AN EVIDENCE REVIEW OF THE EU EMISSIONS TRADING SYSTEM, FOCUSSING ON EFFECTIVENESS OF THE SYSTEM IN DRIVING INDUSTRIAL ABATEMENT

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The views expressed in this report are those of the authors, not necessarily those of the Department for Energy and Climate Change, nor do they reflect government policy.

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Executive Summary

This report summarises the literature on ex-post evaluation of the effectiveness of the European Union Emissions Trading System (EU ETS) in driving abatement of greenhouse gases by industrial firms.

A thorough search through the entire literature on the EU ETS was conducted by using online search engines, targeted emails and specific website searches. A list of 25 terms was defined in English and subsequently translated into French, German and Spanish. After applying specific inclusion and quality criteria, 56 papers were retained as the body of evidence for this review. Most of them were academic papers, both published and unpublished. The two principal criteria for inclusion in this report were that the research (i) was based on data or other evidence and (ii) that it focused on the industrial sector. The selection according to the inclusion and quality criteria revealed that the pertinent evidence was relatively scant. The identification of causality remained very basic except for a half-dozen more rigorous studies, which were still unpublished. A very small number of studies analysed the elements of the EU ETS that were driving abatement.

Research Questions

The available studies provided answers to the following three principal research questions as summarised below.

1. Has the EU ETS driven industrial abatement?

Given the main policy objective of the EU ETS to achieve emission reductions, it is crucial to understand whether the first two trading phases have encouraged participating installations to abate their carbon emissions. In addition, a number of other outcomes could be affected by the ETS and have implications for its effectiveness, such as innovation, economic performance (defined broadly to include competitiveness) and abatement outside the EU, promoted through the flexible mechanisms established under the Kyoto Protocol. The review comprises evidence on all four outcomes.

A. <u>Emissions</u>

While the EU ETS may have led to abatement in the power sector, the evidence on the impact of the EU ETS on participating industrial firms' GHG emissions is not conclusive. Several studies found that, in the aggregate, emissions across all regulated sectors declined by around 3% in Phase I and during the first two years of Phase II, relative to estimated business-as-usual emissions. However, with the exception of Germany, it was not clear how much the industrial sector contributed to this aggregate figure. What is more, these studies relied on aggregate estimates of what emissions would have been had the EU ETS not been in place. The high level of aggregation precluded breaking down the total effect into emission reductions attributable to individual sectors.

In an effort to improve the precision of the impact estimate, a recent analysis of firm-level data revealed that the transition from Phase I to Phase II triggered emission reductions in a few industrial sectors and that the firm-level allocation of permits influenced this effect. The robustness of these results will have to be confirmed in future studies with a more comprehensive coverage of sectors and countries.

B. Economic performance

There was no conclusive evidence about whether the effectiveness of the EU ETS could be jeopardized by adverse impacts on the economic performance of the regulated firms. Some studies found negative effects on employment, profits, or productivity, but these findings were not confirmed in other studies that relied on different statistical models. One study found evidence that the EU ETS increased profits as firms priced in the opportunity costs of permits they had obtained for free. Furthermore, there was no compelling evidence that the EU ETS adversely affected the competitiveness of regulated firms. Some studies tested whether the introduction of the EU ETS weakened net exports of goods into non-regulated countries, with ambiguous findings. There was fairly robust evidence based on price data that a number of sectors were able to pass through the costs of emission permits on to final product markets. However, there was no evidence on whether the EU ETS reduced market shares or changed the composition of supply of regulated firms. Survey evidence showed that EU ETS firms reported a higher propensity to downsize their operations in response to future carbon pricing than non-ETS firms, although this effect was not large.

C. Innovation

For the EU ETS to be effective in the long term, it must induce a shift towards low-carbon technologies, some of which have yet to be invented and commercialized. The literature reviewed contained no strong evidence that the EU ETS in Phases I and II had a causal impact on (new-to-the-market) innovations by directly regulated firms. While clean patent applications increased rapidly from 2005 onwards, the evidence so far cannot rule out that this was due to confounding factors such as concurrent increases in the oil price or the implementation of other climate change policies. Other evidence based on the impact of the post 2012 allocation rules suggested that the less generous allocation rules in Phase III might drive clean innovation.

The evidence of a positive impact is somewhat more favourable when it comes to technology adoption. However, the existing studies are narrowly focused on a limited set of sectors and countries, and they often lack academic rigour as far as the causal identification strategies are concerned.

D. Abatement through the Clean Development Mechanism (CDM)

The available evidence on emissions reductions via the CDM was entirely descriptive. The most successful CDM projects were implemented in Asia and reduced emissions of greenhouse gases other than carbon dioxide. Although CDM credits traded consistently at prices below the EU Emissions Allowance (EUA) price, their use only amounted to one third of the legal limit, and less than one twentieth of total permit allocations. CDMs transferred a small piece of the European carbon pie to developing countries, but the available estimates of how much exactly are not certain. There were no estimates of how much the CDM as a whole lowered the EUA price.

2. Which elements of the EU ETS drive abatement?

Despite being of prime interest for policy design, the evidence on the drivers of abatement was scarce and anecdotal, based on surveys of a small number of participating firms. It was therefore not possible to determine how different aspects of the policy – such as the carbon price, the allocation rules or the signalling effect – differentially impacted on the abatement choices of industrial firms.

3. How does the EU ETS interact with other policies designed to achieve abatement, at the UK, EU and international levels?

The EU ETS overlaps with a range of different policies, both across countries and across policy domains. While it is important to gain a better understanding of the implications of interactions with these policies for the further development of the EU ETS and climate policy more broadly, this report did not find any ex-post analysis of such interactions.

Gap Analysis

In addition to addressing these three research questions, this evidence review also identifies gaps in the literature and some directions for future research.

Since the EU ETS was not designed with evaluation built in, e.g. as a randomized experiment, an ex-post evaluation of the EU ETS must employ on non-experimental techniques. It has become clear in the review that such techniques have not been used to their full potential in the literature so far. Robust inference on the causal impact of the EU ETS on abatement, innovation and economic performance necessitates better data. Future research must thus rely on large, high-quality datasets maintained by national governments, which have not been used thus far to evaluate the EU ETS. Furthermore, the scope of ex-post analysis will need to be broadened. In particular, there is very scant evidence on the role of the CDM in abatement, on the interaction with national policies, and on the mechanisms that drive the observed impacts. A promising way to shed light on this is to collect data in representative large-scale surveys among the affected firms, and jointly analyse these data with high-quality performance data on emissions and performance. Such data are maintained by many governments and an increasing number of them now grant access to them if the confidentiality is secured.

Introduction

The European Union has been a central player in the global effort to curb greenhouse gas (GHG) emissions and mitigate climate change. In 2005, the EU launched the Emissions Trading System (EU ETS), the first international carbon-trading scheme in the world. Following a three-year pilot period, Phase II of the EU ETS was launched in 2008. Across its 27 Member States (MS), the EU ETS covers large plants from CO_2-emission intensive industrial sectors, namely power generation, mineral oil refineries, coke ovens, iron and steel and factories producing cement, glass, lime, brick, ceramics, pulp and paper, and all combustion activities with a rated thermal input exceeding above 20MWh. During the first two years, this scheme included approximately 10,600 industrial installations from 25 MS. Bulgaria and Romania joined the trading scheme in 2007, bringing the total number of installations to 11,300.

The EU ETS is a compliance market and requires that each installation surrenders each year a number of allowances equal to its verified emissions. During the first two phases, each MS allocates in its National Allocation Plan (NAP) a certain number of allowances to each installation. A few MS auctioned a small proportion of total allowances. To balance allocated allowances and actual emissions, regulated companies can trade on the allowance market with other EU ETS companies from any MS as well as with third parties (e.g. brokers), so as to minimise their compliance cost. The common allowance market establishes a uniform carbon price, inducing all regulated facilities to reduce carbon emissions at minimal cost to the system as a whole. While the carbon price does not vary between regulated firms, it is likely that firms react very differently to the same carbon price depending on their carbon intensity, their abatement potential and cost, or on the amount of international competition they are facing, among other things.

The importance of the EU ETS was reinforced in 2007 when the EU Council announced its commitment to abate GHG emissions by 20 percent by 2020 (the so-called 20-20 objective). Ambitious and well-designed climate and energy policies are needed to reach this goal and to persuade Europe's international partners to follow its commitment. While the EU ETS is a prime candidate for such a policy, a fundamental concern of policymakers pondering the implementation of binding GHG emissions targets has been with their potential negative impacts on the competitiveness of domestic businesses and domestic employment. When assessing such concerns, governments are faced with a fundamental information asymmetry, in that the regulated firms know best how costly it is for them to meet certain pollution targets but they have no incentive to reveal this to the regulator. This explains the need for an independent evaluation of the competitiveness impacts of the EU ETS.

The EU ETS is designed as a dynamic policy that has improved over time. Given its pioneering role it was clear from the outset that there would be a constant learning process that would require changes to its design. This was taken into account by defining trading phases allowing regular opportunities to improve the effectiveness of the system. The next trading phase will start in 2013. Most of the structure of the ensuing period through to 2020 has already been agreed. However, there are important elements left open. For example, there is still debate about the overall reduction target (20 vs. 30%). Further, changes to the methodology for the allocation of free permits would be considered, in particular if a 30% target was adopted. This permit allocation process will be reviewed well ahead of 2020. Any such design changes ought to be based on sound empirical evidence.

This report summarizes the existing evidence base on the actual effectiveness and functioning of the EU ETS, with the goal of aiding policy design now and in the future. The review was commissioned by DECC to help inform the understanding about the achievements and contribution of the system to DECC objectives, and inform any re-negotiation of the system, specifically with respect to the review points for Phase III and with respect to the design and implementation of Phase IV.

This report focuses exclusively on the effects of the EU ETS on the industrial sector, meaning that the power sector is not considered here. This reflects the reality that the regulatory challenges for the power sector are intrinsically different from those relevant for the industrial sector, and hence need to be dealt with separately. In the UK, the Electricity Market Reform has been implemented specifically to achieve a decarbonisation of the power sector at the speed and scale required to honour the country's commitments for climate change mitigation.

Based on the existing evidence, three research questions are addressed:

- How effective is the EU ETS in driving industrial abatement in the UK and more widely?

  The report reviews how emission reductions due to the EU ETS have been estimated in the literature. Moreover, we summarize and critically evaluate the evidence on a number of other outcomes that could be affected by the EU ETS and that have implications for its effectiveness. These outcomes include innovation – which is relevant for the dynamic effectiveness of the policy – and economic performance, defined in a broad way that includes competitiveness. Finally, we collect the evidence on whether the EU ETS drives emission reductions and transfer of funds in developing countries through the Kyoto flexibility mechanisms like the Clean Development Mechanism (CDM) and Joint Implementation (JI).

- Which elements of the EU ETS drive abatement?

  This question deals with the channels through which the EU ETS has been driving (or not) emission reductions and investment into abatement technologies.

- How does the EU ETS interact with other policies designed to achieve abatement?

  While the EU ETS is the flagship EU policy to achieve emission reductions, other policies are in place at the national, regional and international levels. For example, such overlapping policies include domestic carbon taxes, European investment tax credits, or the flexibility mechanisms stipulated under the Kyoto Protocol. We review the evidence on the use and interaction of these policies with the EU ETS.

This report addresses these three questions by critically reviewing the existing empirical evidence on the causal impacts of the EU ETS on various outcomes. The review focused in particular on the robustness and quality of different approaches to empirically establish a counterfactual. An ex-post assessment of the impact of a policy on an outcome critically relies on two ingredients: First, data on the outcome of interest needs to be collected before and after the policy is implemented. Second, one must adopt a methodology to determine what the outcome would have been had the policy not been implemented. This is commonly referred to as a counterfactual or Business-As-Usual (BAU) scenario. If this counterfactual is well measured, then comparing actual outcomes with counterfactual ones provides a causal impact of the policy.

The report is organised as follows. The next section explains in detail how relevant papers were selected from the universe of all studies on the EU ETS. Section 3 reports statistical data on this selection process, such as the distribution of the type of outcomes studied by the different papers. Section 4 contains a detailed discussion of how and to what extent the papers included in the review contribute answers the three research questions described above. Within each subsection, studies with higher quality approaches to establish causality have been given most weight. Compared to the ex-ante impact literature, the ex-post literature is rather small. With the EU ETS being in place now for a number of years, and given improvements in data access, there is a vast potential to improve the current literature. Section 5 highlights the gaps in the current literature, identifying where the evidence base is weak or non-existent. It also outlines how these gaps might be filled using appropriate methodologies and data sources.

Methodology

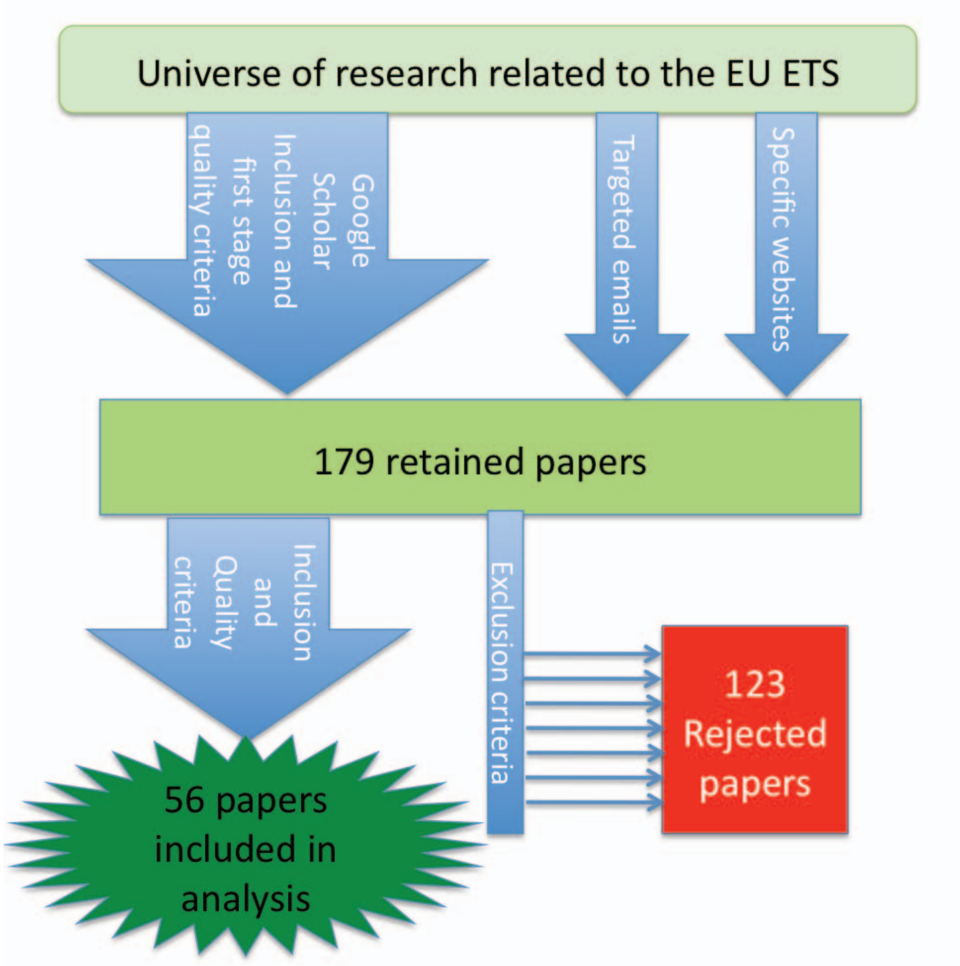
Summary:

A thorough search through the entire literature on the EU ETS was conducted by using online search engines, targeted emails and specific website searches. A list of 25 terms was defined in English and subsequently translated into French, German and Spanish. After applying specific inclusion and quality criteria, 56 papers were retained as the body of evidence for this review. Most of them were academic papers; both published and unpublished. The two principal criteria for inclusion in this report were that the research (i) was based on data or other evidence and (ii) that it focused on the industrial sector.

As depicted in Figure 1, the relevant evidence base was identified in two steps. The first step consisted of a systematic search of the academic literature relating to the effectiveness of the EU ETS. A thorough search was performed using Google Scholar, browsing the websites of specific research institutes and contacting by email 80 experts on the EU ETS in government, industry and academia, using pre-defined search criteria.

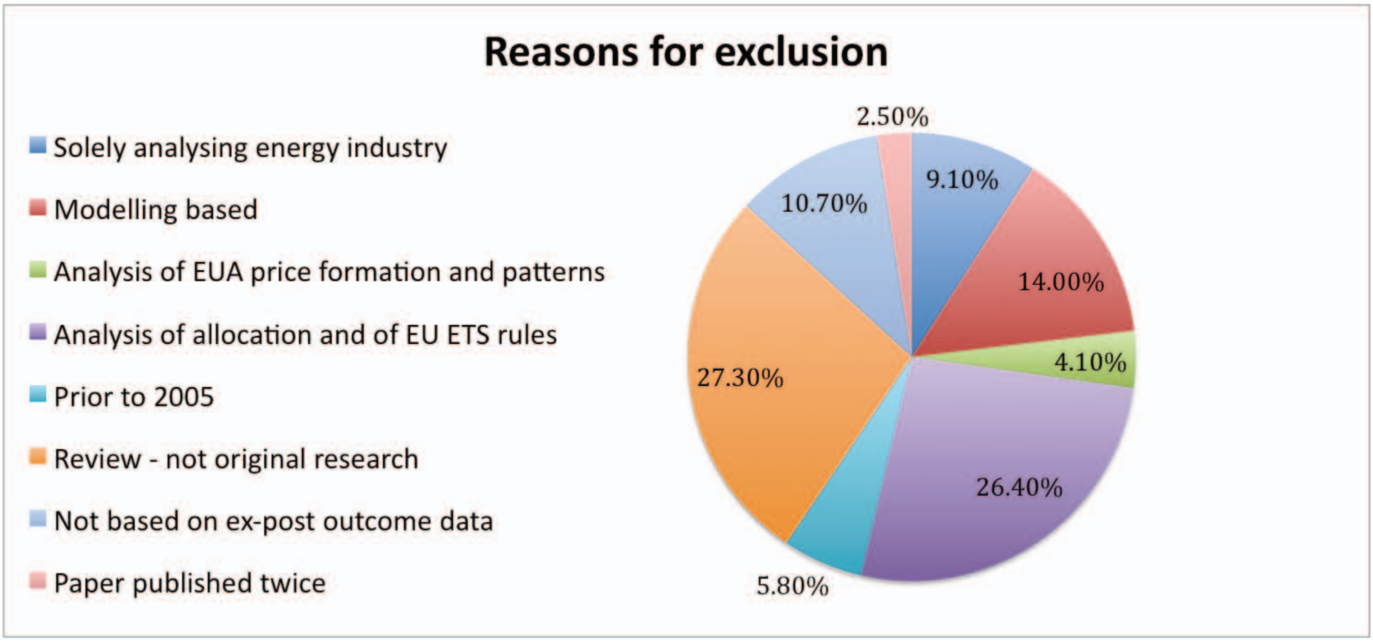
A list of 25 search terms was established ("EU ETS evaluation", "EU ETS efficiency", etc.) to be included in the Google Scholar search. Precise inclusion and quality criteria were applied to these searches to ensure that relevant material was collected for the analysis. For example, the research papers needed to be based on data analysis and focus on the industrial sector. This was essential to base this review on scientifically sound evidence. The details of the search, inclusion and quality criteria are described in the appendix. At this first stage, inclusion decisions were based on the abstract or summary of the papers found online.

