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THE IMPACT OF THE EU EMISSIONS TRADING SYSTEM ON COMPETITIVENESS AND CARBON LEAKAGE: THE ECONOMETRIC EVIDENCE

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Abstract. This paper carefully surveys the econometric literature that tests for competitiveness effects and related carbon leakage caused by the EU Emissions Trading System (EU ETS). The results of this literature tell us that to date there is no evidence of the EU ETS having had widespread negative or positive effects on the competitiveness of regulated firms, nor is there evidence of significant carbon leakage. However, the paper also identifies three important caveats to this general conclusion. Firstly, the evidence we have still largely refers to the first two trading periods, namely Phases I (2005–2007) and II (2008–2012). Secondly, some heterogeneity of estimated effects is observed, but patterns, notably sectoral patterns, hardly emerge. Thirdly, very little explored is whether the EU ETS has had long-term effects on the economy via investment leakage or firm dynamics. Further empirical studies investigating these long-term effects are particularly desirable.

Keywords. EU ETS; Competitiveness effects; Carbon leakage; Econometric evidence

1. Introduction

In operation since 2005, the EU Emissions Trading System (EU ETS) is the cornerstone of the EU's strategy to decarbonize the economy. Covering about 45% of the EU's greenhouse gas (GHG) emissions, it remains today the largest ETS in the world.[1] The EU ETS imposes a cap on emissions of carbon dioxide, nitrous oxide and perfluorocarbons from over 11,000 heavy energy-using and electricity-generating installations in the EU, Norway, Iceland and Liechtenstein, as well as from flights within the region. The cap declines over time so that by the end of the current trading period, which is Phase III (2013–2020), emissions under the EU ETS will have decreased by at least 21% compared to 2005. By the end of Phase IV (2021–2030), they will have decreased by at least 43% relative to the same year (European Parliament and Council, 2018). The EU ETS is a rather sophisticated policy instrument whose regulation has evolved considerably over the years, partly as a result of a learning by-doing process and partly in response to unanticipated events, including first and foremost the consequences of the Great Recession.

Whether implemented through emissions trading or carbon taxation, the prime rationale for carbon pricing is its cost effectiveness in reducing emissions (Baumol and Oates, 1971; Baranzini *et al.*, 2017). In a cap-and-trade system, such as the EU ETS, carbon prices are determined by the interplay between supply and demand of emission allowances. Simply described, allowance supply is given by the cap, which reflects a policy decision, whereas allowance demand depends on the needs and behaviour of

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regulated operators, typically firms.[2] If the allowance market is efficient, marginal (emission) abatement costs are equalized across regulated operators via allowance trading, thus entailing that cheaper abatement opportunities are exploited first.[3]

So far, much of the experience with carbon pricing around the world has proved difficult, however. Above all, concerns about potential negative effects on firms' international competitiveness, due to increased production costs, have hindered unilateral use, or deeper unilateral use, of carbon pricing. The problem of unilateral carbon pricing, or of unilateral climate mitigation policy more generally, in an open economy is not only one of international competitiveness but also of environmental effectiveness. This is because a reduction in domestic emissions resulting from deteriorated competitiveness is offset in some measure by higher emissions in countries where climate mitigation policy is absent or less stringent. A mere displacement of GHG emissions (hence with no effect on the climate) induced by different levels of climate mitigation stringency is called carbon leakage.[4] This issue has been central to the EU ETS throughout its history and is set to become even more relevant in the future given the progressive tightening of the system.[5] The same concerns about competitiveness and carbon leakage have underlain international climate change negotiations since their very beginning, about 30 years ago.

A reason why the problem of unilateral carbon pricing continues to attract the interest of economists is that the adverse effects above described are neither unequivocal nor inevitable. On the one hand, the pollution haven hypothesis, which predicts pollution-intensive production to shift to countries with weaker environmental policy, is supported only by weak empirical evidence (Grether *et al.*, 2012). On the other, evidence on the Porter hypothesis (Porter and van der Linde, 1995), suggesting that market-based environmental policies (as carbon pricing) may, in fact, lead to improved competitiveness by spurring new production processes and products, remains inconclusive (Brännlund and Lundgren, 2009; Ambec *et al.*, 2013; Dechezleprêtre and Sato, 2017). In any case, unilateral carbon pricing can be accompanied by measures guarding against its potential adverse effects.

Over the past dozen years, a large econometric literature has accumulated seeking out evidence of competitiveness effects of the EU ETS and related carbon leakage. While clearly, the pollution haven hypothesis and the Porter hypothesis are fundamental concepts in the background of this literature, the same studies deal with the more specific question of whether the EU ETS net-of-free-allowances affected regulated businesses. Free allocation remains a central feature of the EU ETS and one to which so far most regulatory interventions have been related. Thus, it has always been important to establish whether any sector suffered competitiveness losses due to the EU ETS, despite free allocation, or to the contrary, whether any sector profited from regulation due to over-allocation of free allowances – a controversial issue that has mainly concerned the first two trading periods.

This paper offers the most comprehensive review to date of the econometric literature on the competitiveness effects of the EU ETS and related carbon leakage. Previous authoritative reviews that partly covered the same literature were not exclusively focused on competitiveness effects or on the EU ETS. Notably, Martin *et al.* (2016) also cover the effects of the EU ETS on emissions abatement and on innovation, while Dechezleprêtre and Sato (2017) consider competitiveness effects of existing environmental regulations in general, thus including the EU ETS but also well beyond it. The narrower scope of our investigation means that we can afford to be more exhaustive within the targeted literature. Our search, which terminated in May 2019, led to the identification of 35 relevant studies. Two-thirds of these are articles published on peer-reviewed international journals (25). The others are high-quality working papers (9) – most of which may well become journal articles in the coming months – and a book chapter.[6] Before describing the studies in detail, we map the literature by distinguishing four main types of effects, while also highlighting empirical differences concerning the approach, the data and the sample coverage. The four types of effects regard the competitive performance of regulated firms or sectors, investment leakage, carbon leakage, and stock returns of regulated companies. The paper also differs from previous literature reviews in providing econometric details which allow a better understanding of the results and of the challenges of the different approaches.

The rest of the paper is organized as follows. Section 2 maps the literature and illustrates two popular econometric approaches. Section 3 reviews the literature in detail. Section 4 discusses the evidence and some empirical challenges. Section 5 concludes.

2. Mapping the Literature

The first part of this section systematizes the econometric literature on the competitiveness effects of the EU ETS and related carbon leakage, highlighting the variety of effects, approaches and data. The second part focuses on two particularly popular approaches.

