t} - c\ £/\mathrm{t}) * h\ \mathrm{t} = £\ n$ Lost profits are: $£\,m - £\,n = £\ o$
Costs absorbed by customers	£ *p*	$g\ \% * c\ £/\mathrm{t} * h\ \mathrm{t}\ = £\ p$
Change in consumer surplus	£ *q*	Deadweight loss triangle: $0.5.\,dP.\,dQ\ = £\ q$

Source: Vivid Economics

Appendix B Macroeconomic growth rates

Table 10. **Growth rates**

Sector	UK production			Imports		
	2012 - 2016	2016 - 2020	2020 - 2030	2012 - 2016	2016 - 2020	2020 - 2030
7 Other mining	2.1%	0.2%	-0.2%	0.1%	2.2%	2.5%
8 Mining support service	-0.2%	-1.7%	-1.8%	5.7%	-0.4%	-0.4%
9 Food products	0.0%	0.5%	0.5%	-1.4%	1.3%	1.5%
10 Beverages	1.8%	0.1%	0.2%	-1.7%	4.0%	4.1%
11 Tobacco	-1.3%	0.0%	0.1%	1.3%	3.5%	3.3%
12 Textiles	-3.8%	-2.6%	-2.7%	3.8%	6.4%	6.0%
13 Wearing apparel	-1.4%	-2.6%	-2.5%	0.7%	4.3%	5.3%
14 Leather, etc	-1.9%	-2.5%	-2.3%	2.3%	3.7%	4.0%
15 Wood, etc	-4.7%	-2.1%	-2.0%	3.6%	4.6%	3.5%
16 Paper, etc	-1.9%	-1.2%	-1.1%	1.4%	3.1%	1.7%
17 Printing & recording	-2.2%	-0.3%	-0.4%	0.6%	5.6%	5.4%
18 Coke & petroleum	0.4%	0.5%	0.6%	1.7%	2.0%	1.6%
19 Chemicals, etc	1.4%	2.9%	2.8%	1.3%	0.7%	0.5%
20 Pharmaceuticals	-0.7%	1.8%	1.6%	2.3%	2.7%	2.8%
21 Rubber & plastic	-1.2%	-1.6%	-1.4%	3.6%	1.5%	1.1%
22 Other non-metallic	-1.8%	-0.2%	-0.1%	3.7%	2.2%	1.5%
23 Basic metals	-1.9%	0.0%	-0.4%	5.1%	2.9%	2.9%
24 Metal products	0.4%	0.8%	0.2%	0.3%	1.6%	2.6%
25 Computers, etc	0.1%	2.8%	0.9%	1.8%	2.6%	2.0%
26 Electrical equipment	1.0%	1.2%	0.5%	1.3%	0.3%	1.0%
27 Machinery, etc	1.4%	1.8%	1.3%	0.9%	2.2%	0.9%
28 Motor vehicles, etc	2.7%	2.0%	3.0%	6.0%	3.1%	1.3%
29 Other trans. Equip	1.8%	0.8%	-0.1%	0.4%	3.8%	4.5%
30 Furniture	-0.7%	2.5%	1.7%	2.7%	2.2%	2.4%
31 Other manufacturing	-1.1%	0.5%	0.2%	-0.3%	1.9%	2.0%

Source: Cambridge Econometrics

:vividеconomics

Contact us:
The Media Village
131 - 151 Great Titchfield St
London W1W 5BB
T: +44 (0)844 8000 254
E: enquiries@vivideconomics.com

Company Profile

Vivid Economics is a leading strategic economics consultancy with global reach. We strive to create lasting value for our clients, both in government and the private sector, and for society at large.

We are a premier consultant in the policy-commerce interface and resource- and environment-intensive sectors, where we advise on the most critical and complex policy and commercial questions facing clients around the world. The success we bring to our clients reflects a strong partnership culture, solid foundation of skills and analytical assets, and close cooperation with a large network of contacts across key organisations.