Figure 1: Search and Inclusion Process



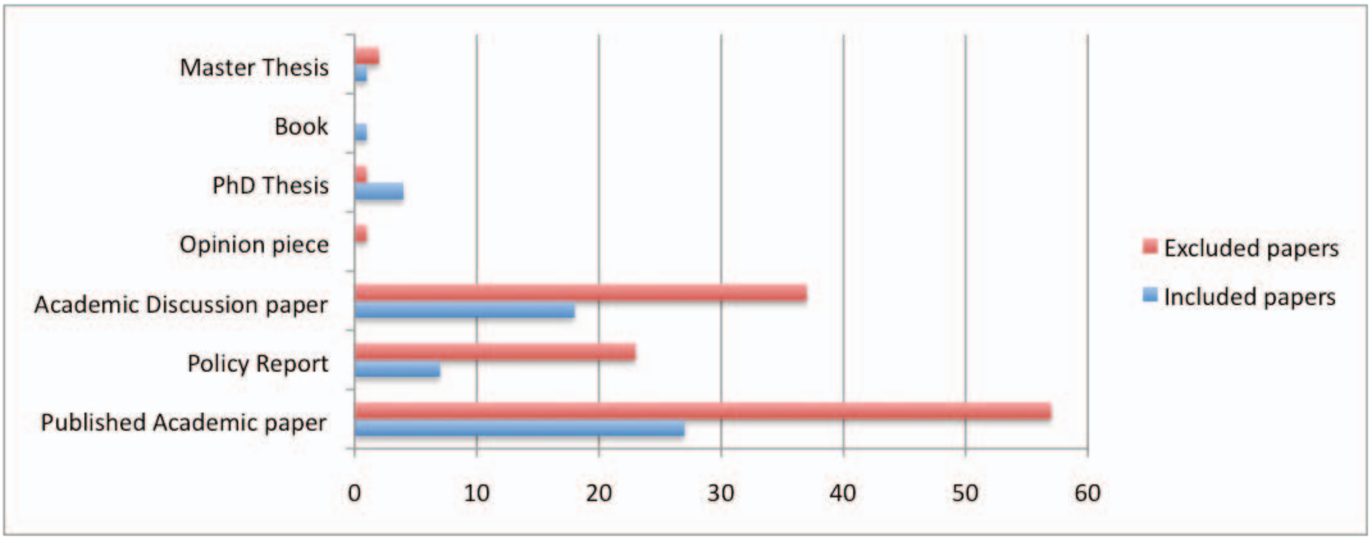
At the second stage, a more detailed and careful reading of the 179 papers and applying inclusion/exclusion and quality criteria identical to the first stage led to exclude 67% of them, as shown in Figure 2. The main reason at this stage for excluding papers was that they did not constitute original research. Another important exclusion category was formed by papers giving a description of the EU ETS rules and of the National Allocation Plans patterns, but not based on ex-post data or with no analysis at all. Research that has been often cited in this context, but was excluded from the analysis is described in Box 1. Another rapidly growing area of research linked to the EU ETS analyses the variation of the EUA price and its determination using financial market analysis techniques (see chapter 5 of Ellerman et al., 2010). However, no piece of research links the price analysis to the behaviour of industrial emitters and to their decisions in terms of investment, emissions or economic performance. This area of research was thus not included in the analysis.

Figure 2: Exclusion criteria results



The resulting body of evidence, composed by the 56 retained papers consisted mainly of published academic work. There was also a large number of unpublished research papers retained, as shown in Figure 3, illustrating the fact that this area of research is still dynamically evolving.

Figure 3: Type of Publications Included and Excluded



Box 1: Excluded papers that are widely cited

Several papers are often cited as evidence on the impact of the EU ETS but were not included in this report. This box presents three categories of such papers.

A series of papers use a modelling approach to analyse the impact on competitiveness of the EU ETS. For example, Demailly and Quirion (2006) studied the cement sector. Based on a combination of a trade model and a bottom-up model of the cement industry, they simulated the different impacts of the EU ETS under two potential allocation methods: grandfathering on the one hand, and output-based allocation on the other hand. The paper was excluded because the analysis was model based and did not use any ex-post data. In a second paper, Demailly and Quirion (2008) analysed the impact on competitiveness of the EU ETS in the iron and steel sector. Although this paper has been widely cited as showing only small competitiveness losses, it was excluded from this report because it was also based on a modelling exercise only, and not on an ex-post data analysis. The impact of the EU ETS was measured by replacing each parameter in the authors' model by estimated values taken from the rest of the economic literature.

A second group of papers that are not included in this report are those that compare allocations and verified emissions without attempting to estimate the counterfactual/BAU level of emissions that would have occurred in absence of the ETS. For example, Clo (2009), Kettner et al. (2008 and 2011b) and others showed that over-allocation occurred in the first phase of the EU ETS. There was great dispersion between countries as well as at the regional level (Robaina-Alves et al., 2011). At the sector level, there was also a great degree of variation between companies' net allocations (see for example Graichen and Graichen, 2007). Electricity production was in a net short position over Phase I while the other sectors were long (Trotignon and Delbosc, 2008). Kettner et al. (2008) compares in that dimension larger and smaller firms with the former displaying less dispersion in excess allocations. Considering Phase II, Sandbag (2011, 2012) calculated that there was overall under-allocation in 2008, but due to increased permit auctioning and the economic downturn, the system was again in a long position in 2009 and 2010. Ellerman and Buchner (2008) and Anderson and DiMaria (2011) are among several papers that were included in the analysis because they do not *only* analyse over-allocation patterns but also attempt to estimate emission reductions.

Third, a large number of studies on the impact of the EU ETS did not fall in the target category as they assessed the impact entirely based on ad hoc assumptions. For instance, the impact assessments of the EU Commission along with a larger number of similar studies (Smale et al, 2006; Grubb and Neuhoff, 2006; Hourcade et al., 2007; Sato et al., 2007 among others) assessed the impact on competitiveness not by looking at productivity, profits or other outcomes of regulated firms. Rather, it is simply assumed that sectors with high trade intensity and/or carbon intensity would experience substantial negative effects on their competitiveness. Such studies are certainly useful ex-ante when no direct outcome data is available. However, given the focus of this review on ex-post evidence, we excluded such studies.

Literature Overview

Summary:

The selection according to the inclusion and quality criteria revealed that the pertinent evidence was relatively scant. The identification of causality remained very basic except for a half-dozen more rigorous studies, which were still unpublished. A very small number of studies analysed the elements of the EU ETS that were driving abatement, e.g. carbon prices, permit allocation and signalling effects.

The 56 retained papers could be classified according to the different categories presented in Table 1. Specifically results were grouped by different outcome categories, by which type of policy aspect of the EU ETS they captured, to which sub-sample they might apply (e.g. which industry or country) and whether or not they identified causality in a correct way.

Table 1: Classification of papers

Outcome types (what has been achieved)		**Policy aspect** (how were outcomes achieved)	
Emissions	32.80%	Price effect	5.20%
Economic Performance	27.60%	Permit Allocation effects	10.30%
Innovation	13.80%	Signalling	0.00%
Behaviour – Management	15.50%	Non-specified	84.50%
Multiple outcomes	10.30%		
Applicability (what group/s research focused on)		**Identification of causality** (have outcomes been attributed to ETS?)	
Few firms of one sector and one country	8.60%	No attempt at causality	22.00%
Few firms of several sectors or countries	27.60%	Subjective or correlation with no control for confounding factors	49.20%
One entire sector or country	24.10%	Correlation with more advanced controls	18.60%
Several sectors or countries	22.40%	Advanced causal identification design	6.80%
The entirety of the EU27	17.20%	High causal identification design	3.40%

Given the definition of the search criteria, it was no surprise that the main outcome type analysed in the papers considered was the effect on emissions. Effects on economic performance and competitiveness were also studied quite commonly, reflecting the intense policy debate that has been taking place. The generalisation of the results derived in these studies needs to be done carefully given that many studies focussed on small subsets of industrial emitters in the EU ETS.

As will be become clear in the subsequent sections, a salient conclusion of this report is that the literature on the effectiveness of the EU ETS in industrial sectors is scarce and the quality of existing evidence is low. In particular, two large gaps in the literature already appear clearly from the classifications presented in Table 1:

- First, the question of which aspects of the EU ETS (price, allocation, signalling or other) are driving changes in emissions and other decisions by market participants has barely been addressed by the literature.
- Second, there have been very limited attempts at identifying a causal relation between the EU ETS and the industry's response to this policy.

Research Findings

Based on the group of papers that satisfied the criteria for search, inclusion and quality described above, this section discuss how and to what extent they answer the three main research questions reproduced below:

- How effective is the EU ETS in driving industrial abatement in the UK and more widely?
- Which elements of the EU ETS drive abatement?
- How does the EU ETS interact with other policies designed to achieve abatement?

Findings relating to each research question have been summarised in relevant sections below.

The first question pertains to the effectiveness of the EU ETS in driving industrial abatement in the UK and more widely. The findings and discussion are organised along four main categories of outcomes: (i) carbon emissions, (ii) innovation, (iii) economic performance and (iv) use of flexible mechanisms such as CDM and JI. Within each section, most weight is given to the discussion of those studies that feature the most robust approaches to establishing causality.[4]

The second question the review sought to answer based on the literature is which elements of the EU ETS drive abatement. Various dimensions of such a policy could be driving responses by firms, such as the carbon price itself, the allocation of permits, the fact that the EU ETS might be perceived as a credible signal of the stringency of future climate policy, etc.

The third and last research question addressed here is how the EU ETS interacts with other policies designed to achieve abatement at the national, EU and international level.

Effectiveness of the EU ETS in driving industrial abatement

How effective is the EU ETS in driving industrial abatement in the UK and more widely?

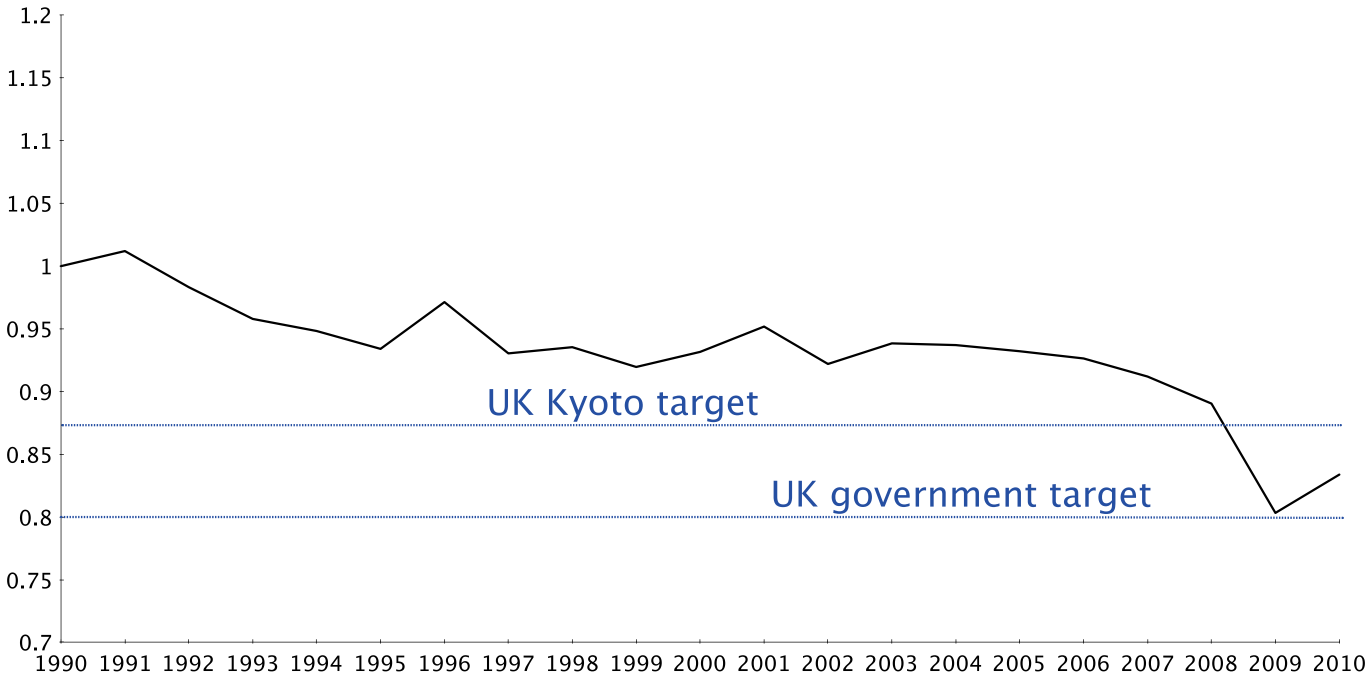
Given the main policy objective of the EU ETS is to achieve emission reductions, it is crucial to understand whether the first two trading phases have encouraged participating installations to abate. It is sometimes remarked that a cap and trade system like the EU ETS by definition delivers emission reductions as long as the cap is set tightly enough and regulated emitters are not in gross violation of the scheme. However, in many industries – and in entire countries such as the UK, see Figure 5 – emissions have been on a declining trend for some time. Moreover, macroeconomic fluctuations such as the recent recession affect emissions, sometimes drastically. Therefore, one would consider an emissions trading scheme to be effective at driving abatement only if it leads to lower emissions than would have occurred in the absence of the scheme; i.e. if the emissions would have reduced to the level of the cap without the cap we can hardly say that the cap delivers emission reductions. This counterfactual level of emissions is of course not observable. However, there are a number of ways to estimate this level. Similarly, to understand if a factor is a barrier to emission reductions, one needs to have an estimate of the firm's (counterfactual) emissions if it was not restricted by that factor.

[4] The Glossary in Annex B clarifies the concept of causality as well as all technical terms used in the report.

This section reviews how the current literature estimates emission reductions and what is assumed about counterfactual emissions.[5] In addition, we also review the evidence on a number of other outcomes that could be affected by the EU ETS and that have implications for its effectiveness, namely innovation and economic performance defined in a broad way that includes competitiveness. Different outcomes will be discussed in different subsections.

An additional dimension that has been considered is the use by installations of the Kyoto flexibility mechanisms like the Clean Development Mechanism (CDM) and Joint Implementation (JI). These allow MS to meet part of their target by financing emission reduction projects in countries outside the EU, including developing countries in the case of CDMs. The review will collect evidence on whether the EU ETS drives emission reductions and transfer of funds in developing countries through these flexible mechanisms.

Figure 4: UK Emissions 1990 – 2010



Notes: 1990 is taken as base year. The Kyoto target is in terms of total GHG emissions. The government target is in terms of CO_2. Source: Gennaioli, Martin and Muûls (2012) based on data from DECC.

[5] Suggestions for improving these estimates will be relegated to the gap analysis below.

Impact on Emissions

Summary:

While the EU ETS may have led to abatement in the power sector, the evidence on the effect of the EU ETS on GHG emissions of participating industrial firms is not conclusive. Several studies find that, in the aggregate, emissions across all regulated sectors declined by around 3% in Phase I and during the first two years of Phase II, relative to estimated business-as-usual emissions. However, the relative contributions to this *aggregate* figure by the industrial sectors on the one hand and the power sector on the other are unavailable in all countries but Germany. Also, these studies rely on aggregate estimates of what emissions would have been, had the EU ETS not been in place.

In an effort to improve the precision of these estimates, a recent analysis of firm level data reveals that the transition from Phase I to Phase II triggered emission reductions in a few industrial sectors and that the firm-level allocation of permits influences this effect. The robustness of these results still needs to be established by increasing sector and country coverage.

Overall, existing evaluations of the effectiveness of the EU ETS remain at a very aggregate level: there is no robust or precise estimate of the policy's specific effect on the industrial sector.

Measuring the impact of the EU ETS on emissions is crucial given the objectives of the policy. Researchers trying to estimate the impact of the EU ETS on emissions reductions for the industrial sector have been facing two main problems. First, precise data on emissions prior to 2005 for installations included in the EU ETS were not readily available. Second, a suitable measure of counterfactual emissions (i.e. emissions had the policy not been in place) is needed. Several methods to measure pre-2005 emissions and estimate this counterfactual (or BAU) have been put forward in the literature. Since most of the factors that determine emissions are known in retrospection (economic activity, prices, etc), ex-post analysis allows for more precise estimations than ex-ante predictions. Three strands of the literature will be presented in this section. The EU ETS started with the so-called "trial" Phase I. The first strand of the literature presented below has been focussing on estimating the impact of this first phase. The EU ETS was then extended into the "Kyoto" Phase II, starting in 2008. The second section presents papers studying Phase II's effectiveness. A third area of work has been providing qualitative findings on the impact of the policy mainly based on a limited number of interviews and case studies.

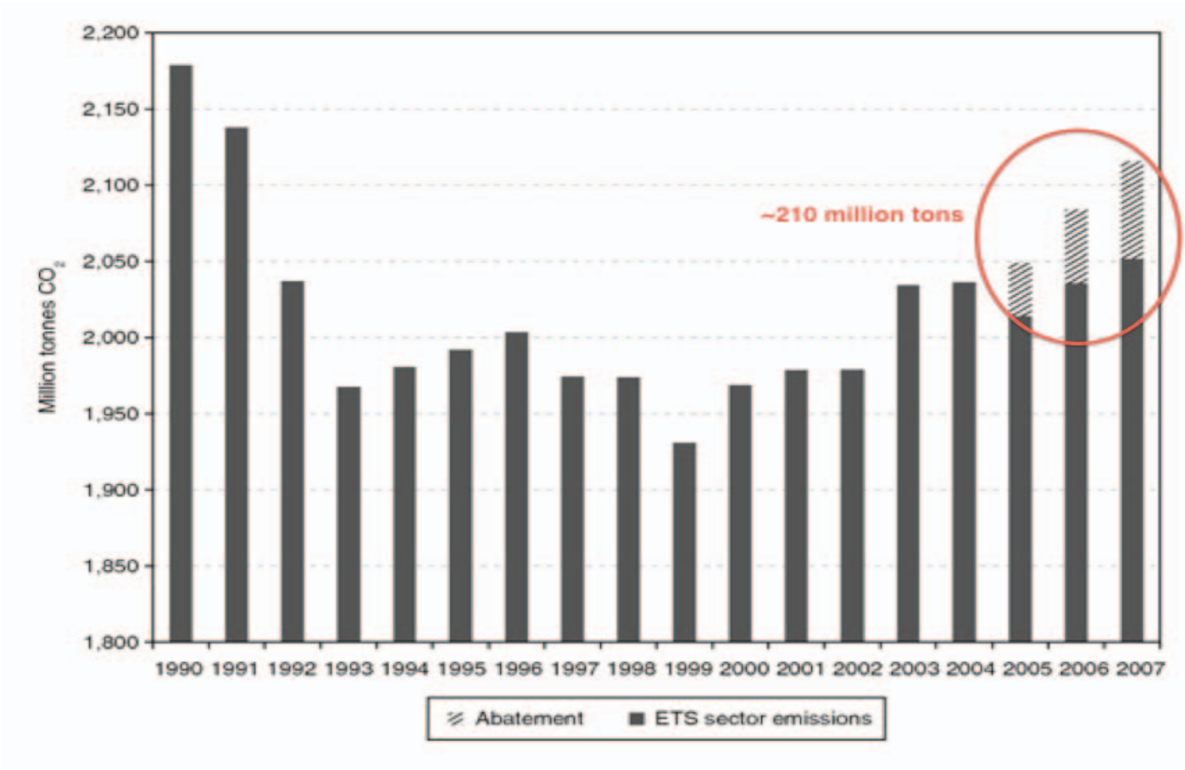
Phase I evaluation

Although Phase I is generally considered as a trial Phase with little expected impact, the availability of data for this period has led several researchers to estimate its emissions reduction effects. Three sources of data were used to estimate both the pre-2005 emissions and to construct the counterfactual BAU for 2005-2007 period:

- NAP: Focussing on the first two years of Phase I, Ellerman and Buchner (2007, 2008) extrapolated these pre-2005 emissions data by taking into account GDP growth and the historical trend of decreasing carbon intensity of production. This data suffered from two problems. First, the data could be biased due to the fact that it was collected under strong time pressure, with minimal verification by authorities. Installations could have had an incentive to inflate emissions, anticipating that doing so would give them a more generous allocation. Second, country level emissions were computed differently, using different years of data and are therefore not perfectly comparable. Based on the available data, they found that CO_2 emissions were reduced by between 100 and 200 million tonnes across all EU ETS sectors and countries in the two years under study, corresponding to a 2.4% to 4.7% abatement rate in total. This makes no distinction for the industrial sectors.