2.1 *Different Types of Effects*

About half (18) of the studies reviewed in this paper cover a range of competitive performance indicators at the firm (most often) or sector level. Competitiveness generally refers to the ability of a firm or sector (as the sum of firms) to survive and grow in terms of market share or profits (Dechezleprêtre and Sato, 2017). Thus, the concept is sufficiently broad to allow for many different competitiveness indicators (WIFO and ZEW, 2017). In the context of unilateral carbon pricing, special concerns about potential negative effects on international competitiveness and related carbon leakage mean that international trade indicators (i.e. export and import-related variables) are particularly relevant, as being more direct measures for those outcomes. In the same literature, however, frequently used indicators of competitive performance also include more general ones related to firms' profits, revenues, employment and productivity.

Carbon leakage occurring due to deteriorated international competitiveness is not only detectable in a country's trade balance. Whether induced by realized or expected negative effects of domestic climate policy on international competitiveness, the diversion of investments to production activities abroad, where climate policy is less stringent, also leads to carbon leakage. In addition, investment leakage, as this phenomenon is called, results in long-lasting economic losses. Despite its special relevance, however, only two studies (Borghesi *et al.*, 2018; Koch and Mama, 2019), out of all those that we found, analyse the effects of the EU ETS on regulated firms' foreign direct investments (FDIs). Conceptually, closely related to the same studies is a third one (Aus dem Moore *et al.*, 2019) which looks at the effects of the EU ETS on regulated firms' holdings of tangible fixed assets, as an (indirect) indicator for industrial relocation.

To the best of our knowledge, so far only two studies (Dechezleprêtre *et al.*, 2019; Naegele and Zaklan, 2019) are also those testing for direct evidence of carbon leakage; that is, for whether emissions outside the EU increased as a consequence of the EU ETS. In this case, the very small number of works may be explained by the greater empirical challenges that the particular research question entails. Compared to econometric identification of competitiveness effects, identification of carbon leakage is indeed less immediate. Much more data are ultimately needed to establish any plausibly causal relationship between the EU ETS and changes in emission levels abroad.

Finally, a fourth, quite numerous groups of studies (12) investigate how carbon prices (i.e. the prices of emission allowances) in the EU ETS affected company stock returns. This subset of the literature clearly distinguishes itself from the rest for the specific underlying conceptual framework. Under capital market efficiency assumptions, stock returns are taken to reflect investors' expectations on companies' future profitability. Thus, in this sense, the effect of carbon prices on firm competitiveness is assessed through the lens of investors. Moreover, stock returns interpreted this way are a forward-looking measure of expected profitability, rather than an indicator of actual profitability. This is relevant because, as Rassier and Earnhart (2015) show, the effects of carbon prices on expected profitability and on actual profitability may turn out not to coincide.

2.2 *Different Approaches and Data*

In the following, the literature in question is mapped with respect to the different types of econometric approaches and data. Relevant information is summarized in Table 1.

2.2.1 *Approaches*

The frequency with which the difference-in-differences (DiD) approach is encountered in the literature evaluating the performance of the EU ETS (not only concerning competitiveness effects) justifies its labelling as the workhorse model in this field. Withholding more technical details for later (Section 2.3.1), the attractiveness of the DiD approach mainly rests in the clear-cut causal interpretation of the effects that the researcher can derive. These are typically the average effects of firm participation in the EU ETS on one or more variables of interest, be it profits, turnover, FDIs, etc. Such effects quantify the average difference with the no-EU ETS counterfactual (i.e. the alternative situation had the EU ETS not been there), for the universe or a subset of regulated firms (or installations/plants[7]). Also, the DiD approach conveniently allows to capture the net causal effect of the EU ETS without having to specify a relationship between carbon prices and the given dependent variable.

The second most frequently used approach in this literature is the multi-factor model (MFM) of stock returns. As the name suggests, its use is specific to the group of studies analysing the effects of changes in carbon prices, as reflected in the returns of emission allowances, on company stock returns. Importantly, while the DiD approach is purely empirical, the MFM approach reflects economic theory, specifically asset pricing theory. In this sense, the two approaches are worlds apart. Given its popularity, the MFM approach too is presented in some detail below. The studies that do not employ the DiD approach or the MFM approach either employ time-series models or panel-data models. In the first case, the effect of the EU ETS on the dependent variable is more specifically that of carbon prices. In the second, estimated effects can refer to participation in the EU ETS, to carbon prices or some other measure of regulatory stringency. Two of the studies employing panel data models (Costantini and Mazzanti, 2012; Naegele and Zaklan, 2019) more specifically estimate gravity-type models stemming from international trade theory.

2.2.2 *Dependent Variables: Statistical Unit and Frequency*

Most econometric applications in this literature use micro-level data, with firms or – only on very few occasions – plants as statistical units.[8] Alternatively, depending on the model type, industrial sectors are the statistical unit. This second case mainly applies to those studies looking at the effects of the EU ETS on international trade flows. Micro-level analyses are encouraged by the fact that information on regulated installations and allowance transactions is freely accessible through the EU Transaction Log (EUTL).[9] Information in the EUTL alone is usually not sufficient to estimate useful econometric models. However, additional information on regulated firms is drawn from company databases, typically commercial licensed databases (more often) or public ones normally used for administrative purposes.

Apart from the literature on stock returns, there is no perfect or almost perfect correspondence between the type of effect tested, the econometric approach and the data used. Still, some correlations can be observed. As regards the time frequency of the dependent variable, annual data are, in general, by far the most common. Because of parameter identification needs, however, monthly or quarterly data are preferred in times-series applications, which usually concern analyses of trade flows. Similarly, only daily or monthly data are used in the MFM applications to stock returns.

2.2.3 *Sample Coverage*

In this literature, time, countries and sectors are critical dimensions of estimation samples. The time dimension is central considering the dynamic nature of the EU ETS, as reflected in the evolution of

Table 1. Overview of the Literature Examined.