- UNFCCC common reporting format (CRF): An extensive comparison between the CRF and the verified EU ETS emissions data for 2005 by Herold (2007) had confirmed that CRF data could be used with some adjustment as a proxy of historical EU ETS sectors' emissions. Ellerman, Convery and de Perthuis (2010) therefore improve on the deficiencies of the NAP data and estimate carbon emissions reductions close to 210 million tonnes (or 3%) over the whole three years of Phase I, as illustrated in Figure 2.

Figure 5: Emissions and abatement



Source : Ellerman, Convery and de Perthuis, 2010. Figure 6.2, p. 165

- Eurostat: Anderson and DiMaria (2011) used these emissions data for a subset of NACE[6] sectors, matched to the corresponding EU ETS sectors. The authors also improved the calculation of the BAU emissions scenario for each country by applying dynamic panel data techniques and including industrial production data, energy production and energy prices as well as information on historical temperature (which affects heating and cooling) and precipitation (which affects hydro-power production). In comparison to the results using the two other sources of data, this leads to abatement of 2.8% during Phase I. This result varied at the country level, with some countries displaying over-allocations and others emitting more than BAU. This latter finding could be due to installations emitting more in 2007 when carbon prices were low in order to secure a more favourable allocation in the future (based on past emissions), once the market becomes tighter.

Based on these three papers, emission reductions over Phase I across all sectors and countries can be estimated as being close to 3%, as shown in Table 1. However, there is no evidence as to what share of this can be attributed to the industrial sector.

Table 2: Estimates of abatement

Authors	*Estimated abatement*	*Country*	*Time period*	*Sector*	*Data source*
Ellerman and Buchner (2008)	50 to 100 Mt per year (–2.4% to -4.7%)	EU	2005-2006	All	NAP
Ellerman, Convery and de Perthuis (2010)	70 Mt per year (-3.3%)	EU	2005-2007	All	CRF (UNFCCC)
Anderson and Di Maria (2011)	58 Mt per year (– 2.8%)	EU	2005-2007	All	Eurostat
Ellerman and Feilhauer (2008)	28.5 Mt per year (– 5.7%)	Germany	2005-2007	All	CRF (UNFCCC)
Ellerman and Feilhauer (2008)	11.7 Mt per year (– 6.3%)	Germany	2005-2007	Industry	CRF (UNFCCC)

Interestingly, both Anderson and Di Maria (2011) and Ellerman et al. (2010) showed that this inferred abatement varied strongly across countries. Most of the abatement occurred in the EU15 rather than in Eastern European countries. This confirmed the result of Ellerman and Feilhauer (2008) who applied the same method to Germany alone and found that abatement per year due to the EU ETS was close to 5% for all EU ETS sectors over Phase I. Given the data availability for Germany, the authors were also able to estimate specifically that German industrial abatement over the same period amounted to 6.3% vs. 4.1% for the power sector.

Given all three datasets contain aggregate figures, the results presented above are aggregate estimates. Apart from Germany, it is therefore not possible to separate the effects of the EU ETS on the different sectors' emissions, in particular for the industrial sector.

[6] NACE stands for "Nomenclature générale des activités économiques dans les Communautés Européennes" or "General Industrial Classification of Economic Activities within the European Communities"

Phase II evaluation

Evaluation based on firm-level data:

The change from Phase I to Phase II offered a good setting to analyse the impact of the policy on emissions. Given the limitations of aggregate analysis and the uncertainties attached to evaluating a BAU counterfactual, Abrell, Ndoye and Zachmann (2011) took a new research approach by estimating, at the firm level, reductions in CO_2 emissions around the transition from the first to the second phase. This study can be regarded as the most advanced research on the impact of the EU ETS on emissions because of the way it identified the causal effect of the transition to the Phase II. We therefore present it in more detail. The thought experiment underlying their estimation is: How different was EU ETS firms' emissions reduction strategies in 2005-2006 compared to 2007-2008? They obtained their dataset by an ambitious firm-to-firm matching of the CITL[7] to the AMADEUS[8] database containing performance data for the years from 2003-2008. The final data set included 2,101 firms (3,608 installations), which accounted for 59% of total verified emissions. 31% of these firms belonged to the electricity and heat generation sector. The very precise data available in AMADEUS enabled the authors to control for turnover, employment and profits. AMADEUS also has a much more precise sectoral classification than the CITL, with each firm being assigned a NACE sector. This meant that on top of controlling for country level trends, precise industry trends were also included.

The results showed that emission reductions between 2007 and 2008 were 3.6% larger than between 2005 and 2006. This difference was statistically significant and robust to the presence of outliers. The controls included in the estimation implied that this shift was likely to be due to the change from Phase I to Phase II, and that it was not implied by a proportionate decrease in production: emissions reductions were not caused only by economic conditions or reductions in the economic activity of firms. Based on the CITL data, it was also possible to differentiate this effect according to the net allocation position of the firm in 2005. Firms whose net allocation was below the median, i.e. firms that were short in 2005, abated the most between 2007 and 2008. Also, firms whose allocation had decreased most between the two periods reduced their emissions more than those whose allocation remained loose.

While the overall aggregate cap determines the equilibrium price on the market, theory predicts that *firm-specific* caps have no effect on a firm's abatement choices. That is because – in the absence of transaction costs, market power or other market imperfections – the firm curbs CO_2 emissions until the marginal cost of abatement equals the permit price. At this point it becomes cheaper for the firm to buy permits for any emissions beyond its target rather than abating those excess emissions internally. Consequently, neither over- nor under-allocation at the firm-level – while determining the distribution of rents that emerge from imposing scarcity on a formerly free good (GHG pollution) – should have any consequences for firm-level abatement. The only thing that should matter for an individual firm's mitigation and investment decisions is the (expected) emissions price. The notion that allocation decisions are independent of the distribution of allowances is referred to as the "independence property" of emissions trading and due to Montgomery (1972).

[7] The CITL is the EU's Community Independent Transaction Log that provides emission trading data as well as data on participating installations details, their allowances and verified emissions for each of the years they participate in the EU ETS.

[8] AMADEUS is a commercial dataset distributed by Bureau Van Dijk that makes available financial and balance sheet data for most European firms.

The results presented by Abrell et al. (2011) challenged the fact that this property also held for the EU ETS in its first two phases. Several potential explanations could explain this link between allocation and abatement, which defies conventional economic thinking. First, it could be that the sectors where mitigation cost was lowest received less permits. However, by including sector dummies in the regression analysis, the estimated effect of Phase II would control for such a possibility. Second, installations that announced that they would reduce production between 2007 and 2008 could have been allocated fewer permits and emitted less in 2008. However, only firms present in both years were included in the regression and turnover was controlled for, so again that effect would not have been included in the estimate. The only remaining explanation was that some of the inefficiencies of the EU ETS, such as limited liquidity or the conditionality of future allocation on past emissions, made companies' abatement dependent of their initial allocation.

Taking a closer look at some sectors, it also appeared that basic metals and non-metallic minerals significantly increased their reduction efforts between 2005-06 and 2007-08 whilst other sectors, such as electricity and heat, showed no change. These sectoral variations could be explained by different shapes of the abatement cost curves for different sectors. This would make abatement economically viable at different prices of CO_2: it could either mean that abatement has already occurred during Phase I or that it would occur only if the price of carbon was higher. Alternatively, as free permit allocations were made differentially at the sector level, the differential response of sectors could reflect allocation effects.

While this is an interesting contribution to the evidence on the EU ETS, it would strongly benefit from extending the data sample to allow an even better coverage of sectors and countries.

Evaluation based on aggregate data:

The paper by Abrell et al. (2011) presented the most detailed analysis of the impact of the transition to Phase II on emissions. But, it is worth noting that at the more aggregate level, Egenhofer, Alessi, Georgiev and Fujiwara (2011) extended the analysis by Ellerman et al. (2010) by estimating the abatement that had occurred during the first two years of Phase II. The emission intensity improvements attributed to the EU ETS were 3.35% on average, or 0.45% when focussing on the industrial sectors alone. In an even more aggregate setting, Cooper (2010) compared the 3% decline in total emissions between 2007 and 2008 to the 2% decline in industrial production over the same period, due to the recession. He concluded that in 2008, emissions were not much reduced by the EU ETS. Kettner, Kletzan-Slamanig and Köppl (2011a) arrived at a similar conclusion in an analysis of the 2005-2009 period which showed a decline in aggregate energy intensity. A closer look revealed a decline in intensity for the pulp and paper industry but not for cement. This could not be attributed to the EU ETS in a causal fashion. The reduction in production due to the economic crisis was presented as the main driver of the concurrent fall in emissions.

On balance, these results confirm how difficult it is to give robust and precise estimates of EU ETS induced emissions reductions based on aggregate data.

Qualitative findings

In addition to the findings above, a third strand of the literature also uses more qualitative methods to assess the impact of the EU ETS on emissions, by surveying a small number of market participants. Although no generality can be claimed for such studies, the results give an insight into the potential underlying mechanisms driving emissions abatement. (See Box 2 for a discussion of other reports on behaviour by market participants)

Of the 120 German firms surveyed by Löschel et al. (2010), a mere 6% stated that the key driver of emissions reductions was the explicit goal to abate emissions. In contrast, close to 90% of the firms, emission reductions were a co-benefit of investments motivated by other factors, such as general efficiency improvements. In line with this, 94% of Swedish EU ETS firms surveyed by Sandoff and Schaad (2009) declined that they would reduce their production volume in order to achieve internal abatement, thus placing greater weight on efficiency improvements to reduce emissions. Ikkatai et al. (2008, 2011) reported results from interviews with five industrial firms in Poland and Belgium. The companies that were interviewed claimed that emission reductions that had occurred during the EU ETS were due to economic conditions and not to the existence of the EU ETS. They also suggested that the over-allocation they benefited from did not incentivise them to abate. Fazekas (2008) interviewed two industrial Hungarian installations and came to the same conclusion. Cost minimization and focus on compliance prevailed.

Other anecdotal evidence was provided by Walker et al. (2009), showing that four cement plants in Ireland did not substitute forest-derived biomass for fossil-fuel as a result of the EU ETS. Technical and logistical concerns, as well as a pulpwood supply risk, appeared to be the major barriers to adoption. Engels (2009) reported that a large share of the more than 300 firms he had interviewed did not appear to know their own abatement costs. Ellerman et al (2010) also reported that SAB Miller, a world-leading brewer, improved carbon intensity by 12% mid-2007. It appears more than questionable to attribute such reductions to CO_2 prices only. More generally, based on evidence from very small subsets of the large number of market participants, it is impossible to draw robust conclusions from these studies.

Impact on Economic Performance

Summary:

There is no conclusive evidence on how the EU ETS affected the economic performance of regulated firms. Some studies found negative effects on employment, profits, or productivity, but these findings were not confirmed in other studies that relied on different statistical models. One study found evidence that the EU ETS increased profits as firms priced in the opportunity costs of permits they had obtained for free. Furthermore, the review did not identify any convincing evidence that the EU ETS adversely affected the competitiveness of regulated firms. Some studies tested whether the introduction of the EU ETS weakened net exports of goods into non-regulated countries, with ambiguous findings. There is fairly robust evidence based on price data that a number of sectors were able to pass through the costs of emission permits on to final product markets. However, there is no evidence on whether the EU ETS reduced market shares or changed the composition of supply of regulated firms. Survey evidence showed that EU ETS firms reported a higher propensity to downsize their operations in response to future carbon pricing than non-ETS firms, although this effect was not large.

In order to comply with the EU ETS, regulated firms must undertake costly abatement and/or buy permits which lowers their profits. As a way of compensating firms for this profit loss, emission allowances were allocated to firms for free in the early stages of the EU ETS. In addition to having a direct cost impact, however, the EU ETS might worsen the competitive position of regulated firms relative to rival firms outside the EU ETS. In the case of power generation, this effect is limited by institutional and technical aspects of European electricity markets, but it might be a real concern for industrial emitters who are competing in international product markets. Such firms might not always be able to pass the cost of carbon on to their final customers without losing market share, which in turn might lead them to curb production and shed jobs. In the worst case, firms might even choose to relocate in order to avoid the policy, thus taking jobs and carbon emissions to unregulated countries. Policymakers are thus concerned that the EU ETS might have too high a price in terms of job losses while achieving too little in terms of reducing carbon emission globally.

This explains why a considerable part of the literature on the EU ETS has been dedicated to the possible impacts on economic performance (broadly defined), which includes indicators such as profits, revenue, output, and employment. The greater part of this strand of the literature consists of ex-ante assessments and is therefore not considered here. Recently, a few ex-post evaluations have been conducted using data on economic performance from the first two trading periods. This evaluation task proves easier than the estimation of the abatement and innovation impacts of the EU ETS discussed above, in the sense that firm-level data on economic performance is relatively easy to obtain, both for the pre- and post-2005 period. Nevertheless, the challenge remains to establish that any measured changes in performance at EU ETS firms can be ascribed to the policy itself, and not to a third factor that also affects all treated firms. The credibility of a given study thus depends on whether the authors can establish that a correlation reflects in fact a causal relationship. If firms had been assigned completely at random to either a “treatment group” (i.e. firms in the EU ETS) or a “control group” (i.e. firms not in the EU ETS), the difference in the average firm-level performance between these groups could be interpreted as the causal impact of the EU ETS. In practice, however, this was hardly the case[9] and any serious evaluation attempt must acknowledge the possibility that treated firms might have been selected according to some criterion that is not unrelated to the outcome and thus induces a bias in the impact estimate.

Evidence on employment, output, and profits

One of the most ambitious studies in this sense is by Abrell et al (2011), and was mentioned above already in the review of emission reductions. In addition to their analysis of emissions, Abrell et al. estimated the economic performance impact of the policy after matching each EU ETS firm with only one firm in a non-EU ETS sector. This control firm was chosen to be the most similar one based on observable firm characteristics.[10] Abrell et al. found that participation in the EU ETS had no statistically significant impact on a company’s added value and profit margins. However, in the period between 2004 and 2008, they found a statistically significant, slight decrease in employment at EU ETS firms of 0.9%. Further analysis revealed that this was driven by a particular sector, non-metallic minerals. Splitting the sample into over- and underallocated firms[11] did not yield a clear pattern. The authors acknowledged that their practice of taking control firms only from non-regulated sectors was problematic because of the possible non-random selection of which sectors were regulated under the EU ETS. Due to this matching problem, their study is likely to suffer from selection bias at the sector level. Moreover, their analysis could not estimate possible indirect impacts on industries not directly regulated under the EU ETS, as these were part of the group of control firms.[12]

Commins, Lyon, Schiffbauer and Tol (2011) also used the AMADEUS database to study the impact of energy taxes and the EU ETS on about 200,000 firms in Europe between 1996 and 2007. Their regression analysis gave rise to a negative effect of the EU ETS on productivity and profits in the order of 6%. The effects on employment and investment were not statistically significant. The main caveat of this study is that the treatment status of a firm was determined at the sector level, i.e. firms with small installations were incorrectly labelled as treated

[9] For example, some sectors such as the chemical or aluminium industries successfully lobbied for an exemption of their process emissions during the first two trading phases of the EU ETS.

[10] In practice, they use the propensity score to determine the similarity.

[11] Firms were considered over-allocated if their allocation factor – defined as the ratio of freely allocated allowances to verified emissions – exceeded 1.15 (the median allocation factor in 2005), and vice versa.

[12] This caveat is shared by other studies that derive causal impact estimates from a comparison of firms in the EU ETS with firms not in the EU ETS. The challenge with estimating indirect effects is to identify a control group of firms that, for reasons unrelated to their economic performance, are not affected by electricity price increases or other indirect effects of the EU ETS.

although only large installations in the sector were subject to regulation. It is unclear how severe a bias this causes, as the thresholds were very low in many sectors. The estimated EU ETS effects therefore included the impact of sector level shocks to the outcome variables which were unrelated to the EU ETS. Moreover, this paper did not address the above-mentioned issue of selection at the sector level. Differences in the sample composition aside, these two studies demonstrate that different assumptions and modelling priorities give rise to rather different results.[13]

In one of the first ex-post analysis of the EU ETS, Anger and Oberndorfer (2008) proposed to use a control group from within the set of EU ETS firms. Using AMADEUS data on 419 EU ETS firms based in Germany, they regressed the change in revenues or employment between 2005 and 2004 on the allocation factor – defined as the ratio of allowances allocated for free to verified emissions – which was taken as an indicator of whether the firm's permit allocation was binding or not. The regression results provided no evidence for a significant impact of the allocation of EU emissions allowances on firm revenue or employment changes in 2005. A caveat of the study is that verified emissions were likely simultaneously determined with revenue or employment in 2005. This means that emissions were an outcome rather than an explanatory variable, and would invalidate the results. The authors tried to address this problem using instrumental variables techniques and also obtained insignificant results. However, little effort was made to convince the reader that the instrumental variables were credible.

Evidence from stock market data

A single study examined stock-market prices as a measure of economic performance in an event-study framework. The event-study method exploits high-frequency data from a very short time window before and after the treatment (the "event") to estimate the effect of the event on an outcome. This effect can be given a causal interpretation under the assumption that any confounding factors between the treatment and control groups remain unchanged during the event window. In a sample of 548 firms (including power generators) included in the EUROSTOXX, Bushnell, Chong and Mansur (2011) found that stock prices fell in response to the precipitous fall of the allowance price in April 2006. This response was found for firms in both carbon- and electricity-intensive industries, and particularly for firms selling primarily within the EU. They interpreted their findings as evidence that investors focused on the positive impact of emissions trading on product prices (as firms passed-through the opportunity costs of EUAs obtained for free), rather than just on negative compliance costs. Moreover, Bushnell et al. found evidence that firms' net allowance positions also influenced how share prices responded to allowance prices. While the event-study method offers a high-degree of internal validity, it is unclear that the results from a particular study can be generalized to the EU ETS in its entirety. For one, the sample was not representative, as it included only publicly-traded firms, and only 124 of them participated in the EU ETS. Furthermore, current economic conditions have led to an increased volatility in stock prices which could make it difficult to corroborate these results for a larger set of firms in future event studies.

[13] Abrell et al. (2011) place greater emphasis on not coding untreated plants as treated whereas Commins et al. (2011) prefer not to code treated plants as not treated. Furthermore, Abrell et al. compare treated firms to their most similar non-treated counterpart only, wheras Commins et al. compare treated firms to all non-treated firms. Both modeling choices lead to a smaller sample size in the former study.

Evidence from trade data

The economic performance of firms subject to the EU ETS is intimately linked to the competitiveness impact of this policy. Constantini and Mazzanti (2012) tested the impact of Phase I on net imports from EU15 countries into more than 100 destination countries and for a broad range of industries. The results indicated that the EU ETS had a negative impact in all industries except in medium-low technology industries, where the effect becomes positive in some specifications. The authors themselves cautioned that their results were not conclusive, and that further disaggregation and longer time series were needed to obtain reliable impact estimates. A general drawback of their empirical strategy was that the variable of interest was defined in a way that would make it impossible to distinguish the EU ETS impact from other macro level shocks.

Reinaud (2008) took a similar approach in a study of the aluminium industry. She regressed net imports of aluminium into the EU27 on the year-ahead EUA price and other control variables, using quarterly data from 1/1999 through 2/2007. She found a negative relationship, which runs counter to the economic intuition that a higher carbon price would increase net imports of electricity intensive aluminium from unregulated countries. However, this negative effect is not necessarily causal, because the research design did not discriminate between the impact of the EU ETS and a secular, upward trend in net imports. Reinaud also found no evidence of a structural break in net imports following the introduction of the EU ETS.

Evidence from price data

Apart from the quantities, the prices at which goods are traded also carry information about the competitiveness impact of the EU ETS. As was explained in the introduction to this subsection, if the regulated sectors pass the cost of carbon through to product prices, this can be taken as an indication that their competitiveness is not affected by the EU ETS in major ways – and vice versa. De Bruyn, Markowska, de Jong and Bles (2008) examined the stochastic relationship between industry-specific price indices in the EU vs. the US, and the carbon price. Using monthly price data from 2001 until 2009, they found that energy-intensive industries such as iron and steel and refining actually passed through a large fraction of the EUA price to the respective product markets. In a similar analysis, Alexeeva-Talebi (2011) found that European refineries fully passed through the price of EUAs on petrol retail prices between 2005 and 2007. Oberndorfer, Alexeeva-Talebi and Löschel (2010) used the same method to study cost-pass through in several UK industries. They found EUA pass-through rates of 50-75% using weekly data on gasoline and diesel prices for 2005 and 2006. For glass and ceramics products, they use monthly data and use cost shocks other than EUA prices to identify pass-through. They found evidence of pass-through of varying degrees and robustness. Further evidence of pass-through of input price shocks was presented using EU-wide monthly prices of chemical products between 2001 and 2007, although this was limited by the low number of observations (75).

In sum, there is robust evidence that the EU ETS has not impeded the competitiveness of firms and sectors that can simply pass-through the EUA cost. This evidence is based on price data that are available at a higher frequency than performance indicators and on high-powered but also data-hungry econometric methodology (co-integration analysis) that in principle allows the researcher to establish causality. The principal caveats of these studies are that (i) the fact that the EU ETS is a relatively recent policy limits the amount of time series data that can be used for these data-hungry techniques, and (ii) the level of aggregation of available price data is too high to allow meaningful estimation. While these studies found fairly high pass-through rates, there is little in the way of direct evidence on whether the EU ETS reduced market shares or changed the composition of supply of regulated firms.

Evidence from survey data

The competitiveness impacts of the EU ETS have been at the heart of sizable amount of ex-ante studies which relied in part on economic modelling and calibration exercises, in part on data collected in surveys. Some surveys were conducted after the EU ETS was implemented and hence should provide ex-post evidence relevant for this review. Although there is a fundamental problem with establishing causality, the survey results pertaining to economic performance can briefly summarized as follows: Based on interviews with senior managers at six large manufacturing firms in the EU ETS, Kenber, Haugen and Cobb (2009) found that the scheme neither resulted in significant costs, nor induced a fundamental shift in strategy such as relocation or reduction of the workforce. Lacombe (2008) interviewed managers at five European refining companies and found very limited economic impact on firms. He attributed this to organizational inertia, weak incentives linked to the low emission permit price that prevailed during the second part of Phase I, and to both industrial and regulatory constraints. Given the small sample size, these studies hardly provided representative evidence, however.

Of course for policy makers the central concern regarding competitiveness is not so much impact on profits or costs as such but whether such impacts trigger the closure or downsizing of business operations in Europe with resulting job losses. Martin, Muûls, de Preux and Wagner (2012b) examine this directly using data collected in 761 interviews with managers in six European countries. Managers were asked whether the company had plans to downsize operations or re-locate abroad in response to carbon pricing over a time horizon until 2020. For EU ETS firms, it was further asked how this re-location risk depended on whether or not the company would continue to receive free allowances after 2012. The answers to these questions allowed for the construction of downsizing risk scores capturing subjective risk with and without free allocation. The authors therefore used both interview data and estimates of how sensitively firms responded to energy price changes, based on hard economic data from 25 countries, to establish the internal and external validity of the risk scores. They found that downsizing risk was generally low, with most firms reporting no impact of future carbon pricing on decisions where to locate business activity. The downsizing risk score was significantly higher for the average firm in the EU ETS compared to non-EU ETS firms, although it did not attain 10% reduction in production or employment.[14] Importantly, within the group of EU ETS firms, there was substantial variation in both the level of downsizing risk as well the degree to which such risk could be mitigated by giving free permits to firms. Martin et al. (2012b) further showed that the rules drawn up by the EU Commission for free permit allocation in Phase III are very ill-suited to address these varying risks.[15] In particular, they showed that the risk to jobs could be reduced dramatically not only without increasing the amount of permits handed out for free, but even when reducing it. This could be achieved by allocating free permits on the basis of a simple index based on both the emissions and employment intensity of a business.

[14] This comparison was based on raw scores and did not control for other factors.

[15] These conclusions emerged after controlling for "noise" due to interviewer characteristics (by including fixed effects), due to manager characteristics (by including the tenure in the company, dummies for gender and professional background) and due to the time of the interview (by including dummies for month, day of week and time of day).

Impact on Innovation

Summary:

This review did not find strong evidence in the literature that the EU ETS in Phases I and II had any causal impact on (new-to-the-market) innovations by directly regulated firms. While clean patent applications increased rapidly from 2005 onwards, the evidence so far suggests that this was due to confounding factors such as concurrent oil price increases or the implementation of other climate change policies. Other evidence based on the impact of the post 2012 allocation rules suggested that the less generous allocation rules in Phase III might drive clean innovation.

The evidence of a positive impact is somewhat more favourable when it comes to technology adoption. However, the existing studies are narrowly focused on a limited set of sectors and countries, and they lack rigour as far as the causal identification strategies are concerned.

The impact of the EU ETS on innovation is of interest from a number of perspectives.

1. Investment in new R&D and new technologies will make it easier and cheaper to achieve a given reduction target.
2. Innovations have the potential to spill over to other businesses that may or may not be regulated. Such spillovers would improve the effectiveness of the EU ETS and of climate policy in Europe more generally. On the one hand, they help to reduce the cost of emission abatement in the non-regulated sectors within the EU, where regulation is necessary to meet the Kyoto targets but not necessarily cost effective for lack of emissions trading. On the other hand, if innovations spill-over across EU borders, they lower the cost of emission reductions in countries with no or less stringent climate policies in place.
3. Understanding the impact of the EU ETS on innovation is a central element of the recent debate on "Green Growth". For climate change to have a positive impact on disposable income in the short run, innovations induced by climate policy need to spill-over more easily than the kind of innovations that would have occurred in absence of the policy.[16]

Note that the existence of innovation spillovers aggravates the problem of market failure created by the global environmental externality. Businesses undertaking privately-funded R&D

[16] There is a wide range of definitions of green growth (Jacobs, 2012). A positive impact of climate policies on short-run economic growth is only one possible definition.

have no incentive to take into account the positive effects of their investment on other firms.[17] This might explain why businesses are not reacting optimally to climate policies.

A recurrent difficulty with discussing the literature on innovation is that different authors use the term innovation for a wide range of very different things. The following table suggests a distinction between different types.[18]

Table 3: Classifying Innovation

Category	Innovation type	Description
Innovation impact/purpose	Product innovation	Helps the innovating firms' customers to reduce emissions
	Process innovation	Helps the innovating firm to reduce emissions.
Degree of innovativeness	New to the market/economy	The firm is inventing a new technology or practice rather than merely adopting an
	New to the firm	Adoption of an existing technology or practice
Impact on climate change	Clean innovation	Innovation leads to GHG emission reductions.
	Dirty (non clean) innovation	Innovation does not lead to GHG emission reductions.
Stage of the innovation process	Innovation input	Resources that are devoted to research and development
	Innovation output	A successful innovation. Typically measured by patent counts; also sales from new products.

Innovations can then be characterised according to all possible combinations of the four categories. An example would be a process innovation that is new to the market and helps the innovating firm to reduce its GHG emissions.

Note that these different types are likely to have different implications as far as spillovers are concerned. For instance, one might expect that innovations that are new to the market are more likely to lead to spillovers than the mere adoption of existing technologies and practices. Having said that, adoption of a new technology could have relevant “external effects”, for instance by alerting other firms to the feasibility of doing something in a new way.

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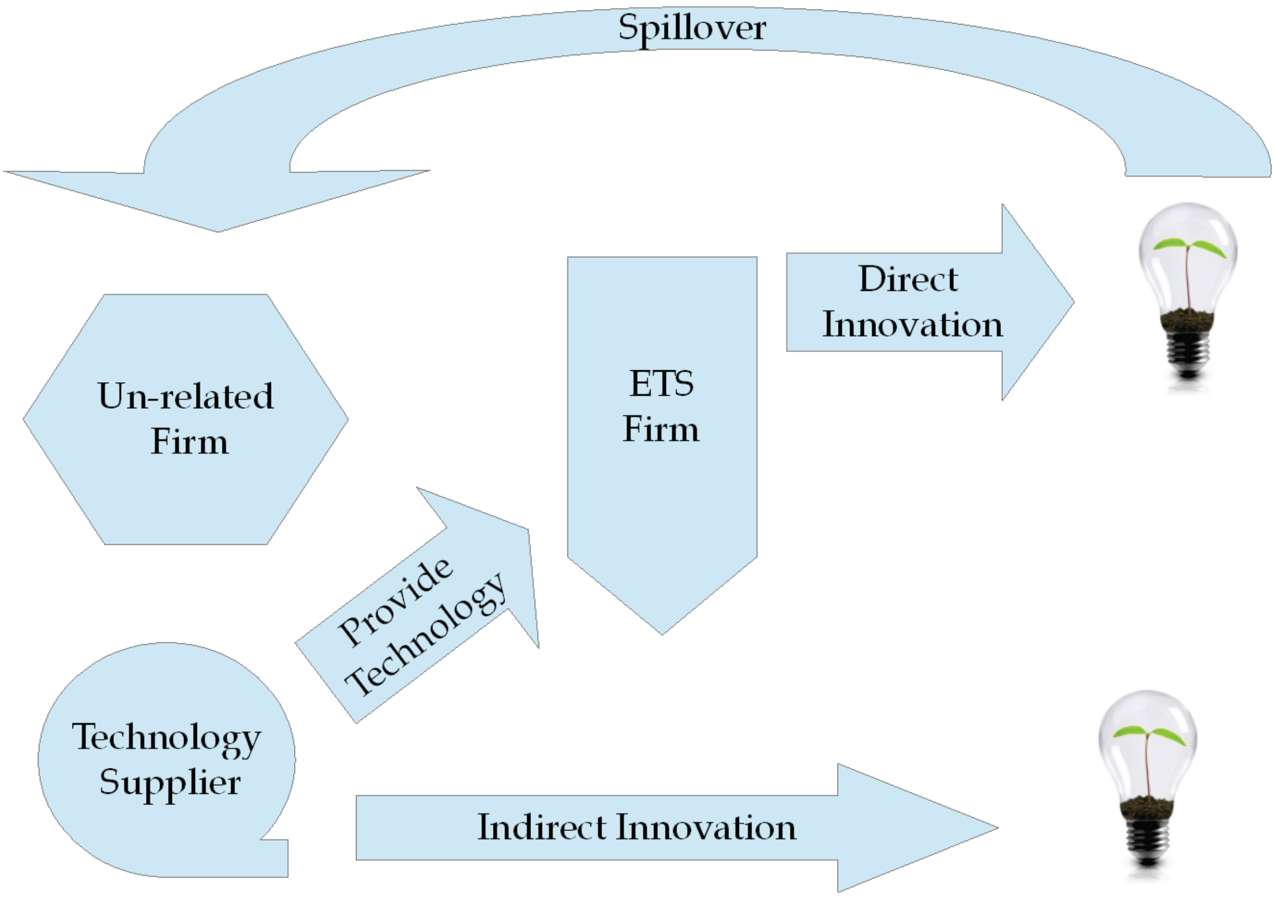
[17] See Jaffe, Newell and Stavins (2005) for more discussion on this.

[18] This is a synthesis of innovation classifications used in surveys such as the CIS (a dataset used e.g. in Borghesisi et al, 2012 or Martin et al, 2011)

The distinction between the direct and indirect effects of innovation is an important one. Direct effects occur when firms regulated by the EU ETS show an innovation response. An example of an indirect effect is increased innovation by the technology suppliers of a regulated industry. It is important not to confound indirect effects with spillovers, even though it is sometimes hard to distinguish between the two in practice. For example, suppose that a regulated firm purchases new energy-saving equipment ,say solar panels, in response to being regulated. In order to meet this demand, the equipment supplier embarks on more R&D to improve the energy efficiency of her equipment. In this scenario, no spillover has occurred. Suppose now that, because of a new insight obtained from research on improving solar panels, an unrelated manufacturer of semiconductors can improve the performance of her products. If the semiconductor manufacturer does not compensate the solar panel manufacturer by means of licence payments or the like, then a spillover has occurred. This is illustrated in Figure 7.

Figure 6: Spillovers versus indirect innovation effects



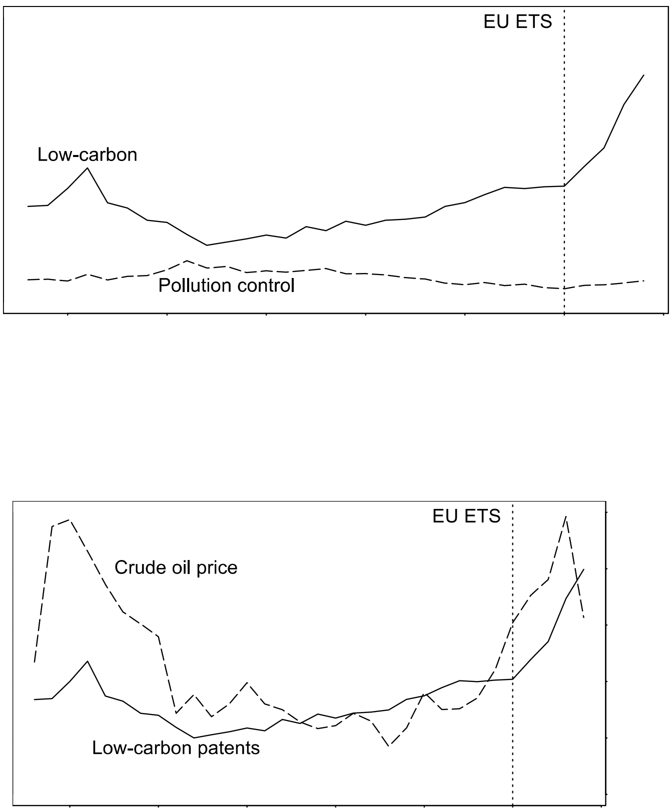
Source: Authors

Based on these inclusion criteria, we identified 8 papers on the link between the EU ETS and innovation outcomes. All of them are based on firm-level data and, with the exception of Hagberg and Roth (2010), Calel and Dechezleprêtre (2012) and Borghesi, Cainelli and Mazzanti (2012), they rely on cross sectional survey or interview data gathered by the researchers. The papers vary widely in the representativeness of the evidence, the breadth of sector and country coverage as well as in the efforts and possibilities to establish a robust causal inference. Further, the studies use different types of innovation outcomes and consider different EU ETS trading phases.

Large sample evidence for multiple countries and sectors

Figure 8 which is reproduced from Calel and Dechezleprêtre (2012) provides a first glance at the evidence. The top panel of the figure reports the share of low-carbon and pollution-control patents in total patent applications submitted to the European Patent Office (EPO) between 1978 and 2009. In terms of the classification scheme presented above, these represent innovation outputs that are clean, new to the market, and could represent product or process innovations. The introduction of the EU ETS in 2005 coincided with a dramatic acceleration of the share of low-carbon patents but not pollution-control patents. To the casual observer, this might indicate a strong impact of the EU ETS on innovation as the EU ETS is distinctly about carbon emissions, and not about local air pollutants that are abated with pollution control technologies. However, the bottom panel of Figure 8 suggests that this might not be the only explanation: the increase in patent applications followed a similar increase in oil prices, which might have incentivized energy efficiency improvements and, hence, low carbon patents. Note that the increase after 2005 is markedly stronger than the spike in patenting during the oil price shocks of the late seventies and early eighties. Moreover a number of other climate policy instruments have been implemented across the EU in recent years that might have had a positive effect on clean innovation.

Figure 7: The share of low-carbon patents and oil prices (1978-2009)



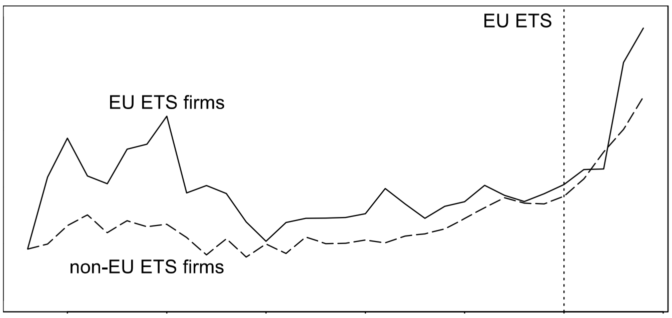
Source: Calel and Dechezleprêtre (2012)

Calel and Dechezleprêtre examined this further by adopting a firm-level perspective. They compared the patenting across firms regulated and not regulated by the EU ETS. The study is particularly impressive in that they managed to match almost all EU ETS firms to the set of firms that are recorded in the patent data. The comparison of innovating EU ETS firms with innovating firms not in the EU ETS yielded the result that the former group had a larger increase in patenting after 2005. The increase was particularly pronounced from 2008 onwards, i.e. in Phase II of the EU ETS (see Figure 9). This effect vanished, however, once the authors compared EU ETS firms with non-EU ETS firms that were more similar. This was necessary because the typical EU ETS firm was found to be very different from a typical non-EU ETS firm. Similarity was defined within sector[19]-country cells on the basis of variables such as employment size and amount of patenting pre-ETS. The authors excluded a number of observations because no adequate match could be found.

Hence the evidence so far could not reject the hypothesis that the EU ETS had *no* effect on innovation as proxied by patents. Several caveats remain however. Firstly, it might be the case that innovation effects occurred in regulated firms that had to be excluded because no match could be found. The authors addressed this by adopting less stringent criteria for finding matched firms thereby more than tripling the number of EUETS firms that are included in the analysis. Again they could not find a statistically significant effect, however.

Secondly, it might be the case that innovation effects occurred indirectly; i.e. in firms that were not directly regulated by the EU ETS. This is a key question that needs to be addressed in future research and will be discussed in the gap analysis below.