Study	Effect type	Approach	Dependent variable		Sample coverage		
			Level	Frequency	EU ETS years	Country	Sector
Yu (2013)	Competitive performance	DiD	Firm	Annual	2005–2006	Single (SE)	Single (Energy)
Reinaud (2008)	Competitive performance	Time series	Sector	Quarterly	2005–2007	Multiple	Single (Aluminium)
Commins *et al.* (2011)	Competitive performance	Panel data	Firm	Annual	2005–2007	Multiple	Multiple
Costantini and Mazzanti (2012)	Competitive performance	Panel data[a]	Sector	Annual	2005–2007	Multiple	Multiple
Abrell *et al.* (2011)	Competitive performance	DiD	Firm	Annual	2005–2008	Multiple	Multiple
Lundgren *et al.* (2015)	Competitive performance	Panel data	Firm	Annual	2005–2008	Single (SE)	Single (Paper)
Chan *et al.* (2013)	Competitive performance	DiD	Firm	Annual	2005–2009	Multiple	Multiple
Petrick and Wagner (2014)	Competitive performance	DiD	Firm	Annual	2005–2010	Single (DE)	Multiple
Colmer *et al.* (2018)	Competitive performance	DiD	Firm	Annual	2005–2012	Single (FR)	Multiple
Jaraite and Di Maria (2016)	Competitive performance	DiD	Firm	Annual	2005–2010	Single (LT)	Multiple
Sartor (2012)	Competitive performance	Time series	Sector	Quarterly	2005–2011	Multiple	Single (Aluminium)
Marin *et al.* (2018)	Competitive performance	DiD	Firm	Annual	2005–2012	Multiple	Multiple
Branger *et al.* (2016)	Competitive performance	Time series	Sector	Monthly	2005–2012	Multiple	Multiple
Lutz (2016)	Competitive performance	DiD	Firm	Annual	2005–2012	Single (DE)	Multiple
Löschel *et al.* (2018)	Competitive performance	DiD	Firm	Annual	2005–2012	Single (DE)	Multiple
Dechezleprêtre *et al.* (2018)	Competitive performance	DiD	Firm	Annual	2005–2012	Multiple	Multiple
Klemetsen *et al.* (2016)	Competitive performance	DiD	Plant	Annual	2005–2013	Single (NO)	Multiple
Boutabba and Lardic (2017)	Competitive performance	Time series	Sector	Monthly	2005–2015	Multiple	Multiple
Borghesi *et al.* (2018)	Investment leakage	DiD	Firm	Annual	2005–2010	Single (IT)	Multiple
Aus dem Moore *et al.* (2019)	Investment leakage	DiD	Firm	Annual	2005–2012	Multiple	Multiple
Koch and Basse Mama (2019)	Investment leakage	DiD	Firm	Annual	2005–2013	Single (DE)	Multiple
Naegele and Zaklan (2019)	Carbon leakage	Panel data[a]	Sector	Annual	2007, 2011	Multiple	Multiple
Dechezleprêtre *et al.* (2019)	Carbon leakage	Panel data	Firm	Annual	2007–2014	Multiple	Multiple
Jong *et al.* (2014)	Stock returns	MFM[b]	Firm	Daily	2005–2006	Multiple	Multiple
Oberndorfer (2009)	Stock returns	MFM	Firm	Daily	2005–2007	Multiple	Single (Energy)
Veith *et al.* (2009)	Stock returns	MFM	Firm	Daily	2005–2007	Multiple	Single (Energy)
Bushnell *et al.* (2013)	Stock returns	MFM[b]	Firm	Daily	2005–2007	Multiple	Multiple
Mo *et al.* (2012)	Stock returns	MFM	Firm	Daily	2006–2009	Multiple	Single (Energy)

(*Continued*)

Table 1. *Continued.*

Study	Effect type	Approach	Dependent variable		Sample coverage		
			Level	Frequency	EU ETS years	Country	Sector
Venmans (2015)	Stock returns	MFM	Firm	Daily	2007–2011	Multiple	Multiple
Oestreich and Tsiakas (2015)	Stock returns	MFM	Firm	Monthly	2005–2012	Single (DE)	Multiple
Tian *et al.* (2016)	Stock returns	MFM	Firm	Daily	2005–2012	Multiple	Single (Energy)
Pereira da Silva *et al.* (2015)	Stock returns	MFM	Firm	Daily	2013–2014	Single (ES)	Multiple
Pereira da Silva *et al.* (2016)	Stock returns	MFM	Firm	Daily	2008–2014	Single (ES)	Single (Energy)
Moreno and Pereira da Silva (2016)	Stock returns	MFM	Firm	Daily	2008–2015	Single (ES)	Multiple
Bernardini *et al.* (2019)	Stock returns	MFM	Firm	Monthly	2006–2016	Multiple	Single (Energy)

Note: [a]Gravity-type model of international trade.
[b]event study.

carbon prices and in the many regulatory changes that have taken place over the years. Most studies are based on datasets covering Phase I (2005–2007) or both Phases I and II (2008–2012). As Table 1 shows, only 20% of all the studies reviewed draw on data stretching as far as the first years of Phase III (2013–2020). This is relevant because major changes were introduced in the third trading period, most notably regarding free allocation rules (Verde *et al.*, 2019). Besides, carbon prices have increased dramatically in the final part of Phase III (a fourfold increase between autumn 2017 and autumn 2018). As regards the country and sectoral coverage, less than half of the studies draw on samples covering both multiple countries and multiple sectors. Most of the others either cover multiple sectors or multiple countries (while covering single countries and single sectors, respectively), with only few covering a single sector in a single country.

2.3 *Two Popular Approaches*

The DiD approach and the MFM of stock returns are here briefly described with specific reference to their application to the EU ETS.

2.3.1 *Difference-in-Differences*

The DiD approach is one popular econometric method used to assess a certain effect of a policy intervention or other treatment of interest (Abadie and Cattaneo, 2018). The EU ETS happens to generate the basic data structure that any type of DiD application requires. First, as the EU ETS only covers part of the economy, some firms are regulated, while others are not. That is, some firms own installations that are subject to the EU ETS, while other firms (many more) do not. Second, longitudinal data on some relevant variables can be available for both regulated and non-regulated firms, before and after the onset of the EU ETS.

By the DiD approach, the average causal effect of the EU ETS on a variable of interest Y (say, profits) is inferred by comparing its average variations for a group of regulated firms (treatment group) and for another one of non-regulated firms (control group), over a time interval striding the start of the EU ETS. The difference between the two variations is the effect ascribed to the EU ETS. Identification of the causal effect rests on the so-called common trend assumption. In our context, this assumption means that, had the EU ETS not been introduced, the two Y averages for regulated and non-regulated firms would have continued to develop in parallel. Other relevant identifying assumptions are the common support assumption and the stable unit treatment value assumption (SUTVA). Again, in this context, the first posits that both regulated and non-regulated firms have positive conditional probabilities (on observables $\boldsymbol{X}$) to be treated as well as not to be treated. This implies that there is some overlap in the observed characteristics of the two groups, and therefore, that the risk of unobserved time-variant differences is limited.[10] The SUTVA means that the EU ETS only affects regulated firms, thus ruling out the possibility of spillovers or general equilibrium effects on non-regulated firms. Importantly, only the common support assumption can be directly assessed in the data, not the other two assumptions. Their plausibility, however, can be assessed through indirect tests.

In more formal terms, let $D_i = 1$ if firm i owns one or more installations under the EU ETS, and $D_i = 0$ otherwise; let also $Y_{it}(1)$ and $Y_{it}(0)$ denote the level of the outcome variable (e.g. profits, value added, turnover, etc.), for firm i at time t, conditional on participation and non-participation, respectively. Typically, one wants to estimate the average treatment effect on the treated (ATET), which here is the average effect of the EU ETS on regulated firms' Y:

$$\alpha_{ATET} = E\left[Y_{it'}(1) - Y_{it'}(0)\,|D_i = 1\right] \tag{1}$$

where t' represents a year following the introduction of the EU ETS.

The fundamental problem in the estimation of the ATET is that realizations of $[Y_{it'}(0)|D_i = 1]$ are not observed, because they are counterfactuals.[11] With the DiD approach, estimates of these counterfactuals are obtained using observed outcomes for the control group of non-regulated firms.

Two main estimation approaches are found in the literature. The more basic one applies ordinary least squares to the following specification:

$$Y_{it'} - Y_{it^0} = \boldsymbol{\beta}'\boldsymbol{X}_i + \alpha D_i + \varepsilon_i \quad (2)$$

where $\boldsymbol{X}_i$ is a vector of observable covariates and t^0 denotes the time period prior to the introduction of the EU ETS.

Under the above said assumptions, α corresponds to the ATET ($\hat{\alpha}_{OLS}^{DiD}$ is the estimate for α_{ATET}).

Matched DiD is an alternative more sophisticated approach, by far the most popular in our literature. It uses matching estimators, an extension of standard regression approaches. Specifically, the ATET is estimated by implementing the generalized DiD matching estimator (Heckman *et al.*, 1997):

$$\alpha_{MATCH}^{DiD} = \frac{1}{N_1} \sum_{j \in I_1} \left\{ \left(Y_{jt'}(1) - Y_{jt^0}(0) \right) - \sum_{k \in I_0} w_{jk} \left(Y_{kt'}(0) - Y_{kt^0}(0) \right) \right\} \quad (3)$$

where I_1 denotes the set of regulated firms, I_0 denotes the set of matched non-regulated firms and N_1 is the number of regulated firms. Regulated firms are indexed by j, while matched non-regulated ones by k. The weights $w_{jk}(\boldsymbol{X}_j, \boldsymbol{X}_k)$, placed on non-regulated firms when constructing counterfactuals for regulated ones, can be calculated using any matching approach.

Matching is recommendable because it further lowers the risk of bias induced by unobserved time-variant differences between treated and control groups. Plus, it is flexible in avoiding parametric assumptions on the relationship between the outcome variable and the control variables.

2.3.2 *Multifactor Models of Stock Returns*

The studies investigating how carbon prices in the EU ETS affect company stock returns present themselves as highly homogeneous with respect to the methodology. Almost all of them are focused on estimating the sensitivity of stock returns to the returns on EU Emission Allowances (EUAs). The basic logic goes as follows. Assuming that a company's stock price reflects the stream of expected discounted future profits, the effect of changes in EUA prices on stock price returns reveals investors' beliefs about the influence of the EU ETS on profitability. Therefore, the sign of the correlation between EUA returns and stock returns indicates how investors see the EU ETS affecting companies' profits.

Typical is the use of MFMs – a development of the capital asset pricing model (Sharpe, 1964) – in which daily returns on a company's stock are explained by daily returns on the market portfolio and on other prices deemed to be relevant. These include carbon prices and fuel prices (e.g. coal, oil, gas). The basic MFM framework comes in the following form:

$$R_{it} = \alpha + \sum_j \alpha_i D_i^j + \beta_1 R_t^m + \beta_2 R_t^c + \sum_j \gamma_j R_t^j + \varepsilon \quad (4)$$

where R_i is the return on the stock of company i, D_i is a company dummy variable (taking the value 1 when $i = j$), R^m is the return on the market portfolio, R^c is the return on emission allowances and the R^js are the returns on fuel prices.

With reference to (4), β_2 is the parameter of interest, the one capturing the sensitivity of stock returns to EUA returns. The number of companies can vary significantly, from a dozen to over a hundred. Early contributions tend to focus on the electricity sector, within which dirtier companies are distinguished from cleaner ones based on the carbon intensity of the generation fuel mix. More recent studies tend to extend the analysis to other sectors and some can draw on data covering the first years of the third trading period.

The most significant methodological variations on the basic MFM framework above consist in event studies, exploiting past exceptional variations in allowance prices, and extensions to vector co-integration. As to more substantive conceptual variations, noteworthy are two studies (Oestreich and Tsiakas, 2015; Bernardini *et al.*, 2019) which, by a applying a different type of MFM, estimate and compare abnormal excess returns for dirty and clean investment portfolios differing in emission intensity, across the EU ETS trading periods.

3. The Evidence

In this section, the literature is reviewed in detail. The structure of the review follows the four main types of effects: effects on competitive performance, investment leakage, carbon leakage and effects on stock returns.

3.1 *Effects on Competitive Performance*

Within the studies estimating the effects of the EU ETS on competitive performance, we make a distinction based on the specificity of the effects with respect to both their sector and country dimensions. That is, the studies are classified according to both whether they provide (a) sector-specific or cross-sector effects and (b) country-specific or cross-country effects.[12,13] Organized in this way, the review makes more obvious for which sectors' and countries' specific evidence exists or is missing.

3.1.1 *Cross-Sector Cross-Country Effects*

Using a large firm-level longitudinal dataset mainly sourced from Amadeus (Bureau van Dijk), a comprehensive database of European companies, Commins *et al.* (2011) assess the effects of energy taxes and of the EU ETS on different competitiveness indicators. Four panel data models are estimated for firm-level (a) employment, (b) investment in tangible fixed assets, (c) total factor productivity (TFP) (derived as the residual of an estimated production function) and (d) return on capital (ROC), over 1996–2007. In each model, the effect of the EU ETS is captured by a binary variable indicating whether the firm's main business is in one of the regulated sectors. Participation in the EU ETS is found to have negative effects both on TFP (−3.2%) and ROC (−4.7%). Conversely, the effect on employment turns out to be positive (1.5%). All these effects are statistically significant only at the 10% level. Moreover, as participation in the EU ETS is defined at the sector level (rather than at the firm level),[14] measurement error and sectoral shocks may confound estimation of the effects. The authors caution that their results are indicative only.

Costantini and Mazzanti (2012) estimate a sector-level gravity model of international trade for manufacturing exports from 15 EU countries to 145 importing countries, over 1996–2007. The effect of the EU ETS is captured by a binary variable for the years 2005–2007, which is the period corresponding to Phase I. Its estimated coefficient suggests that the EU ETS increased exports of medium–low technology sectors, which roughly correspond to those covered by the EU ETS: an outcome consistent with the Porter hypothesis. The authors themselves, however, qualify this finding as being far from conclusive, admitting that more detailed sectoral data and longer time series are needed to infer on the real impact of the EU ETS on the competitiveness of regulated firms.