Figure 8: The share of low-carbon patents in EU ETS vs non EU ETS firms (1978-2009)



Source: Calel and Dechezleprêtre (2012)

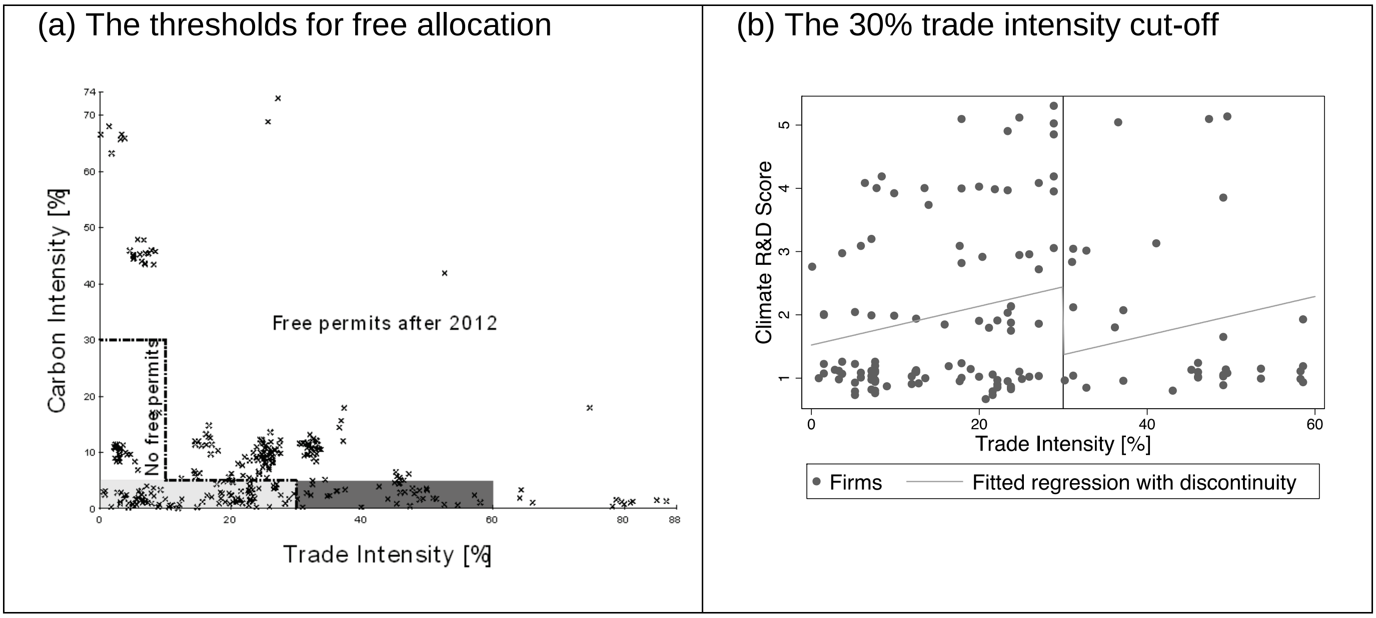
Martin, Muûls and Wagner (2011) pursued a different approach (see also the above discussion of Martin et al., 2012b). Based on interviews conducted in 2009 with managers at 761 manufacturing firms in 6 European countries, they constructed scores (on a scale from 1 to 5) for clean innovation in processes and products, respectively. The scores captured the company's clean R&D activities in the widest sense, i.e. innovation inputs. Like Calel and Dechezleprêtre, Martin et al. (2011) found no significant difference in innovativeness between EU ETS and non-EU ETS firms. This confirmed the results from an earlier 2008 wave of

[19] Economic sectors were defined at the 3-digit level for the NACE Rev. 2 industry classification.

interviews with managers at almost 200 medium-sized manufacturing firms in the UK, where no significant differences emerged in similarly constructed innovation measures (Martin, Muûls, de Preux and Wagner, 2012a).

As was mentioned earlier, comparisons in the cross section are, however, prone to omitted variables bias. To circumvent this problem, Martin et al. (2011) also examined the innovation impact of changes in innovativeness around the thresholds set by the EU for continued grandfathering of emission permits after 2012. As is displayed in Figure 10, these thresholds are defined in terms of sectoral trade and carbon intensity; i.e. firms in sectors with high carbon and/or trade intensity will continue to receive free permits after 2012. Firms that were just below the thresholds required for free allocation conducted significantly more innovation than others. This discontinuity in innovation activity around the cut-off threshold remained strong in a number of robustness checks.

Figure 9: A regression discontinuity design for allocation effects



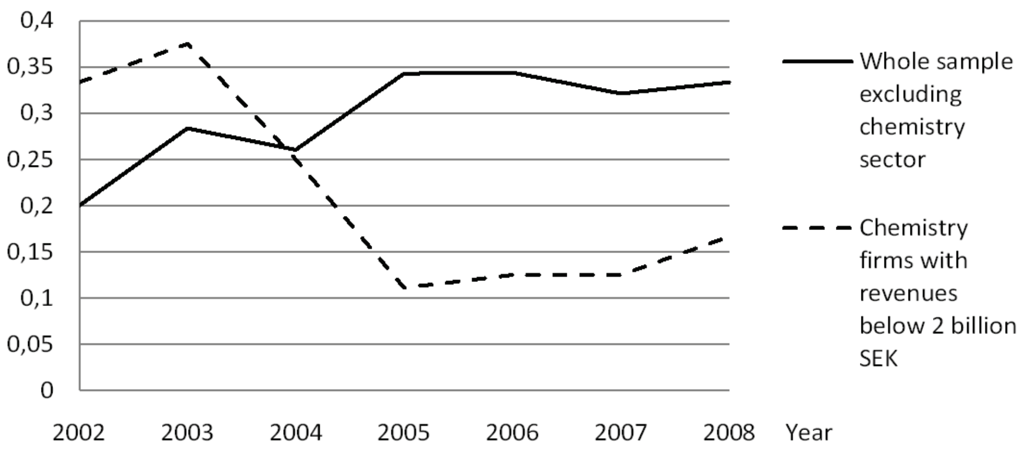
Source: Martin, Muûls and Wagner (2011)

This result has a number of implications. First, it suggests that there might be some tangible innovation effect in Phase III. Second, the impact on innovation depends on the detailed EU ETS policy design; i.e. the requirement to pay for permits, rather than getting them for free might have an important signalling effect. Clearly, this contradicts the so-called independence hypothesis of cap and trade systems (Hahn and Stavins, 2010).

Large sample evidence for specific countries

Hagberg and Roth (2010) analyzed technology adoption using a unique panel dataset of around 600 Swedish firms in a number of energy intensive manufacturing sectors as well as in the energy sector. The dataset provided information on carbon abatement investment for the years 2002 to 2008. The authors found a significant increase in such investments after 2004. Unfortunately, they seemed unable to identify EU ETS firms explicitly in their dataset. To address time-varying confounding factors, they resorted to comparing the whole sample with firms in the chemical industry which were small and therefore unlikely to be part of the EU ETS. This revealed a gap in abatement investments after 2004, as shown in Figure 11. The authors performed a number of robustness checks and concluded that the EU ETS had indeed a causal effect on such investments. While this is a plausible story, it relies on the assumption that innovation by EU ETS firms would have evolved in the exact same fashion as innovation by small chemical firms, had it not been for the introduction of emissions trading. Yet Calel and Dechezlepretre (2012) demonstrated that it is important to compare EU ETS firms to non-treated firms that are similar in all other characteristics. As this requires making comparisons *within* sectors and size classes, comparing small chemical firms with all other firms might be too much of a stretch.

Figure 10: Carbon Abatement Investments for different subsectors of the Swedish Economy (2002-2008)



Note: Number of observations for whole sample excluding chemical sector is 450.
Number of observations for chemical firms with revenues below 2 billion SEK is 50.

Source: Hagberg and Roth (2010)

Borghesi et al (2012) worked with data on about 1,000 firms in the 2008 Italian Community Innovation Survey (CIS) which is part of an official European effort to gather data on innovation at the firm level. They found that EU ETS firms were more likely to be involved with environmental innovation, defined in a broad way. This is merely a correlation, however, not necessarily the causal impact. They also examined the effect of a sectoral EU ETS stringency measure, defined as sectoral emissions divided by sectoral allocations. This measure was negatively correlated with innovation. When taken at face value, this contradicts the result by Martin et al. (2011) that firms in sectors with less stringency (i.e. more free permits) innovate less. However, the study design adopted by Martin et al. (regression discontinuity) controls for confounding unobserved factors; for instance, more energy intensive sectors could be less innovative. Additional results in Martin et al. (2011) indicated that the relationship between innovation and energy intensity was hump-shaped indeed, irrespective of the EU ETS or the generosity of allocations.

Small sample evidence and case studies

The remaining studies reviewed in this section relied on much smaller datasets and often were akin to case studies. Causality in these studies is typically based on the subjective assessment of survey or interview participants. For instance, on the basis of interviews with 27 EU ETS firms in Ireland, Anderson, Convery and di Maria (2011) found that the first phase of the EU ETS was effective at stimulating moderately clean technological change and also raised awareness about emissions reduction possibilities.

Rogge, Schleich, Haussmann, Roser and Reitze (2011) conducted face-to-face interviews with interviewees at three paper producers and four technology providers, between June 2008 and September 2009. In the medium term (between 2013 and 2020), the majority of paper producers felt that they would be negatively affected by all climate policy elements, primarily by long-term targets. The majority of technology providers felt currently unaffected by climate policies. The share of technology providers feeling unaffected reduced somewhat when considering the medium run up to 2020. Also, the share of technology providers feeling positively impacted by climate policies was larger than the share feeling negatively impacted (18% vs. 12%). The EU ETS was ranked only seventh among several determinants of R&D activities among paper producers, only 21% of which thought it was very relevant. Factors that rank higher include market forces (e.g. the price of raw materials) and technology specific regulation, which are all not too surprising. A somewhat less expected result is that public opinion seems to be a more important driver than the EU ETS. Among technology providers, 8% thought that the EU ETS was very relevant whereas 61% thought it was not relevant at all. None of the respondents expected near-term changes, but two thirds of both groups expected that, by 2020, the relevance of R&D would rise due to climate policy.

Pontoglio (2011), based on a survey of 38 Italian paper manufacturers in 2006, reported that most firms (66%) were short of allowances and met this shortage by borrowing (72%). One half of the firms (52%) had not undertaken efforts to reduce emissions, e.g. by investments in new technologies, and the other half (48%) had undertaken such efforts or was planning to do so. Further interviews with equipment suppliers revealed that none of them had the intention of making energy or CO_2 efficiency a selling point for their products or company.

Petsonk and Cozijnsen (2007) described a small number of new technological approaches that were adopted by companies regulated under the EU ETS. For instance they give the example of a Dutch oil refinery that recycled waste CO_2 as fertiliser in adjacent greenhouses. However, no attempt was made to establish a causal relationship.

Emission Reductions via the Clean Development Mechanism

Summary:

The available evidence on emissions reductions via the CDM is entirely descriptive. The most successful CDM projects were implemented in Asia and reduced GHG emissions other than CO_2. Although CDM credits traded consistently at prices below the EUA price, their use only amounted to one third of the legal limit, and less than one twentieth of total permit allocations. CDMs transferred a small piece of the European carbon pie to developing countries, but the available estimates of exactly how much remain highly uncertain. There are no estimates of how much the CDM as a whole lowered the EUA price.

The Clean Development Mechanism (CDM) and Joint Implementation (JI) allow the parties to the Kyoto Protocol to meet part of their emission target by financing emission reduction projects in countries outside the EU, including developing countries in the case of CDMs. The EU "Linking Directive" 2004/101/EC allows for the inclusion of abatement credits from CDM and JI in the EU ETS. The former are called certified emission reductions (CERs), and the latter Emission Reduction Units (ERUs). The primary goal of these emission offsets is to reduce the total compliance cost. As low-cost abatement opportunities outside of the EU ETS are included in the scheme, the supply of cheaper permits will drive down the EUA price. At the same time, if emission reductions are properly accounted for and monitored, the environmental effectiveness of abatement in third countries is the same as that of internal abatement at EU ETS firms. A secondary goal can be seen in the transfer of funds and technology to non-Annex B countries, and to engage these countries in the process of climate change (Wara and Victor, 2008).

Imports of CERs and ERUs into the EU ETS are subject to limits that are formulated in terms of a maximum proportion of the installation level allocation of EUAs. These offset limits vary between 0 and 20%, depending on the country, and average at 13.5% (Trotignon 2011). CERs can either be imported directly, e.g. when an EU ETS firm or a third party sets up a CDM project, or bought in secondary markets.

By some estimates, CERs could account for up to ten times the actual emission abatement within the EU ETS (Wara and Victor, 2008), but there is little ex-post evidence on the share of CER credits in total abatement. Trotignon (2011) provided a descriptive analysis of CER use by EU ETS installations during 2008 and 2009. In the two years, 170 million CERs were surrendered, amounting to 4% of allocations and one third of the average annual import limit.

Most CERs were coming from HFC and NOx projects in China (about half), India, Brazil and South Korea. CER use was highly concentrated, in that 70% of CERs were surrendered by 10% of installations that surrendered CERs (1.5% of all installations). Overall, only 9% of installations imported CERs, i.e. CER use fell way short of the allowable maximum. CERs were coming mainly from the largest and oldest projects. According to Braun (2011), about 900 installations were at their offset limits, which corresponds to 25% of installations that used CERs or ERUs .

CDM projects that reduce CO_2 emissions are still a minor provider of CDM credits. Based on a survey of ten wind energy developers with projects in developing countries, Blanco and Rodrigues (2008) found that CDM and JI project-based schemes played a role in the development of wind energy projects in third countries, but the decisive element for a company considering to invest there was to be seen in the local institutional framework and the long-term stability of CO_2 markets. Both the small sample size and the ex-ante nature of this survey (it was carried out before CERs could actually be traded in the EU ETS) would call for this topic to be revisited in future research.

Apart from encouraging abatement in developing countries, trading in CERs diverted some of the rents created by the EU ETS to developing countries. The magnitude of these transfers could be proxied by multiplying the volume of CER imports by the CER price. However, this would likely overstate the financial flows to developing countries because the marginal cost of directly imported CER credits might have been lower than the CER price in secondary markets.

With regard to the demand side of the CER market, Trotignon estimated the benefits of offsets to EU ETS participants by multiplying the volume of trades with the average annual EUA/CER price spread. This yielded a mid-estimate of 283 million Euros for the two years, which can be interpreted as an arbitrage profit of firms that sell EUAs and buy CERs (Vasa, 2011). However, this could overstate the benefits because the price spread might simply account for higher transaction costs, information costs or risk discounts applicable to CER credits (Braun, 2011; Vasa, 2011). The fact that the offset limits were far from being fully exhausted suggests that such factors may have played a role.

Drivers of Abatement

There is no robust evidence as to the channels through which the EU ETS has been driving (or not) emission reductions in the industry sector, apart from the few results from interviews with EU ETS firms reported in the previous section. Also, Abrell et al. (2011) and Martin et al. (2011) pointed to the fact that the independence property should hold on the carbon market, implying that only the price affects emission reductions. However, their results seemed to suggest otherwise, with allocations driving abatement differentially.

Besides, an important literature has analysed the financial characteristics of the carbon market (see for example Ellerman et al (2011), chapter 5). Yet, this literature has not established any link between the market's characteristics (such as its liquidity) and the abatement decisions of firms. There is also no evidence on how important the signalling effect of the EU ETS has been: despite low prices and unbinding allocations, it could also be the case that the mere existence of the system signals more stringent days to come in the medium term.

Box 2: Mechanisms behind the EU ETS impact: Evidence on behaviour and management

In addition to a mere quantification of the impact of the EU ETS in terms of abatement, clean innovation or economic performance, it is interesting to study the mechanisms behind such impacts. So far, there is no direct evidence on the mechanisms driving specific impacts. However, some studies provided a closer examination of behavioural and managerial aspects of the EU ETS.

Trading

The bulk of this strand of the literature has focused on various aspects of how firms behave on the permit market. To the extent that this was investigated using data from CITL, this has been discussed above. Other studies used survey data to shed light on this question. Economists often take for granted that firms make rational decisions based on a comparison of the allowance price and their marginal abatement cost. In contrast, the empirical evidence shows that firms were trading mostly to buy the permits they needed to be in compliance. This finding appeared to be fairly robust as it emerged in a number of different studies, including a survey of 120 German EU ETS firms (Löschel, Heindl, Alexeeva-Talebi, Lo, and Detken, 2010), interviews with managers of 432 EU ETS firms (Anderson et al., 2011), a survey of all Swedish EU ETS firms (Sandoff and Schaad, 2009), and in the Carbon Disclosure Project (Pinkse and Kolk, 2007). This could have raised the overall compliance cost, as firms with excess amounts of permits did not make them available to other market participants. Anderson et al. (2011) showed that the reluctance to trade prevailed among firms with less than 5,000 permits, whose aggregate impact on the permit price was limited.

Management

Judging from the number of firms where emissions trading decisions are a responsibility of management, the EU ETS carries considerable weight and status within the organization (Sandoff and Schaad, 2009; Anderson et al., 2011; Lappalainen, 2006). A survey of 50 EU ETS companies in 2006 demonstrated that the majority had established an own EU ETS risk management strategy rather than using their general risk management strategy (Lappalainen, 2006). Half of these companies supported their risk management by using portfolio analysis, or by constructing price or market models. The use of financial instruments was generally more extensive in large companies. These risk management strategies followed a few basic compliance strategies – EUA trading, internal abatement, and investments in emission reduction projects or carbon funds. Faure, Hildebrandt, Rogge, and Schleich (2008) tried to shed light on what criteria firms use to rank different compliance strategies. Based on a survey of 50 German EU ETS firms, they found that abatement costs were deemed most important and reputation effects the least important.

While these studies based their conclusions on EU ETS firms only, others related management practices and EU ETS participation. Jeswani, Wehrmeyer, and Mulugetta (2008) compared UK and Pakistani firms and found that the environmental friendliness of a company's management strategy is lower in companies that are not in the EU ETS, such as small chemical firms. It was not clear, however, if this was a statistically significant difference, and how the influence of confounding factors was mitigated. Okereke (2007) documented that many FTSE100 companies were engaging in some form of action regarding climate change and attributed this to the EU ETS and other government policies.

Interaction of policies

The EU ETS naturally interacts with a range of different policies, both across countries and across policy domains. While it is important to gain a better understanding of the implications of such interactions for the further development of the EU ETS and climate policy more broadly, the review did not find any ex-post analysis of such interactions.

While the EU ETS is the main EU policy to achieve emission reductions, other policies are in place at the national, EU and international levels. Their interactions with the EU ETS are important elements to be understood for future negotiations over the design of future EU ETS trading phases as well as over a global climate policy architecture that involves non-EU countries.

Following Sorrell and Sijm (2005), one can distinguish between three types of interactions.

1. **Direct interactions** arise if, for example, some participants in the EU ETS are also subject to CO_2 emission limits or to a carbon tax.
2. **Indirect interaction** occurs if, for example, a non-EU ETS firm is indirectly affected by the EU ETS due to higher electricity prices and directly affected by a carbon tax.
3. The linkage of two emissions trading schemes gives rise to **trading interactions**, as was the case when the linking directive allowed CERs to be traded on the European carbon market.

At the national level, energy and carbon taxes that pre-dated the introduction of the EU ETS played an important role for the total amount of emission abatement. For the UK, Martin, de Preux and Wagner (2011) found that the Climate Change Levy caused manufacturing firms to improve their energy intensity by a substantive margin, relative to firms that were in the Climate Change Agreements, during the four years preceding the introduction of the EU ETS. On the one hand, given that EU countries face binding targets on carbon emissions under the Kyoto Protocol, carbon taxes are bound to remain *the* economically preferable policy instrument for as long as the EU ETS does not cover all carbon emissions. This is because a carbon tax in the non-trading sector would induce firms to equate their marginal abatement cost to the tax rate, so that overall abatement costs are minimized. On the other hand, many EU countries have seen initiatives to reduce or eliminate such taxes for firms that are regulated under the EU ETS, especially with regard to Phase III when grandfathering of permits will be replaced by benchmarking and partial auctioning of permits. The net effect of making permits more expensive while reducing the tax burden is unclear a priori and has yet to be studied.

At the EU level, other policies such as the 2020 target of 20% of renewable energy or the Energy Efficiency plan seek to achieve emissions reductions. While there are some qualitative analyses of the interactions of such policies in the power sector (Del Rio, 2009; Del Rio, Labandeira, and Linares, 2009), there is no ex-post analysis for the industrial sector.

Finally, the EU ETS interacts directly - by virtue of the Linking Directive - with the Kyoto flexibility mechanisms CDM and JI, which have been discussed above. In addition, the future could see linking of this to other national or regional carbon trading schemes in North America, Australia or Asia. As of the writing of this report, there is no ex-post evidence on such interactions.