Using firm-level data and applying the DiD approach, Marin *et al.* (2018) estimate the effects of the EU ETS on a large set of competitiveness indicators: value added, number of employees, turnover, investment intensity (gross fixed capital formation over total assets), labour productivity, wages, return on investment

(ROI), TFP and markup (expressed as the ratio between price and marginal cost), the last two estimated by the authors. The Amadeus database (Bureau van Dijk) is the main data source, providing information on regulated firms and on the matched counterparts. The estimation samples cover between approximately 500 and 800 regulated firms (and over 2000 non-regulated ones), depending on the number of missing data, over 2002–2012. Positive (statistically significant) effects are found (a) in the first two trading periods, for markup (1.5% and 3.2% in Phases I and II, respectively) and investment intensity (1.2% and 1.5%), and (b) only in Phase II, for turnover (6.6%) and labour productivity (5.1%). For employment, a negative effect is found (−2.1%), but only in Phase I. Firms appear to have reacted to the EU ETS, on the one hand, by passing-through carbon costs and, on the other hand, by investing more, thereby improving labour productivity.

3.1.2 *Cross-Sector Country-Specific Effects*[15]

Petrick and Wagner (2014) estimate the impact of the EU ETS on CO_2 emissions and CO_2 intensity, as well as on employment, gross output (sales) and the exports of regulated manufacturing firms in Germany. The DiD approach is applied to firm-level panel data obtained from the national production census, covering over 90% of the EU ETS installations operated by manufacturing firms and located in Germany. About 400 regulated firms are in the estimation samples. In the reference model, the effects on employment are not statistically significant, while positive effects on the value of both sales and exports are identified for the first three years of Phase II (i.e. 2008–2010).[16] The positive effects are clearly non-robust, however, as they become statistically insignificant in most of the alternative estimations performed.

Jaraite and Di Maria (2016) estimate the impact of the EU ETS on CO_2 emissions and CO_2 intensity, as well as on the investment and the profitability of Lithuanian regulated firms. The DiD approach is applied to a panel dataset sourced from the national business survey, of almost 5000 firms (about 330 of which are regulated), from 2003 to 2010. Investment and profitability are measured by the change in total tangible capital assets and the ratio of before-tax profit to turnover, respectively. It turns out that, up to 2009, regulated firms invested, on average, less than non-regulated firms, but conversely, in 2010, they invested more. This may well be the consequence of a Lithuanian law passed in 2009, mandating that all revenues received from the sale of emission allowances should be spent on environmental measures. Negative effects on profitability, though statistically significant only at the 10% level, are detected in 2009 and 2010. This may be explained by allowance allocation in Phase II being much tighter for Lithuanian firms than in Phase I.

Klemetsen *et al.* (2016) estimate the impact of the EU ETS on CO_2 emissions and CO_2 intensity, as well as on value added and labour productivity (value added per man hour) of Norwegian-regulated manufacturing plants. The DiD approach is applied to a plant-level panel dataset obtained by combining different datasets, the most important of which is compiled by the Norwegian Environment Agency. The sample eventually used for estimation comprises 152 plants (72 regulated) from 2001 to 2013. Very large positive effects, though only for Phase II (when carbon prices were higher), are found both on value added and labour productivity: respectively, 24% and 26%. The authors relate these results to generally non-stringent allowance allocations and also to the pass-through (to output prices) of the connected opportunity costs.

Colmer *et al.* (2018) assess the impacts of the EU ETS on GHG emissions, value added and employment of regulated manufacturing firms in France. The DiD approach is applied to panels of firm and plant-level administrative data, from 2000 to 2012. While a sizeable reduction on emissions is found for Phase II (−13.5%), smaller negative effects are found for value added (−2.3% and −0.5% in Phases I and II, respectively) and employment (−4.5% and −7.5% in Phases I and II, respectively), none of which is, in fact, statistically significant. Importantly, the study provides strong evidence of heterogeneity in effects as well as evidence pointing to intra-firm carbon leakage, that is, of firms owning both regulated and non-regulated plants shifting emissions from the first to the second. In average terms, emission abatement is carried out only by firms operating solely regulated plants (-12% and -24% in Phases I and II, respectively).

3.1.3 *Sector-Specific Cross-Country Effects*

Abrell *et al.* (2011) have the merit of being the first to use the DiD approach in an application to the EU ETS. The study draws on a large dataset extracted from the Amadeus company database. The dataset covers over 2000 regulated firms (operating about 3600 installations) from 2003 to 2008. Separate models for CO_2 emissions, value added, employment and profit margin are fitted. Average impacts of the EU ETS on regulated firms are found to be not statistically significant, with the exception of a modest negative effect (0.9%) on employment over 2004–2008. Some heterogeneity in estimated average effects arises when the models are fitted to widely defined sector sub-samples.[17] Notably, the profit margins of firms in the energy sector (electricity and heat) benefit from participation in the EU ETS. By contrast, firms producing non-metallic mineral products (e.g. glass, cement, ceramics, bricks) are negatively affected. The authors warn that the results should be interpreted with caution: firstly, because firms in the treatment and control groups (while similar with respect to a number of variables) operate in different sectors; secondly, because the potential indirect effects (of the EU ETS through electricity prices) on firms in the control groups are ignored.

The study by Chan *et al.* (2013) is similar to Abrell *et al.*'s (2011) both in terms of the data used and approach. The main methodological difference is that matched firms, in the treatment group and in the control group, here belong to the same sector, thus reducing the risk of estimation bias. As to the scope of the analysis, three sectors are examined: electricity, cement and iron and steel. For each of them, three competitiveness indicators are considered: unit material cost (i.e. the ratio of total material costs to turnover), which include fuel costs; employment; and turnover. Statistically significant effects are found only for the electricity sector, which exhibits increases both in unit material cost (by 5% and 8% in Phases I and II, respectively) and, more substantially, in turnover (by 30% in Phase II). The authors conjecture that the increase in material costs may reflect additional compliance costs incurred for purchasing allowances or switching from coal to gas. The larger increase in turnover would reflect the carbon cost pass-through to output prices.

Branger *et al.* (2016) and Boutabba and Lardic (2017) deal with the impact of the EU ETS on the competitiveness of the cement and the steel industries. Both contributions model EU27's net imports of the two products applying time-series regression techniques. In Branger *et al.* (2016), both the effects of EUA prices on net imports of cement and of steel are not statistically significant. Boutabba and Lardic (2017) revisit Branger *et al.*'s (2016) analysis applying a rolling co-integration approach, which accounts for multiple structural changes, and uses longer data series updated with more recent information. The EUA prices are found for both cement and steel to have (time-varying) effects on net imports that are positive and statistically significant for some subperiods. The authors interpret the results as suggesting that modest operational leakage took place, and that it was more evident in the steel sector than in the cement sector.

Using similar approaches to those of the two aforementioned studies on steel and cement, Reinaud (2008) and Sartor (2012) investigate the impact of the EU ETS on the competitiveness of the primary aluminium sector. Direct emissions from (both primary and secondary) aluminium production came under the EU ETS only in 2013, with the start of Phase III. However, as primary aluminium is an electricity-intensive product (electricity represents over a third of total production costs), the impact of the EU ETS on the sector is principally felt indirectly through electricity prices.[18] In Reinaud's (2008) preliminary regression of the EU's net imports of primary aluminium, only the first two years of the

EU ETS are covered. She finds the effect of EUA prices not to be statistically significant. The main explanation offered is that electricity used in primary aluminium production was most often provided under long-term electricity contracts, shielding aluminium producers from rising electricity costs. Sartor (2012) extends Reinaud's (2008) analysis, using longer data series, which reach 2011 (by when many electricity contracts were expected to have expired), and controlling for both additional variables and co-integration. The findings, nevertheless, confirm those of the previous study. They suggest that other factors are much more important than the carbon price in determining the competitiveness of the primary aluminium sector: energy prices, electricity contracts and other factors driving electricity prices, as well as exchange rate movements.

Dechezleprêtre *et al.* (2018) analyse the impact of the EU ETS on both emissions and economic performance of regulated firms. Using the matched DiD approach, applied to a remarkably large firm-level dataset (extracted from Orbis) covering all countries and sectors in the EU ETS, the authors specifically look at effects on revenues, fixed assets (including intangibles), profits and employment. The final estimation sample comprises a group of almost 1800 regulated firms and almost as many non-regulated ones (similar to the first in all observed characteristics prior to the introduction of the policy), over 2002–2014. No negative statistically significant effects are found for any of the subsectors either. In fact, the EU ETS turns out to have led to an increase in regulated firms' revenues, by 7–18% depending on the specification, and in fixed assets, by 6–10%. While it cannot be determined whether the results on revenues are due to volume or price increases (or both), they are consistent with ample evidence of carbon cost pass-through in various EU ETS sectors. As regards the positive impact on fixed assets, which is also found in other similar analyses, it is interpreted as potentially reflecting investments in emissions abatement.

3.1.4 *Sector-Specific Country-Specific Effects*

Yu (2013) estimates the impact of the EU ETS on profit margins (ratio of net profits to the turnover) of Swedish firms in the energy sector (electricity production, electricity distribution, steam and hot water supply) in 2005 and 2006. The DiD approach (with and without matching[19]) is applied to a panel dataset, extracted from Statistics Sweden's business database, comprising almost 1000 firms (113 regulated), from 2004 to 2006. The estimation results do not show a statistically significant impact for the EU ETS on firm profitability in 2005. However, a negative significant impact (1.1 percentage point decrease in the profit margin ratio) is found for the following year. The results are tentatively interpreted in light of carbon prices and machinery investments (a proxy for abatement investments). Notably, an increase in machinery investment is observed in 2006 only for regulated firms.

Lundgren *et al.* (2015) assess the effects of the EU ETS (as well as of the Swedish energy and carbon taxes) on the TFP of Swedish pulp-and-paper sector firms. A firm-level panel dataset (supplied by Statistics Sweden) is used, of some 100 firms over 1998–2008. Their approach involves two steps. Firm-specific Luenberger indicators of TFP growth are first computed,[20] distinguishing between: (a) efficiency change and (b) technological development. In the second step, the impact of the EU ETS carbon price on TFP growth is estimated, using a dynamic panel data approach. Interestingly, carbon prices are found to have a positive effect on efficiency change and, conversely, a negative one on technological development. The latter result is in line with those of Commins *et al.* (2011) above.

Lutz (2016) estimates the impact of the EU ETS on the TFP of regulated manufacturing firms in Germany. Using firm-level administrative data comprising about 15,000 firms (of which about 400 are regulated), for the period 1999–2012, industry-specific production functions are first estimated and firm-specific productivity levels are then derived. The DiD approach, with and without matching, is then applied. Positive effects on productivity are detected. Specifically, for Phase I, 0.7% and 1.5–2.7%, without and with matching, respectively; and for Phase II, 1.2–1.4%, only with matching. Moreover, subsample analysis (presented only for DiD without matching) reveals some heterogeneous effects across sectors: a positive one (2.4%) for basic metals in Phase I; while no statistically significant effects are found for the food, paper and chemical industries. The author warns, however, that, since the productivity measure employed is revenue-based, the results may at least in part reflect pass-through of regulation costs.

Using data and methods similar to those employed by Lutz (2016), Löschel *et al.* (2018) investigate whether the EU ETS had any impact on production efficiency of regulated manufacturing firms in Germany. In this study, the firm-level distance to the estimated sector-specific production frontier is the relevant measure of economic performance.[21] Across the array of modelling strategies, no evidence is found of negative effects of the EU ETS on production efficiency. On the contrary, the EU ETS is found to have had a positive impact for firms in the paper sector (−1.3% and −1.6% over 2005–2007 and 2005–2012, respectively) and, more generally, on regulated firms during the first year (only) of Phase I.

3.2 *Investment Leakage*

Borghesi *et al.* (2018) investigate whether the EU ETS had any effect on outward FDIs of regulated manufacturing firms in Italy. The DiD approach is applied to a longitudinal dataset extracted from the Aida database (Bureau van Dijk) of Italian companies from 2002 to 2010. The samples used for estimations include treatment groups of about 300 regulated firms. The authors identify two types of statistically significant effects on FDIs: a positive weak effect on the number of new subsidiaries abroad and a larger effect on the production occurring in foreign subsidiaries, especially in trade-intensive sectors.