Synthesis/Policy implications

A central challenge for the EU ETS, as it continues to develop into a mature cap-and-trade system, is to establish a more meaningful carbon price. The key questions for the regulator therefore are (i) how high a price should this be or, alternatively, how tight a cap should be set in going forward to deliver the desired level of emission abatement, and (ii) what consequences does this cap have for economic growth and competitiveness. Unfortunately, none of the studies reviewed here provided any guidance on the required price level on the basis of ex post evidence.[20] If anything, Martin et al. (2011) found that managers expected an average price level in the range of €40 by 2020. This price level should be seen in conjunction with their result that only a small fraction of businesses expected downsizing or relocation due to climate policies.

On the one hand, the lack of an impact on innovation is consistent with the view that the carbon market established an insufficient price signal for induced innovation. On the other hand, on the basis of the currently available ex-post evidence, it is impossible to rule out alternative explanations for this phenomenon.

Another important policy parameter concerns the practice of free allocation. Several studies concluded that free allocation can have a negative effect on both the environmental and cost effectiveness of the EU ETS (Abrell et al, 2011; Martin et al. 2011; and Anger and Oberndorfer, 2008). Reducing free allocation would therefore appear to be a good policy objective in going forward, without losing sight of the key objective of free allocation to mitigate the risk of carbon leakage and job losses. The index for free allocation proposed in Martin et al. (2012b) provided a starting point for this kind of initiative.

[20] It may seem that ex-post analysis is the opposite of the analysis of counterfactual scenarios, usually done via simulation. However, the truth is that ex-post evaluation can lend the necessary credibility to a fitted econometric model used to simulate counterfactual policies. For instance, Aghion, Dechezlepretre, Hemous, Martin and van Reenen (2012) calculate the counterfactual fuel price increases required to incentivise radical clean innovation in the automotive industry.

Gap Analysis

Summary:

Since the EU ETS was not designed as a randomized experiment, an ex-post evaluation of the EU ETS must necessarily rely on non-experimental techniques. It has become clear in the review that such techniques have not been used to their full potential in the literature so far. Robust inference on the causal impact of the EU ETS on abatement, innovation and economic performance necessitates better data. Future research must thus rely on large, high-quality datasets maintained by national governments, which have not been used thus far to evaluate the EU ETS. Furthermore, the scope of ex-post analysis will need to be broadened. In particular, there is very scant evidence on the role of CDMs in abatement, on the interaction with national policies, and on the mechanisms that drive the observed impacts. A promising way to shed light on this is to collect data in representative large-scale surveys among the affected firms, and jointly analyse these data with "hard" performance data on emissions and performance, available from official sources.

The identification problem and the ideal solution

The principal challenge in policy evaluation research – known as the identification problem – is to attribute only the part of the observed behavioural change to the policy that was actually caused by the policy – no more and no less. This is difficult because many factors might impact on behaviour at the same time. For various reasons, such factors could be correlated with the policy and hence confound the impact estimate.

The state-of-the-art solution to the identification problem is to conduct a randomized-control trial (RCT), or field experiment. For example, in an RCT of emissions trading, a group of randomly selected firms would be regulated in a cap-and-trade program whereas another group of firms would not be regulated at all. The impact of emissions trading could then be consistently estimated as the average difference in the outcome between the two groups. This is because, thanks to the randomness of the assignment, any idiosyncratic differences in how firms respond to the treatment are distributed identically across treatment and control group, and hence average out.

Blueprint for a non-experimental evaluation study

In many real-world settings, randomization is neither feasible nor desirable. Therefore, programme evaluation must resort to non-experimental techniques. Given this constraint, an ideal evaluation study of the EU ETS would marry a representative firm or plant-level dataset of suitable quality with a research design that establishes the causal impact of the policy on the outcome considered, as opposed to a mere correlation. These conditions are detailed in what follows.

Data

- The data should be a large and representative sample of the industrial sector. Other sectors, such as power or services, should not be included given the focus on industrial emissions.
- The data should cover several years before and after the introduction of the EU ETS. The frequency should be at least annual.
- As a rule, data should be available at the level of the firm or plant, because this minimizes the chance that aggregation affects the evaluation results. For example, if the impact of the EU ETS on output was estimated using sector aggregates, the researcher would be comparing treated sectors to control sectors. Since treated sectors are energy-intensive, the effect of confounding factors that affect energy-intensive industries (for instance, think of an energy price shock that coincided with the introduction of the EU ETS), would be erroneously ascribed to the EU ETS. An analysis at the firm level, on the contrary, would be comparing treated and non-treated firms *within* energy-intensive industries. To the extent that energy-intensive firms respond to an energy price shock regardless of their EU ETS participation status, the firm-level comparison purges the impact estimate of this confounding factor.
- The data should contain accurate measures of the outcome of interest. For example, direct carbon emissions should be calculated based on the consumption of various fossil fuels, multiplied by their respective carbon coefficients. Monetary outcome variables (output, value added, prices, profits, cost, etc.) should be converted to real terms using appropriate deflators, innovation variables should be differentiated by innovation type (clean/dirty).
- The matching of CITL data (the relevant database on the treatment status) to other data sources should be as complete and as reliable as possible in order to avoid that EU ETS firms are treated as non-EU ETS firms, and vice versa.

Administrative datasets on plants and firms in the industrial sector are maintained by many governments and constitute a rich source of high-quality data suitable for impact analysis. These data have not been used to date in the evaluation of the EU ETS, mostly because governments have restricted access to them. As some ongoing research projects show, these access restrictions are no longer prohibitive, and one can expect that research on the EU ETS will progress to use only such high-quality data.

Research design

Various techniques are available to address the identification problem.

- Matching: The idea is to compare each ETS firm only to observationally identical firms that are not in the EU ETS, rather than to all firms not in the EU ETS. This technique is more credible, the larger the number of observable variables that are used to single out observationally equivalent firms. On the flip side, if the match is based on few variables, there is a chance that the firms are dissimilar along some unobserved dimension, and this would invalidate the comparison.

- Regression-discontinuity design (RDD): Size thresholds are defined for each EU ETS sector, and firms that fall below the threshold are not included in the EU ETS. The threshold induces a discontinuous change in the propensity of treatment. RDD takes advantage of this discontinuity and compares treated firms just above the threshold with not-treated firms just below the threshold. The proximity to the threshold is meant to ensure that treated and control firms are otherwise very similar in there characteristics, so that the assignment can be regarded as random.
- Instrumental variable estimation: The identification problem can also be solved if one or more variables are available that are correlated with EU ETS participation but do not have a direct impact on the outcome. The following hypothetical example illustrates this method. Suppose that participation in the EU ETS was mandatory only for firms whose VAT number (or the last digit thereof) is an even number. Then an indicator variable for even VAT numbers would be a valid instrument as it would be correlated with treatment status, but not with the outcome variable.

How this relates to the research reviewed above

Based on the ideal evaluation study defined above, the remainder of this section highlights the gaps in the existing literature and suggests directions for future research. For a given outcome variable of interest, a gap is defined either if there is a lack of evidence or if existing evidence lacks a causal or representative estimate of the impact of the EU ETS. That is, there is a gap if for a specific policy-outcome combination there is only correlation but no sound identification of a causal relationship.

Gaps

- No experimental evaluation of carbon trading has been undertaken thus far.

  Although the EU ETS is sometimes referred to as the grand carbon trading experiment, its implementation cannot be described as an experience in scientific terms, in that treatment and control groups were not selected at random. Clearly, nothing can be done about this at the current state of affairs. Nevertheless, from a conceptual point-of-view, it is worthwhile pointing out that the first evaluation gap already opened up at the stage of implementation.

- Non-experimental evaluation methods have not been used to their full potential.

  There is currently a single study using matching techniques (Abrell et al. 2011) and another one using the regression discontinuity design (Martin, Muûls and Wagner, 2011). No study thus far has exploited the size thresholds for an RDD analysis.

- The analysis of the effectiveness of the EU ETS in driving abatement is incomplete in a number of ways.

  - Existing studies have not been consequent at distinguishing between the power sector and industrial emitters. This is mostly due to data limitations that prevent the construction of counterfactuals for more narrow sectors of the economy. Neither have

the results been differentiated by country. For example, there is no study that focuses on the UK despite the fact that it represents a large share of EU ETS emissions.
- Existing work at the firm-level has relied on emission data from CITL. This meant that no emission data were available prior to 2005 neither for a control group of firms not in the EU ETS. There is a clear opportunity for improvement by using firm-level data from official sources, which comprise carbon emissions or a large representative sample of industrial emitters.
- The match of firm-level data to the CITL could be improved to refine existing studies.
- Very little is known about the mechanisms that encourage or discourage firms to respond to a positive carbon price, and about the effects of permit allocation on firm behavior.
- The causality of emissions impact estimates in the literature reviewed here is not well established. Improved methodological approaches that could disentangle the directions of causality between participation in the EU ETS and emissions reductions require better data, as explained above.

- The evaluation of the impact of the EU ETS on economic performance is incomplete.

  - Typical data constraints include the limitation to a specific country, to a specific sector, and/or incomplete matching of CITL data to economic performance data.
  - Furthermore, many studies do not distinguish the results between the energy sector and energy-intensive industries.
  - Even the more technically advanced studies did not convincingly establish the causality of their impact estimates. Identification challenges arise from the non-random selection of sector coverage, and from exemption rules within the sectors if the impacts are heterogeneous (vary with size). Progress on these issues will likely go in lockstep with overcoming the data constraints.

- The evaluation of the innovation impact of the EU ETS is incomplete.

  - New-to-market, clean innovations by regulated firms (i.e. direct innovations) are not necessarily the most likely way in which the EU ETS might induce such innovations. A more plausible scenario is that it might lead to innovations by the technology providers. Some of the case studies discussed above looked at this. However, this evidence should be corroborated and put on a broader and more robust basis.
  - The work on technology adoption should be widened to more countries and sectors.
  - No study so far has dealt with the issue of potential impacts on non-clean innovation areas. The key question here is the extent to which clean innovation replaces other innovation, and to which extent it is additional. This is particular relevant for the debate on green growth. In other words, finding that the EU ETS has a positive impact on clean innovation does not necessarily imply that there is a positive impact on economic growth in the short to medium run if R&D investments in clean technologies come at the expense of other R&D investments in non-clean areas. Clearly, as long as there is no sound evidence on the impact on clean innovation, there is no need to investigate other areas. However, looking at non-clean innovations could also be revealing of errors in how clean innovation is measured.

- Lack of research on the Clean Development Mechanism

  - Are emission offsets really additional? The question of how much the EU ETS contributes to emission reductions in the rest of the world is closely linked to the main issue surrounding the use of offsets, which relates to the additionality of those emissions. Wara and Victor (2008) gave a dire account of CDM credits that did not represent real emissions reductions. They concluded that future offsets on a scale sufficient to provide substantial cost-control for a cap-and-trade program would likely exacerbate this problem. The question about additionality of offsets, while beyond the scope of this review, is very timely and relevant, and hence will deserve more scrutiny in empirical research.

- o The potential cost savings that accrue to EU ETS participants have not been estimated in the literature. On the one hand, this would require a reliable estimate of the true cost of CERs arising to a trading partner. On the other hand, there is a gap regarding the even more important question of how much the supply of cheap CER credits has reduced the market price for EUAs. As such a reduction would benefit all market participants on the demand side. The potential benefits are large but to date they have not yet been quantified.

- Lack of empirical research on policy interactions

  This gap goes beyond the above-mentioned lack of evidence for specific countries. Filling it requires the analysis to explicitly account for pre-existing national policies with which the EU ETS might interact.

- Lack of research on the mechanisms behind the estimated impacts

  There is no evidence so far that links the observed impact to specific mechanisms. For example, is abatement achieved by switching fuels or by installing a more efficient technology? A promising way to shed light on this is to collect data on mechanisms in representative, large-scale surveys among the affected firms. Subsequently, these data can be matched to and jointly analysed with “hard” performance data from official sources, which is informative of the impact on emissions, performance and other outcomes.

Closing these gaps is important for a number of reasons.

- To justify a large and costly policy such as the EU ETS a serious effort needs to be made to understand its causal impact.
- Both, the costs and benefits of the EU ETS are likely to differ across sectors. A better understanding of these variations will help design more effective and equitable regulation across firms and sectors, e.g. when it comes to compensation schemes via free permit allocation.
- Causal effects might also depend on auxiliary policies or on the interactions between different elements of the EU ETS policy package. For example, if the permit allocation process is not neutral with respect to the overall efficiency of the trading scheme, policy makers need to be aware of this in order to reap the full benefits of the policy.
- With the EU ETS as well as other climate policies the countries of the EU are currently applying more stringent measures than most other countries globally. This entails the risk of carbon leakage and relocation of economic activity. At the same time, fears of such risks can be exploited by lobby interests to extract rents from governments. Improving the evidence base on these issues is therefore essential for reducing the negative impact the EU ETS may have on public spending. This concerns the issue of auctioning vs. free allocation of emission permits, among others.
- Finally, because regulating European emissions alone is insufficient to successfully mitigate climate change, clean innovation effects are arguably more important than direct

emission effects. To the extent that such innovation spills over to non-regulated emitters, particularly the large emerging emitters such as China and India, this allows Europe to punch above its carbon weight. Innovation effects also entail the possibility of “green growth” in the short to medium run if they lead to spillovers within the EU that are larger than would have been the case otherwise. Hence, to understand better if there are innovation effects and under which conditions they arise should be a priority for future investigations.

Conclusion

This review examined the available ex-post evidence on the impact of the EU Emissions Trading System on emissions of the industrial sector and related outcomes. Ideally, an ex-post evaluation of the EU ETS recovers an estimate of the causal impact, defined as the difference between the average outcome that is observed and the average outcome that would have been observed had the EU ETS not been implemented. The bulk of the research reviewed here failed to meet this ideal standard. The available evidence suggested that the impact on emissions was on the order of 3% in the first Phase, averaged across all sectors and countries. Specific results for industrial sectors were scarce and difficult to generalise. Regarding Phase II, early results are mixed, with some evidence that it induced stronger emission reductions in its first year, but other signs that the economic recession could have been the driver of later abatement.

For the EU ETS to be dynamically efficient, it must provide incentives not only for emission abatement in the short run but also for innovation in clean technologies. This is all the more important as climate change is a long-run problem that will require formidable efforts to curb GHG emissions over a prolonged time period. There is no doubt that clean innovation experienced a steep increase since the start of the EU ETS, but there was no convincing evidence that this increase was caused by the EU ETS and not other factors that impact patenting. There was some evidence of technology adoption which was more compelling than evidence on genuine innovation of new technologies or methods. Other evidence suggested that clean innovation might pick up speed in the next trading Phase.

Any desired effects on emissions or innovation have to be balanced with potentially negative effects on economic performance. The evidence here was not robust to modelling choices. When negative effects were found, they were rather small and/or concentrated in a few industries. While the evidence is not conclusive, an encouraging result is that there was no evidence of strong negative effects on economic performance – even in going forward into Phase III. Furthermore, the research reviewed here documented ample scope for improving the efficiency of current policies designed to compensate those industries for negative impacts.

Finally, future research will have to fill important gaps in the literature to provide robust causal impact estimates. Doing so will be challenging both methodologically and in terms of data requirements. One should be optimistic, however, that these challenges can be overcome in the future, particularly by using administrative panel datasets at the firm or plant level. Such datasets are maintained by many national governments and constitute a rich source of high-quality data that has been largely untapped so far.

References

J. Abrell, A. Ndoye, and G. Zachmann. Assessing the impact of the EU ETS using firm level data. Bruegel Working Paper 2011/08, Brussels, Belgium, July 2011.

P. Aghion, A. Dechezlepretre, D. Hemous, R. Martin, and J. Van Reenen. Carbon taxes, path dependency and directed technical change : Evidence from the auto industry, 2012.

V. Alexeeva-Talebi. Cost Pass-Through of the EU emissions allowances: Examining the European petroleum markets. *Energy Economics*, 2011.

V. Alexeeva-Talebi. Cost pass-through in strategic oligopoly: Sectoral evidence for the EU ETS. *ZEW Discussion Papers*, 2010.

B. Anderson, F. Convery, and C. Di Maria. Technological change and the EU ETS: the case of Ireland. *IEFE Working Paper No. 43*, 2011.

B. Anderson and C. Di Maria. Abatement and allocation in the pilot phase of the EU ETS. *Environmental and Resource Economics*, pages 1–21, 2011.

N. Anger, C. Böhringer, and U. Oberndorfer. Public interest vs. interest groups: allowance allocation in the EU emissions trading scheme. *ZEW Discussion Papers*, 2008.

N. Anger, B. Brouns, and J. Onigkeit. Linking the EU emissions trading scheme: economic implications of allowance allocation and global carbon constraints. *Mitigation and Adaptation Strategies for Global Change*, 14(5):379–398, 2009.

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

G. Arsuaga Arana. Evolución del mercado europeo de derecho de emisiones de CO2 2005-2007. Master's thesis, Universidad Pontificia Comillas, Madrid, Spain, June 2008.

I Bachiller Méndez, J.L. Fernández-Cavada, and J. Martín Juez. Derechos de emisión temporales procedentes de actividades de forestación y reforestación en el EU ETS. *Economía Agraria y Recursos Naturales*, 7(14):21–44, 2007.

A. Baena and A. Pueyo. *Competitividad y cambio climático. Nuevos retos para la industria española*. Fundación EOI, 2006.

I. Bailey and C. Ditty. Energy markets, capital inertia and economic instrument impacts. *Climate Policy*, 9(1):22–39, 2009.

M. Barrett, M. Paulet, and H. Young. Impact of the proposed emissions trading scheme in the Latrobe valley, Australia. 2009.

R. Betz and M. Sato. Emissions trading: lessons learnt from the 1st phase of the EU ETS and prospects for the 2nd phase. 2006.

M. I. Blanco and G. Rodrigues. Can the future EU ETS support wind energy investments? *Energy Policy*, 36(4):1509–1520, 2008.

R. Bleischwitz, K. Fuhrmann, and E. Huchler. The sustainability impact of the EU emissions trading system on the European industry. 2007.

C. Böhringer, H. Koschel, and U. Moslener. Efficiency losses from overlapping regulation of EU carbon emissions. *Journal of Regulatory Economics*, 33(3):299–317, 2008.

M. Bonacina and S. Cozialpi. Carbon allowances as inputs or financial assets: lessons learned from the pilot phase of the EU ETS. Technical report, Università Bocconi IEFE Working Paper n19, 2009.

S. Borghesi. The European emission trading scheme and renewable energy policies: credible targets for incredible results? *International Journal of Sustainable Economy*, 3(3):312–327, 2011.

S. Borghesi, G. Cainelli, and M. Mazzanti. Brown sunsets and green dawns in the industrial sector: Environmental innovations, firm behavior and the European emission trading. *Nota de Lavoro FEEM*, 2012.

N. E. Braun. *Accounting for permit price differentials in the European union emissions trading system*. PhD thesis, Montana State University Bozeman, 2011.

T. L. Brewer. Business perspectives on the EU emissions trading scheme. 2005.

J.B. Bushnell, H. Chong, and E.T. Mansur. Profiting from regulation: An event study of the European carbon market. Dartmouth College Working Paper, Hanover, NH, November 2011.

S. Cadez and A. Czerny. Carbon management strategies in manufacturing companies: An exploratory note. *Journal for East European Management Studies*, 15(4):348–360, 2010.

R. Calel and A. Dechezleprêtre. Environmental policy and directed technological change: Evidence from the European carbon market. Grantham Research Institute on Climate Change and the Environment Working Paper No. 75, London School of Economics, London, UK, February 2012.

M. Cames, F. Matthes, and S. Healy. Functioning of the ETS and the flexible mechanisms. 2011.

K. Capoor and P. Ambrosi. State and trends of the carbon market 2008. *Washington, DC: The World Bank*, 2008.

S. Clo. The effectiveness of the EU emissions trading scheme. *Climate Policy*, 9(3):227–241, 2009.

S. Clo. Grandfathering, auctioning and carbon leakage: Assessing the inconsistencies of the new ETS directive. *Energy Policy*, 38(5):2420–2430, 2010.

N. Commins, S. Lyons, M. Schiffbauer, and N. C. Tol. Climate policy & corporate behavior. *The Energy Journal*, 32(4), 2011.

F. Convery, D. Ellerman, and C. De Perthuis. The European carbon market in action: Lessons from the first trading period. *Journal for European Environmental & Planning Law*, 5(2):215–233, 2008.

F. Convery, D. Ellerman, and De Perthuis. Le marché Curopéen du carbone en action: Enseignements de la première phase. 2008.

F. Convery. Reflections - the emerging literature on emissions trading in europe. *Review of Environmental Economics and Policy*, 3(1):121–137, 2009.

F. Convery and L. Redmond. Market and price developments in the European union emissions trading scheme. *Review of Environmental Economics and Policy*, 1(1):88–111, January 2007.

R. Cooper. Europe's emissions trading system. *Harvard Project on International Climate Agreements Discussion Paper*, pages 10–40, 2010.

V. Costantini and M. Mazzanti. On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports. *Research Policy*, 2011.

E. Dardati. Pollution permit systems and firm dynamics: Does the allocation scheme matter? 2011.

S. De Bruyn, D. Nelissen, M. Korteland, M. Davidson, J. Faber, and G. van de Vreede. Impacts on competitiveness from EU ETS: An analysis of the Dutch industry. *CE Delft report, The Netherlands*, 2008.

S. de Bruyn, A. Markowska, F. de Jong, and M. Bles. Does the energy intensive industry obtain windfall profits through the EU ETS? An econometric analysis for products from the refineries, iron and steel and chemical sectors. CE Delft Publication No. 10.7005.36, April 2010.

P. Del Rio. Interactions between climate and energy policies: the case of spain. *Climate Policy*, 9(2):119–138, 2009.

E. Delarue, K. Voorspools, and W. D'haeseleer. Fuel switching in the electricity sector under the EU ETS: review and prospective. *Journal of Energy Engineering*, 134:40, 2008.

E. D. Delarue, A. D. Ellerman, W. D. D'haeseleer, and Others. Short-term CO2 abatement in the European power sector. 2008.

J. Delbeke, G. Klaassen, T. Van Ierland, and P. Zapfel. The role of environmental economics in recent policy making at the European commission. *Review of Environmental Economics and Policy*, 4(1):24–43, 2010.

D. Demailly and P. Quirion. 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, 2006.

D. Demailly and P. Quirion. European emission trading scheme and competitiveness: A case study on the iron and steel industry. *Energy Economics*, 30(4):2009–2027, 2008.

M.J. Domínguez Conde and J. J. García Machado. Mercados derivados de los derechos de emisión del protocolo de kioto ¿Un nuevo mercado de futuros? *Boletín Económico de ICE*, 2888:29–43, September 2006.

S. Dupressoir, J. Nieto, A. Sanchez, P. Nussbaumer, J. Riechmann, P. Bobe, D. Dubois, and Others. Climate change and employment: impact on employment in the European union-25 of climate change and CO2 emission reduction measures by 2030, 2007.

C. Egenhofer. EU ETS options for cap setting, allocation and distribution of allowances after 2012. *CEPS Background paper*, 2007.

C. Egenhofer. The making of the EU emissions trading scheme: Status, prospects and implications for business. *European Management Journal*, 25(6):453–463, 2007.

C. Egenhofer. *The EU Emissions Trading System and Climate Policy Towards 2050: Real Incentives to Reduce Emissions and Drive Innovation?* Centre for European Policy Studies (CEPS), 2011.

C. Egenhofer, European C. Platform, Belgium Centre for European Policy Studies Brussels, and Climate Policy Research Programme. *The EU Emissions Trading Scheme: Taking Stock and Looking Ahead*. Centre for European Policy Studies, 2006.

A. D. Ellerman and B. K. Buchner. The European union emissions trading scheme: origins, allocation, and early results. *Review of Environmental Economics and Policy*, 1(1):66–87, 2007.

A. D. Ellerman and B. K. Buchner. Over-allocation or abatement? a preliminary analysis of the EU ETS based on the 2005–06 emissions data. *Environmental and Resource Economics*, 41(2):267–287, 2008.

A. D. Ellerman, F. J. Convery, and C. De Perthuis. *Pricing carbon: the European Union emissions trading scheme*. Cambridge Univ Pr, 2010.

A. D. Ellerman, S. M. Feilhauer, Massachusetts Institute of Technology. Center for Energy, and Environmental Policy Research. *A Top-down and Bottom-up Look at Emissions Abatement in Germany in Response to the EU ETS*. MIT Center for Energy and Environmental Policy Research, 2008.

A. D. Ellerman and P. L. Joskow. The European union's emissions trading system in perspective. Technical report, Pew Center on Global Climate Change, 2008.

A. Denny Ellerman and R. Trotignon. Cross border trading and borrowing in the EU ETS. *The Energy Journal*, 30(Special Issue# 2):53–78, 2009.

A. Engels. The European emissions trading scheme: An exploratory study of how companies learn to account for carbon. *Accounting, Organizations and Society*, 34(3-4):488–498, 2009.

A. Engels, L. Knoll, and M. Huth. Preparing for the 'real'market: national patterns of institutional learning and company behaviour in the European emissions trading scheme (EU ETS). *European Environment*, 18(5):276–297, 2008.

A. Erias Rey and J. Dopico Castro. Los mercados de carbono en la unión Europea fundamentos y proceso de formación de precios. *Revista Galega de Economía*, 20(1):1–25, 2011.

K. Ericsson, L. J. Nilsson, and M. Nilsson. New energy strategies in the Swedish pulp and paper industry–The role of national and EU climate and energy policies. *Energy Policy*, 2011.

F. J. Evans Miranda. Escenarios de evolución de precio del mercado EU-ETS (fase II). Master's thesis, Universidad Pontificia Comillas, Madrid, Spain, July 2009.

C. Faure, A. Hildebrandt, K. Rogge, and J. Schleich. *Reputational impact of businesses' compliance strategies under the EU Emissions Trading Scheme*, pages 257–270. Springer, 2008.

D. Fazekas. Hungarian experiences with the EU ETS. *Forthcoming at: http://www. aprec. net/documents/*, 2008.

F. Frasch. Transaction costs of the EU emissions trading scheme in german companies. *Sustainable Dev. L. & Pol'y*, 7:48, 2006.

F. Gagelmann and M. Frondel. The impact of emission trading on innovation–science fiction or reality? *European Environment*, 15(4):203–211, 2005.

C. Gennaioli, R. Martin, and M. Muuls. Using micro data to examine causal effects of climate policy. forthcoming in the Handbook on Energy and Climate Change, 2012.

J. Graichen and V. Graichen. The EU emissions trading scheme in numbers. *ETC/ACC Technical Paper 2007*, 2, 2007.

V. Graichen, F. C. Matthes, L. Mohr, and K. Schumacher. Impacts of the EU ETS on industrial competitiveness in germany. In *Proceedings of the Conference on the International Dimensions of Climate Policies, Bern, Switzerland*, 2009.

O. Gras. L'introduction d'une â taxe carboneâ et ses effets sur la compétitivité en France et en Europe. *Documents de Travail de l'OFCE*, 2010.

H. Groenenberg and H. De Coninck. Effective EU and member state policies for stimulating CCS. *International Journal of Greenhouse Gas Control*, 2(4):653–664, 2008.

M. Grubb. Lessons in carbon trading. *Nature*, 465(7299):691–692, 2010.

M. Grubb and K. Neuhoff. Allocation and competitiveness in the EU emissions trading scheme: policy overview. *Climate Policy*, 6(1):7–30, 2006.

M. Grubb and German M. of the United States. *Climate Policy and industrial competitiveness: Ten insights from Europe on the EU emissions trading system*. German Marshall Fund of the United States, 2009.

T. Hagberg and S. Roth. Trading with carbon: Technological trends in swedish industries from a climate perspective. *Master Degree Project 2010: 94*, 2010.

R. W. Hahn and R. N. Stavins. The effect of allowance allocations on Cap-and-Trade system performance. *Fondazione Eni Enrico Mattei Working Papers*, page 469, 2010.

R.W. Hahn. Market power and transferable property rights. *The Quarterly Journal of Economics*, 99(4):753–765, November 1984.

R.W. Hahn and R.N. Stavins. The effect of allowance allocations on Cap-and-Trade system performance. RFF Discussion Paper 10-21, March 2010.

H. Hermann, V. Graichen, C. Gammelin, F. C. Matthes, and V. Cook. Free allocation of emission allowances and CDM/JI credits within the EU ETS analysis of selected industries and companies in Germany.

A. Herold. Comparison of verified CO 2 emissions under the EU emission trading scheme with national greenhouse gas inventories for the year 2005. *European Topic Center on Air and Climate Change, Technical Paper*, 3:81, 2007.

M. Hervé-Mignucci. Rôle du signal prix du carbone sur les décisions d'investissement des entreprises. Technical report, Université Paris-Dauphine, 2011.

B. Hintermann. Allowance price drivers in the first phase of the EU ETS. *Journal of Environmental Economics and Management*, 59(1):43–56, 2010.

V. Hoffmann and T. Trautmann. *Three types of impact from the European Emissions Trading Scheme: direct cost, indirect cost and uncertainty*. 2008.

V. H. Hoffmann. EU ETS and investment decisions::: The case of the german electricity industry. *European Management Journal*, 25(6):464–474, 2007.

V. H. Hoffmann, T. Trautmann, and M. Schneider. A taxonomy for regulatory uncertainty–application to the European emission trading scheme. *Environmental Science & Policy*, 11(8):712–722, 2008.

S. Ikkatai, K. Hori, and I. Kurita. The impact of the European union emissions trading scheme on the polish economy: Interviews with four companies in poland. *KIER Discussion Paper*, 786, 2011.

S. Ikkatai, D. Ishikawa, and K. Sasaki. Effect of the European union emission trading scheme (EU ETS) on companies: Interviews with European companies. KIER Working Papers 660, Kyoto University, Institute of Economic Research, August 2008.

A.B. Jaffe, R.G. Newell, and R.N. Stavins. A tale of two market failures: Technology and environmental policy. *Ecological Economics*, 54(2-3):164–174, August 2005.

H. K. Jeswani, W. Wehrmeyer, and Y. Mulugetta. How warm is the corporate response to climate change? Evidence from pakistan and the UK. *Business Strategy and the Environment*, 17(1):46–60, 2008.

B. Johansson, G. Modig, and L. J. Nilsson. Policy instruments and industrial responses–experiences from Sweden. *Proceedings of the 2007 ECEEE summer study Saving energy-just do it, Panel*, 7:1413–1421, 2007.

I. Juergens, J. Barreiro-Hurlé, and A. Vasa. Identifying carbon leakage sectors in the EU ETS and implications of results. 2012.

J. K. Kaldellis, D. Zafirakis, and N. Mantelis. Critical evaluation of the national allocation plans under the European union emission trading scheme. case study Greece. *Fresenius Environmental Bulletin*, 20(7):1629–1641, 2011.

N. Kautto, A. Arasto, J. Sijm, and P. Peck. Interaction of the EU ETS and national climate policy instruments : impact on biomass use. *Biomass and Bioenergy*, 38(0):117–127, 2012.

M. Kenber, O. Haugen, and M. Cobb. The effects of EU climate legislation on business competitiveness: A survey and analysis. *Washington, DC: The German Marshall Fund of the United States*, 2009.

C. Kettner, D. Kletzan-Slamanig, and A. Köppl. The EU emission trading Scheme–Sectoral allocation patterns and the effects of the economic crisis. Technical report, WIFO Working Paper, 2011a.

C. Kettner, D. Kletzan-Slamanig, and A. Köppl. The EU emission trading scheme. allocation patterns and trading flows. *WIFO Working Papers*, 2011b.

C. Kettner, A. Köppl, Stefan, and G. Thenius. Stringency and distribution in the EU emissions trading scheme: first evidence. *Climate Policy*, 8(1):41–61, 2008.

D. Kierkegaard, A. Klinton, and J. Moberg. Carbon emission costs in capital budgeting-The effect of the EU ETS on swedish companies. *rapport nr.: Industriell och finansiell ekonomi 08/09: 43*, 2009.

G. Klepper. The future of the European emission trading system and the clean development mechanism in a post-Kyoto world. *Energy Economics*, 2011.

O. Kuik and F. OOsterhuis. *Economic impacts of the EU ETS: preliminary evidence*. 2008.

X. Labandeira Villot, P. Linares Llamas, and P. Río González. La interacción del sistema europeo de comercio de emisiones con otros instrumentos de política. *Papeles de economía española*, 121:211–224, 2009.

X. Labandeira Villot and M. A. Rodríguez. Mercados para el control del cambio climático en españa. *Cuadernos económicos de ICE*, 71:177–197, 2006.

R. H. Lacombe. *Economic impact of the European Union Emission Trading Scheme: Evidence from the refining sector*. PhD thesis, Massachusetts Institute of Technology, 2008.

E. M. Lappalainen. *Risk Management Strategies And Practises In Response To The European Union Emissions Trading Scheme*. Phd Thesis, Helsinki University Of Technology, 2006.

S. Long and G. Kaminskaite-Salters. The EU ETS latest developments and the way forward.

CCLR The Carbon and Climate Law Review, 1(1):64–72, 2007.

A. Löschel, P. Heindl, V. Alexeeva-Talebi, V. Lo, and A. Detken. KfW/ZEW CO 2 panel: Vermeiden oder kaufen–Deutsche unternehmen im emissionshandel. *Zeitschrift für Energiewirtschaft*, 34(1):39–46, 2010.

P. Lund. Impacts of EU carbon emission trade directive on energy-intensive industries–Indicative micro-economic analyses. *Ecological Economics*, 63(4):799–806, 2007.

P. Lund. Impacts of EU carbon emission trade directive on energy-intensive industries–Indicative micro-economic analyses. *Ecological Economics*, 63(4):799–806, 2007.

T. Markovi-Hribernik and A. Murks. Slovenia's climate policy efforts: CO2 tax and implementation of EU ETS. *Climate Policy*, 7(2):139–155, 2007.

R. Martin, M. Muuls, L. de Preux, and U. Wagner. Industry compensation under the risk of relocation: A firm-level analysis of the EU emissions trading system. Technical report, April 2012.

R. Martin, M. Muuls, L. de Preux, and U. Wagner. Anatomy of a paradox: Management practices, organizational structure and energy efficiency. *Journal of Environmental Economics and Management*, 63(2):208–223, March 2012.

A.I. Mateos Ansótegui. Trading en los mercados voluntarios del carbono. Technical report, Universidad CEU Cardenal Herrera, 2010.

F. Matthes. Vorbereitung auf die dritte phase des EU-emissionshandelssystems. was wir bereits in der vorbereitungsphase gelernt haben, 2011.

F. Matthes, S. Gores, and H. Hermann. Zusatzerträge von ausgewählten deutschen unternehmen und branchen im rahmen des EU-emissionshandelssystems analyse für den zeitraum 2005-2012. 2011.

F. Matthes, V. Graichen, J. Repenning, C. Doble, J. Macadam, S. Taylor, D. Zanoni, and M. Chodor. The environmental effectiveness and economic efficiency of the European union emissions trading scheme: Structural aspects of allocation. *A report to WWF. Berlin*, 2005.

McKinsey and Ecofys. EU ETS review: Report on international competitiveness. *Conducted for European Commission DG Environment*, 2006.

McKinsey and Ecofys. Review of EU ETS-survey results. *Conducted for European Commission DG Environment*, 2006.

T. Merklein. Auswirkungen des EU-emissionshandels auf investitionen in der luftfahrt. *Arbeitsberichte des Lehrstuhls für Produktionswirtschaft*, 2010.

A. Mezquita, E. Monfort, and V. Zaera. Sector azulejero y comercio de emisiones: reducción de emisiones de CO2, benchmarking europeo. *Boletín de la Sociedad Española de Ceramica y Vidrio*, 48(4):211–222, 2009.

R. Morgenstern, J. E. Aldy, E. M. Herrnstadt, M. Ho, and W. A. Pizer. Competitiveness impacts of carbon dioxide pricing policies on manufacturing. *Assessing US Climate Policy Optionsâ. Resources for the Future, Washington DC (USA)*, 2007.

K. Neuhoff. Reflections on implementing EU ETS. 2011.

K. Neuhoff, M. AAhman, R. Betz, J. Cludius, F. Ferrario, K. Holmgren, G. Pal, M. Grubb, F. Matthes, K. Rogge, and Others. Implications of announced phase II national allocation plans for the EU ETS. *Climate Policy*, 6(4):411–422, 2006.

U. Oberndorfer. EU emission allowances and the stock market: evidence from the electricity industry. *Ecological Economics*, 68(4):1116–1126, 2009.

U. Oberndorfer, V. Alexeeva-Talebi, and A. Löschel. Understanding the competitiveness implications of future phases of EU ETS on the industrial sectors. 2010.

C. Okereke. An exploration of motivations, drivers and barriers to carbon management::: The UK FTSE 100. *European Management Journal*, 25(6):475–486, 2007.

S. Peterson and G. Klepper. The future of ETS and CDM in a post-Kyoto world. *Open Access publications from Kiel Institute for the World Economy*, 2010.

A. Petsonk and J. Cozijnsen. *Harvesting the Low-Carbon Cornucopia: How the European Union Emissions Trading System (EU-ETS) is Spurring Innovation and Scoring Results*. Environmental Defense, 2007.

J. Pinkse. Corporate intentions to participate in emission trading. *Business Strategy and the Environment*, 16(1):12–25, 2007.

J. Pinkse and A. Kolk. Multinational corporations and emissions trading::: Strategic responses to new institutional constraints. *European Management Journal*, 25(6):441–452, 2007.

J. P. Ponssard and N. Walker. EU emissions trading and the cement sector: a spatial competition analysis. *Climate Policy*, 8(5):467–493, 2008.

S. Pontoglio. The role of environmental policies in the eco-innovation process: evidences from the European union emission trading scheme. 2011.

G. Reece, D. Phylipsen, M. Rathmann, M. Horstink, and T. Angelini. Use of JI/CDM credits by participants in phase II of the EU ETS. *London: ECOFYS*, 2006.

M. Reguant and A. D. Ellerman. Grandfathering and the endowment effect - an assessment in the context of the Spanish national allocation plan. MIT Center for Energy and Environmental Policy Research Paper 0818, November 2008.

J. Reinaud. Ex-post evaluation of the EU ETS: Ex-post evaluation of the EU ETS: Impacts on the aluminium sector impacts on the aluminium sector, 2008.

J. Reinaud. Trade, competitiveness and carbon leakage: challenges and opportunities. *Energy, Environment and Development Programme Paper*, 9(01), 2009.

J. Reinaud and International Energy Agency. *Climate policy and carbon leakage: Impacts of* *the European emissions trading scheme on aluminium*. OECD/IEA, 2008.

C. Riestra, A. López, and E. González. El CO2 y la industria en España. de la primera asignación de derechos a la etapa post-Kioto. *Economía industrial*, 371:59–77, 2009.

P. Río Gonzalez and X. Labandeira Villot. El sistema europeo de comercio de emisiones: Diseno, funcionamiento y perspectivas. Technical report, Madrid, Spain, 2008.