Similarly to Borghesi *et al.* (2018), Koch and Mama (2019) test for whether the EU ETS affected FDI volumes of regulated multinational firms in Germany as well as the number of their affiliates and of FDI country destinations outside the EU.[22] The DiD approach is applied to a panel of firm survey data (Deutsche Bundesbank) spanning 1999–2013. Within this, 232 regulated firms are identified, almost exclusively manufacturing firms. For the universe of regulated multinationals in Germany, no statistically significant effect is found on FDI volumes. However, remarkable +28% and +19% effects are found, respectively, on the number of affiliates and of FDI destinations outside the EU. These effects are interpreted as suggestive of endeavours undertaken by regulated firms to facilitate relocations in the future. Importantly, subsample analysis reveals strong heterogeneity in effects. For firms in process-regulated sectors (including basic metals, non-metallic mineral products, paper and chemicals),[23] characterized as more capital intensive, and thus, less footloose, the average effect on FDI volumes flowing outside the EU is −16%. Conversely, for firms in non-process sectors, characterized as more footloose (they include the machinery, electrical equipment and automotive sectors), the effect on FDI volumes is as big as +52%. Short positions in allowance holdings seem to be a driver of this last result, but further investigation is needed to justify more general statements about the role of free allocation in preventing relocation. The authors stress that this subset of firms, which would appear to be extremely sensitive to carbon costs, only accounts for about 3% of total regulated German emissions and 9% of the sample FDI activity. Again, further research and detailed information about firms in the non-process sectors are warranted.

Although it does not test directly for effects of the EU ETS on FDIs, the analysis by Aus dem Moore *et al.* (2019) speaks to the issue of investment leakage. The study investigates the impact of the EU ETS on firms' holdings of tangible fixed assets as an indicator for industrial relocation. The matched DiD approach is applied to a large firm-level dataset, extracted from Orbis (Bureau van Dijk), covering almost all regulated firms, over 2002–2012. Baseline results indicate that, by the end of Phase II, the EU ETS led to an average increase of regulated firms' fixed assets in the range of 10–11%. These results, which are consistent with those of other studies, might reflect the adoption of abatement technologies. In any case, they refute – in keeping with the paper's title – the spectre of creeping deindustrialization caused by the EU ETS. For a particular group of regulated multinationals, however, namely those lacking a sectoral sibling outside of the EU ETS, fixed assets increased on average only by 2%. For these companies, which represent about 15% of emissions from regulated manufacturing firms, the EU ETS may have induced a shift in investment priorities.

3.3 *Carbon Leakage*

Dechezleprêtre *et al.* (2019) are the first to directly test for carbon leakage caused by the EU ETS. An ingenious strategy is put to work, made viable by a special database. The Carbon Disclosure Project collects climate-relevant data at the firm level, including on the emissions of multinational firms broken down by country. As they already operate from multiple locations, multinational firms are believed to be the most prone to shift production activity across countries and, hence, to carbon leakage. Using a sample covering 1122 companies (261 regulated), over 2007–2014, the authors test the relationship between changes in firms' European share of their own emissions and changes in their extra-EU emissions share. Existence of carbon leakage would imply that such relationships would be negative. No negative effects are found. The authors note, however, that region-specific productivity shocks could potentially confound the estimated effects of the EU ETS.

Naegele and Zaklan (2019) investigate whether the EU ETS caused carbon leakage in European manufacturing sectors, as measured by changes in sector-level international trade flows and related carbon movements. Sector-level trade flows in embodied carbon and value are computed using detailed trade and input–output data (from the Global Trade Analysis Project) for the years 2004, 2007 and 2011. Two models are estimated, namely for net imports and for bilateral flows (thus allowing for intra-industry trade), and four alternative measures of environmental stringency are considered for representing the EU ETS. The simplest of these measures is an indicator variable for regulated sectors, while the others are (sector-specific) direct, indirect and total net costs based on emissions (direct/indirect), allowance allocations and allowance prices. As no significant effects are found, the authors conclude that, during its first two phases, the EU ETS did not have a systematic impact on flows of trade or embodied CO_2 emissions.

3.4 *Effects on Stock Returns*

The studies looking exclusively at stocks of companies in the electricity sector are first considered. We then turn to those extending the analysis to multiple sectors.

3.4.1 *Electricity Sector*

Oberndorfer (2009) and Veith *et al.* (2009) are the first to analyse the effect of changes in EUA prices on stock returns. The two studies present similarities beyond the MFM approach. Though the samples differ somewhat in the number of companies (12 and 22,[24] in Oberndorfer and in Veith *et al.*, respectively), the time spans largely coincide (August 2005–June 2007 and April 2005–August 2007, in the same order). Above all, the analyses share the main outcome: on average, changes in carbon prices and in stock prices were positively correlated. Deeper analyses offer additional results and insights. Notably, Oberndorfer (2009) finds that effects varied by time and by country (where companies have their headquarters). Moreover, Veith *et al.* (2009) find that increases in carbon prices did not have a positive effect on carbon-free generation companies.[25]

Mo *et al.* (2012) extend the analysis of previous works mainly by comparing estimated effects across trading periods. The estimation sample covers the years 2006–2009, thus straddling Phases I and II. The authors find that, on average, correlation between changes in carbon prices and in stock prices was positive in the first trading period (as in both Oberndorfer, 2009 and Veith *et al.*, 2009) and, by contrast, it was negative in the second. Moreover, stock prices were much more sensitive to changes in carbon prices in Phase II than they were before. In both cases, differences are attributed to more stringent allowance allocations in Phase II.

Further variations on the theme are provided by Tian *et al.* (2016) and by Pereira da Silva *et al.* (2016). The first, who can rely on a sample covering Phases I and II in full, show that the relationship between carbon prices and stock prices was largely driven by (two) specific shocks in the carbon market. Outside these special periods, the relationship depended on the carbon intensity of electricity producers: negative for carbon-intensive companies and positive for less carbon-intensive ones. Limiting the analysis to the Spanish stock market, but importantly drawing on data straddling Phases II and III, Pereira da Silva *et al.*'s (2016) extend the standard MFM approach to vector co-integration. Applying a co-integrated vector error correction model (VECM), which allows for a control on dynamic interactions among variables, the authors find that: the equilibrium relationship between carbon prices and stock prices was weak but positive in Phase II, and statistically non-significant in Phase III. This result fits well with the switch from free allocation to full auctioning for the electricity sector. Moreover, the said positive relationship is significantly stronger for the subset of clean energy producers.

In a more recent study, Bernardini *et al.* (2019) take a different view on the influence of the EU ETS on stock returns. Following Oestreich and Tsiakas (2015), they estimate an extended version of the Capital Asset Pricing Model to test for the presence of abnormal excess returns for two investment portfolios differing in emission intensity. The authors find a statistically significant low-carbon premium, which gets larger over the years 2012–2016. This means that investors engaged in strategies focused on low-carbon companies would have had a higher risk-adjusted return.