R. A. Ritz. Carbon leakage under incomplete environmental regulation: An industry-level approach. 2009.

M. Robaina Alves, M. Rodr'iguez, and C. Roseta-Palma. Sectoral and regional impacts of the European carbon market in portugal. *Energy Policy*, 2011.

R. Stavins. Transaction costs and tradeable permits. *Journal of Environmental Economics and Management*, 29(2):133–148, September 1995.

K. Rogge and Fraunhofer-Institut für System-und Innovationsforschung Karlsruhe. *Increasing the ambition of EU emissions trading: an assessment of the draft second allocation plans and verified emission reports of Germany, the United Kingdom and the Netherlands; a report to Greenpeace International*. Greenpeace International, 2006.

K. S. Rogge and V. H. Hoffmann. The impact of the EU ETS on the sectoral innovation system for power generation technologies–Findings for Germany. *Energy Policy*, 38(12):7639–7652, 2010.

K. S. Rogge, J. Schleich, P. Haussmann, A. Roser, and F. Reitze. The role of the regulatory framework for innovation activities: the EU ETS and the german paper industry. *International Journal of Technology, Policy and Management*, 11(3):250–273, 2011.

K. S. Rogge, M. Schneider, and V. H. Hoffmann. The innovation impact of the EU emission trading System–Findings of company case studies in the German power sector. *Ecological Economics*, 2010.

A. Sandoff and G. Schaad. Does EU ETS lead to emission reductions through trade? The case of the Swedish emissions trading sector participants. *Energy Policy*, 37(10):3967–3977, 2009.

M. Sato, M. Grubb, J. Cust, K. Chan, A. Korppoo, and P. Ceppi. Differentiation and dynamics of competitiveness impacts from the EU ETS. CWPE 0712, Faculty of Economics, University of Cambridge, UK, 2007.

J. Schleich, R. Betz, and K. Rogge. EU emission trading: better job second time around? *Working Papers*, 2007.

J. Schleich, K. Rogge, and R. Betz. Incentives for energy efficiency in the EU ETS. *Energy Efficiency*, 2(1):37–67, 2009.

A. Schmitz, J. Kamiski, B. Maria Scalet, and A. Soria. Energy consumption and CO2 emissions of the European glass industry. *Energy Policy*, 39(1):142–155, 2011.

R. J. Shapiro. Addressing the risks of climate change: The environmental effectiveness and economic efficiency of emissions caps and tradeable permits, compared to carbon taxes. *February.[http://www. theamericanconsumer. org/shapiro. pdf]*, 2007.

H. Sigman. Monitoring and enforcement of climate policy, 2011.

S. Siitonen and P. Ahtila. The influence of operational flexibility on the reduction of c02 emissions in industrial energy production. *Chemical Engineering*, 18:3, 2009.

S. Siitonen and P. Ahtila. The influence of operational flexibility on the exploitation of CO2 reduction potential in industrial energy production. *Journal of Cleaner Production*, 18(9):867–874, 2010.

J. Sijm. The impact of the EU emissions trading scheme on the price of electricity in The Netherlands. *Energy research Centre of the Netherlands (ECN), Policy studies, Petten/Amsterdam*, 2004.

J. Sijm, M. Berk, M. G. J. den Elzen, and R. A. van den Wijngaart. Options for post-2012 EU burden sharing and EU ETS allocation. *Scientific Assessment and Policy Analysis for Climate Change*, 2007.

G. E. Sinden, G. P. Peters, J. Minx, and C. L. Weber. International flows of embodied CO2 with an application to aluminium and the EU ETS. *Climate Policy*, 11(5):1226–1245, 2011.

J. B. Skjaerseth and J. Wettestad. Fixing the EU emissions trading system? Understanding the post-2012 changes. *Global Environmental Politics*, 10(4):101–123, 2010.

M. Skou Andersen. Environmental and economic implications of taxing and trading carbon: Some European experiences. *Vt. J. Envt. L.*, 10:61, 2008.

M. Skou Andersen. Europe's experience with carbon-energy taxation. *SAPI.EN. S. Surveys and Perspectives Integrating Environment and Society*, (3.2), 2010.

A. Slechten. Intertemporal links in cap-and-trade schemes. *Working Papers ECARES*, 2011.

R. Smale, M. Hartley, C. Hepburn, J. Ward, and M. Grubb. The impact of CO2 emissions trading on firm profits and market prices. *Climate Policy*, 6(1):31–48, 2006.

P. Söderholm. Technological change and carbon markets. *Low Carbon Economy*, 1, 2010.

C. Stenqvist and L. J. Nilsson. Energy efficiency in energy-intensive industries: an evaluation of the Swedish voluntary agreement PFE. *Energy Efficiency*, pages 1–17, 2011.

J. Sumner, L. Bird, and H. Dobos. Carbon taxes: a review of experience and policy design considerations. *Climate Policy*, 11(2):922–943, 2011.

R. A. F. Tomás, F. Ramôa Ribeiro, V. M. S. Santos, J. F. P. Gomes, and J. C. M. Bordado. Assessment of the impact of the European CO2 emissions trading scheme on the Portuguese chemical industry. *Energy Policy*, 38(1):626–632, 2010.

R. Trotignon. Combining cap-and-trade with offsets: Lessons from CER use in the EU ETS in 2008 and 2009. *Working Papers*, 2011.

R. Trotignon and A. Delbosc. Allowance trading patterns during the EU ETS trial period: What does the CITL reveal. *Climate Report*, 13, 2008.

R. Trotingnon, A. D. Ellerman, Massachusetts Institute of Technology. Center for Energy, and Environmental Policy Research. *Compliance behavior in the EU-ETS: Cross border trading, banking and borrowing*. MIT Center for Energy and Environmental Policy Research, 2008.

A. Tuerk, A. Cowie, and A. Leopold. The influence of emissions trading schemes on bioenergy use. *IEA task*, 38, 2011.

A. Tuerk, M. Mehling, C. Flachsland, and W. Sterk. Linking carbon markets: concepts, case studies and pathways. *Climate Policy*, 9(4):341–357, 2009.

H. Van Asselt. The EU ETS in the European climate policy mix: Past, present and future.

A. Vasa. Certified emissions reductions and CDM limits: Revenue and distributional aspects. 2011.

F. Venmans. L’efficacité environnementale et économique du marché du carbone européen. *Courrier hebdomadaire du CRISP*, (14):5–91, 2011.

R. Veugelers. Activating the private clean innovation machine. *FBE Research Report MSI_1116*, 2011.

N. Walker. Concrete evidence? An empirical approach to quantify the impact of EU emissions trading on cement industry competitiveness. Technical report, University College Dublin, 2006.

N. Walker, M. Bazilian, and P. Buckley. Possibilities of reducing CO2 emissions from energy-intensive industries by the increased use of forest-derived fuels in Ireland. *Biomass and Bioenergy*, 33(9):1229–1238, 2009.

M. W. Wara and D. G. Victor. A realistic policy on international carbon offsets. Technical report, 2008.

D. A. Weisbach. Carbon taxation in Europe: Expanding the EU carbon price. 2011.

G. Westner and R. Madlener. The impact of modified EU ETS allocation principles on the economics of CHP-based district heating systems. *Journal of Cleaner Production*, 2011.

J. Wettestad. EU energy-intensive industries and emission trading: losers becoming winners? *Environmental Policy and Governance*, 19(5):309–320, 2009.

J. Wettestad. Interaction between EU carbon trading and the international climate regime: synergies and learning. *International Environmental Agreements: Politics, Law and Economics*, 9(4):393–408, 2009.

J. Woodley. Reviewing the European trade. *Public Utilities Fortnightly*, (3):22–25, 2007.

M. Wraake, D. Burtraw, A Löfgren, and L. Zetterberg. What have we learnt from the European union’s emissions trading system? *AMBIO: A Journal of the Human Environment*, pages 1–

11, 2012.

Haishan Yu. The EU ETS and firm profits: An ex-post analysis for Swedish energy firms. Technical report, February 2011.

G. Zachmann and C. Von Hirschhausen. First evidence of asymmetric cost pass-through of EU emissions allowances: Examining wholesale electricity prices in Germany. *Economics Letters*, 99(3):465–469, 2008.

D. Zahare and M. Rosa. Analysis of energy intensive enterprises under EU emission trading system in Latvia. *Scientific Journal of Riga Technical University. Environmental and Climate Technologies*, 7(-1):125–132, 2011.

L. Zetterberg, K. Holmgren, and Institutet för vatten-och luftvaardsforskning Sweden. *Sectoral agreements and competitive distortions: a Swedish perspective*. IVL report ; B1835. IVL, Swedish Environmental Research Institute, 2009.

L. Zetterberg, M. Wraake, T. Sterner, C. Fischer, and D. Burtraw. Short-Run allocation of emissions allowances and Long-Term goals for climate policy. *AMBIO: A Journal of the Human Environment*, 41:23–32, 2012.

Y. J. Zhang and Y. M. Wei. An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect. *Applied Energy*, 87(6):1804–1814, 2010.

Annex A: Search, Inclusion and Quality criteria

Relevant literature was searched for using Google Scholar[21]. Besides, close to eighty individuals working in government, the EU Commission, think tanks, lobby groups and academia were contacted personally as a further search step.

This ensured the collection of information on both published and unpublished research in economics as well as wider evidence published as policy papers or industry studies. These are search terms that were included.

EU ETS ex-post
EU ETS industry
EU ETS ex-post industry
EU ETS impact
EU ETS effectiveness
EU ETS impact emissions
EU ETS competitiveness
EU ETS CDM
EU ETS JI
EU ETS Cement
EU ETS Chemicals
EU ETS Paper
EU ETS Behavior/Behaviour
EU ETS management
EU ETS evaluation
EU ETS effects
EU ETS lessons
EU ETS low carbon technology
EU ETS abatement
EU ETS minerals
EU ETS aluminium
EU ETS steel
EU ETS ceramic
EU ETS combined heat and power

[21] Using alternative engines such as JStore, IDEAS, and Social Science Research Network proved to yield similar results for the first three search terms, and Google Scholar was chosen as the most comprehensive.

For each term the search was constrained to publications dating from 2005 or later and to the first 200 records resulting from the search engine. In addition, equivalent searches were made in German, French and Spanish.

The websites of research institutes that appear to host a research team on the EU ETS were also searched for specifically. They are the following:

CEPS Brussels
IDDRI
Wuppertal Institut
CEPS Brussels
Oko-Institut
EU Commission
CE Delft
Climate Strategies

To narrow down the initial the following **inclusion criteria** were applied:

Analyses of the impact of the EU ETS on emissions
Impact on use of CDM/JI
Impact on competitiveness
Impact on innovation/investment
Policy interaction of EU ETS with other policy
Mechanism of change in behaviour
Not solely analysing energy industry
Not modelling based
Not analysis of EUA price formation and patterns
Not policy design – or theoretical analysis or description of the rules
Not prior to 2005
Lessons for phase III impact /effectiveness (if based on evidence from phase I / II)
Indirect impact / outside EU – e.g. where it has led by example to the

Moreover we apply the following more quality based criteria (for inclusion):

Data/ evidence driven
Academic papers
Reports
Discussion papers
Not opinion piece

Once the 56 papers were included according to the criteria set out above, a secondary quality analysis was performed to answer the research questions set out in the introduction. When valuing and discussing the evidence provided in each paper to perform the analysis the following quality criteria will have been applied. None of the papers would be excluded on the grounds of these secondary quality criteria.

Data reliability
 	
Reported behaviour (derived from survey data):
• Sampling frame representative yes/no
• Sample size sufficient for inference yes/no
• Response rate sufficiently high to mitigate selection bias yes/no
• Survey method (questionnaire online or paper&pencil, telephone interview, interview in person)
• Timing (ex ante/ex post/both); recalled or actual changes
 	
Revealed behaviour (derived from performance data):
• Sampling frame representative yes/no
• Official data from administrative sources yes/no
• Sample size sufficient for inference yes/no
• Possible issues:
    o Quantities vs. total values (e.g. physical output vs revenue, energy expenditures vs. energy usage in kWh)
    o Appropriate deflators available yes/no

Data pertinence for the research question: Is it data on the variables of interest to the literature review that are being considered?
Industry vs firm-level data analysis Firm level data typically facilitates more robust identification designs and as well as addressing heterogeneity.
Geographical scope of the analysis: Focus on a single country or relevant for the EU as a whole? How general are the results of the analysis for other countries and firms?
Correlation or causal identification strategy For example, the following would be a ranking of causal identification strategies in order of increasing credibility: • Low: Correlation between ETS participation and levels of outcome variables • Medium: Correlation between change in ETS participation status and change in outcome variables (differences-in-differences) • High: Correlation between change in outcome variables and change in variables that drive ETS participation but have no direct impact on the outcome variables (differences-in-differences with instrumental variables). Assessment of the quality of the instrumental variable, i.e. of the credibility of the assertion that it does not affect outcome variables directly but only through its effect on ETS participation. e.g. is there a plausible counter example? Other techniques such as matching estimators or regression-discontinuity design would fit the medium and high categories, depending on how well the application at hand satisfies

the assumptions upon which they are based.

These criteria are equivalent to those that would be used when peer-reviewing papers for an academic journal. In other words, rigorous academic standards were applied to assess each piece of evidence, by comparing it to the state-of-the-art in current research methods. In particular, these standards applied to the suitability and quality of the data used, as well as the methodology employed to identify the effect of the EU ETS.

As an example of the question of correlation vs. causality, much of the existing empirical - i.e. not simulation-based - literature examines the impact of climate policies in terms of time series variation only but does not clearly establish causality. For instance, early studies on the Climate Change Levy, which was introduced in 2001, looked at energy consumption for the UK industry as a whole or at the sectoral level and examined if, relative to pre-2001 trends, there was a change after 2001. The issue with such an approach is that it confounds the effects of the policy with all other factors that might have changed in a non-linear way after 2001. This could include other policies - for instance 2001 also saw the introduction of the UK Carbon Trust - or other time-varying shocks to the economy.

While papers applying a sector-level analysis in this literature review were included, more credibility was given to papers that could control for these issues, for example by using firm-level data to evaluate the EU ETS.

Annex B: Glossary

Technical terms that have been used in this report are explained below.

Term	Description
Causality, Reverse Causality	Direction of causation between different events, for example, the events "reduction of CO_2 emissions of a firm" and "firm is subject to a policy". We typically would think that the causality runs from policy to emission reductions. However, when looking at data we also need to consider the possibility that the causality runs the other way round; i.e. that firms who reduced emissions are more likely to be affected by the policy. This could be because the policy is discretionary or voluntary (e.g. like the Climate Change Agreements). Alternatively, the reverse causality could be driven by other factors that are not observed. For example, if we were to compare the level of emissions in ETS and non-ETS firms we would always find that ETS firms have higher emissions than non ETS firms. A naïve observer might conclude that ETS regulation causes this higher level. However, in reality the causation is in reverse: because larger and more energy intensive firms are the target of the ETS regulation we find the observed pattern in the data.
Co-integration	Co-integration is a property of certain kinds of times series data. If two variables are found to be co-integrated there is likely to be a causal relationship between them (although it is not clear in which direction). The term co-integration was coined to differentiate stable relationships from spurious correlation of trending time series. A naïve correlation test of many time series would not be rejected simply because they share the common feature of trending upwards (or downwards). For example, consider the time series of the height of a child from birth until its 18th birthday and the time series of GDP at the same time. Because both are trending upwards they are likely to be highly correlated if no further transformation of the data is undertaken.
Control Group, Treatment group	To establish the causal impact of a policy on an outcome for "treated" units or the "Treatment Group" (e.g. firms, we think of them like patients in a drug trial) we need to estimate what the outcome would have been had they not been treated. We typically do this by comparing them to a group of units that are similar to the treated units. This is the Control Group. Often it is difficult to find units that are exactly similar. However, if we have a large number of units it is enough that they are not systematically different on average concerning the outcome variable. Sometimes (i.e. in a difference in differences design) researchers make the assumption that treatment and control group are systematically different but that the difference is constant over time were it not for the policy intervention.
Dummy Variable	Variable that captures a binary qualitative state rather than a continuous quantitative outcome. Typically these variables take on a

Term	Description
	value of either one – indicating that the state is true – or zero – indicating that the state is not true. For example, a dummy variable could be defined to capture whether or not a firm was regulated by the ETS.
Elasticity	A unit free way to express how one variable responds to changes in another. An elasticity reports the response as a percent change of one variable after a one percent change in another. For instance the carbon price elasticity of carbon emissions indicates by how many percent carbon emissions change if the carbon price goes up by 1 percent.
Endogeneity Problem	In an econometric model, endogeneity arises when an explanatory variable is correlated with the error term. This violates the fundamental necessity to distinguish between dependent and independent variables in an econometric model. It is often the result of reverse causality or omitted variable bias.
Event study	The event-study method exploits high-frequency data from a very short time window before and after the treatment (the "event") to estimate the effect of the event on an outcome. This effect can be given a causal interpretation under the assumption that any confounding factors between the treatment and control groups remain unchanged during the event window.
Gravity Equation	A popular model in trade theory inspired by Newton's research on gravity. Gravity equation studies typically look at trade between two countries and try to explain it by various characteristics of the country respective countries (e.g. their GDPs) as well as a term that allows distance to decay geometrically. Thus, what would be the force of gravity in Newton's case becomes the trade flow between the two countries.
Identification	The procedure of assigning a concrete value to a theoretical parameter. For example, if we think that two variables Y and X can be linked by a line, then the procedure how we go about to find the slope of the line would be the identification. Sometimes it is not possible to identify certain parameters. For instance, with a dataset that only reports on firms in the ETS (e.g. like the CITL) we cannot identify an ETS effect.

Term	Description
Instrumental Variable	The Instrumental Variable approach is an econometric strategy designed to address reverse causality/endogeneity issues. Suppose we have a policy treatment which we want to assess, but think it is endogenous. This could arise because the treatment is voluntary and treated units (e.g. firms) with a certain type of outcome tend to participate in the programme. An instrumental variable would be a factor that impacts on a firms decision to participate without having any other systematic relation to the outcome. Identification of the causal impact can then be achieved using this instrumental variable. For instance, suppose we want to evaluate the impact of free energy audits as undertaken by the Carbon Trust. We might be concerned that firms that are already more energy efficient might be more likely to participate in the audit so that comparing the energy efficiency of audited firms with that of non-audited firms would lead to an overestimate of the effect of the Carbon Trust. Suppose the Carbon Trust undertakes a telephone marketing campaign of its auditing service where contacted businesses are selected at random. Because of the random selection of businesses there should be no systematic relation between which businesses are contacted and their energy usage. However, if the marketing campaign is successful it should lead to increased audit participation of some of the contacted businesses. We can then identify the impact of Carbon Trust auditing by comparing the energy efficiency of contacted with non contacted firms (taking into account how many actually ended up participating)
OLS(Ordinary Least Squares)	A basic econometric method to identify an econometric model. Suppose a model is a line linking two variables Y and X, then OLS would require that we find the slope of the line by minimizing the squared deviation of Y from the line.
Omitted variable bias	An issue closely related to endogeneity and reverse causality. There is an (omitted variable) bias in an estimate of policy impact if we fail to control for an important heterogeneity between units treated and non treated by the policy.
Panel data	Type of data which provides time series information, typically for a large number of observational units over time. This is different from pure time series data; i.e. data for just one observational unit over time (e.g. just UK GDP per quarter) or cross sectional data; i.e. one observation per unit.
Regression discontinuity design	An approach to identify the causal impact of a policy that can be applied if the policy can be expected to create sudden jumps in the outcome when moving from one observation to another, which are unlikely to occur otherwise. This typically applies if policy treatment depends on exceeding or not exceeding certain thresholds of some

Term	Description
	variable.
Selection bias	A bias in the estimate of the treatment impact because units with certain type of outcome systematically select themselves (or are selected) into the treatment.

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