3.4.2 *Multiple Sectors*

Bushnell *et al.*'s (2013) study stands out in this literature for adapting the standard MFM approach to the form of an event study, as well as for the depth of analysis. The abrupt April 2006 fall in EUA prices, following the disclosure of 2005 verified emissions,[26] had immediate repercussions on the European stock market. Focusing on a three-day window (April 26–28), the authors examine the changes in stock returns, across sectors and firms, to elicit investors' beliefs about the influence of the EU ETS on firms' profitability. As a result of the crash in carbon prices, stock prices fell for firms in energy-intensive sectors, particularly for those selling primarily within the EU. In the electricity sector, price stocks of less carbon-intensive producers were more affected than those of dirtier ones. Data variation is not sufficient for identifying an effect of allowance holdings (emissions and allowances are highly correlated), but findings are unaffected when allowance holdings are considered. The main conclusion of the study is that, under free allocation,[27] investors focused on increasing profits through higher output prices. Analysing the same market event and using a similar approach, Jong *et al.* (2014) find evidence confirming the stronger negative impact of the fall in carbon prices on dirtier firms.

Venmans (2015) contributes firm and sector-specific estimates of correlations between changes in EUA prices and in stock prices. These refer to all companies in the StoxxEurope Total Market Index belonging to EU ETS sectors, over the period 2007–2011. Mean effects are positive for all seven sectors under consideration. The least important effects are found for the electricity, refining and the paper sectors; intermediate effects are found for the cement and chemicals sectors, whereas the iron and steel and the nonferrous sectors present the largest effects. However, the study emphasizes that effects are firm-specific and that variation within sectors can be significant. Out of 97 firms, 19–24 (depending on the model) exhibit negative effects. Within the electricity sector, less carbon-intensive firms, as expected, benefit more from carbon price increases.

Focusing on the Spanish stock market, Pereira da Silva *et al.* (2015) apply the VECM variant of the MFM approach to firms in five different sectors: electricity, refining, iron and steel, pulp and paper and finally the cement, ceramics and glass sectors taken together. The estimation sample is short in time, as it only covers (and not in full) the first two years of Phase III (2013–2014). Estimated effects are positive for all sectors, except for the iron and steel and for the pulp and paper sectors; here they are, respectively, negative and statistically not different from zero. Using the standard MFM approach, Moreno and Pereira da Silva (2016) extend the analysis by including full Phase II and by adding companies in the chemicals sector. Effects are shown to be both sector- and phase-specific. Unlike other studies, negative effects are found for the electricity sector both in Phase II and, especially, in Phase III. The authors explain the first with under-allocation of the Spanish electricity sector (its total emissions exceeding allocations by 17%) and the second with the full auctioning regime introduced in Phase III. The only sector for which positive effects are found in both trading periods is the refining sector.[28]

Using monthly data from the German stock market, Oestreich and Tsiakas (2015) provide compelling evidence on the role of the allocation method in affecting the relative financial performance of different companies. The comparison between the average excess returns of ‘dirty’ firms, who received the largest amounts of free allowances, and those of ‘clean’ ones, who did not receive any, is unequivocal. Namely, before 2005, no difference can be detected; then, dirty firms significantly outperformed clean firms, but only up to March 2009: when the second ETS Directive stipulated that allowances would be mainly auctioned beginning in 2013. After March 2009, clean firms outperformed dirty ones.

4. Discussion

There follow a few considerations on the general indications of the literature presented and its limitations.

4.1 *Existing Evidence Raises No Concerns, But Has an Important Delay*

Our literature review confirms the main general conclusion of previous similar ones covering fewer and less recent studies. Namely, it allows us to reiterate that, to date, there is no evidence of the EU ETS having had widespread negative effects on the competitiveness of regulated firms nor is there evidence of significant carbon leakage. Indeed, by far the most frequent conclusion in the literature is that no evidence of negative competitiveness effects was found. As Table 2 shows, some studies – a minority – find statistically significant effects, but half of these are positive (though more often reflecting carbon cost pass-through rather than improved productivity). Moreover, even restricting our attention to the effects reported in Table 2 (many more are the statistically non-significant effects), no clear patterns across sectors or countries emerge. In some cases (e.g. Commins *et al.*, 2011, Costantini and Mazzanti, 2012), the authors themselves warn that for specific technical reasons the estimated effects should not be taken as definitive.

There is a general consensus that the main explanation for the very limited evidence of negative effects is the combination of low-to-moderate carbon prices and generous free allocation, which to a varying degree has characterized the first two trading periods and a good part of Phase III (Joltreau and Sommerfeld, 2019). The literature, however, suffers from a substantial delay in that most estimates refer to Phases I or II and only few go as far covering the first years of Phase III (see Table 1). The release of new data, their acquisition by applied researchers sufficiently familiar with the EU ETS and interested in it – not a multitude – the elaboration of non-trivial econometric analyses and their publication, are all steps that take time. In most recent years, the delay of econometric results has become more relevant because the level of carbon prices has increased fourfold. Immediately after final political agreement on the reform for Phase IV was achieved, in late 2017, carbon prices started to rise, the price of EU allowances (EUAs) passing from €5 to €25 in less than a year and stabilizing thereafter. Thus, in terms of carbon prices, the last few years, for which no evidence on competitiveness effects exist, are clearly different from previous Phase III years. Also, Phase III (in general), for which evidence on competitiveness effects is still very

Table 2. Sign of Estimated Statistically Significant Effects on Competitive Performance Indicators.

		Type of dependent variable (type of economic effect)				
	Years	International trade	Profitability	Turnover	Employment	Productivity
Cross-sector cross-country effects						
Commins *et al.* (2011)	2005–2007		−		+	−
Costantini and Mazzanti (2012)	2005–2007	+				
Marin *et al.* (2018)	2005–2012			0/+	−/0	0/+
Cross-sector country-specific effects						
Petrick and Wagner (2014)	2005–2010	+ (DE)		+ (DE)		
Jaraite and Di Maria (2016)	2005–2010		−/0 (LT)			
Klemetsen *et al.* (2016)	2005–2013			0/+ (NO)		0/+ (NO)
Sector-specific cross-country effects						
Abrell *et al.* (2011)	2005-2008		+ (Energy), − (Non-metallic minerals)			
Chan *et al.* (2013)	2005–2009			+ (Electricity)		
Boutabba and Lardic (2017)	2005–2015	−/0 (Cement; Steel)				
Dechezleprêtre *et al.* (2018)	2005–2012		+ (Basic metals)	+ (Non-metallic minerals; Basic metals; Energy)	+ (Basic metals; Energy)	

(*Continued*)

Table 2. *Continued.*

	Years	Type of dependent variable (type of economic effect)				
		International trade	Profitability	Turnover	Employment	Productivity
Sector-specific country-specific effects						
Yu (2013)	2005–2006		−/0 (SE, Energy)			
Lundgren *et al.* (2015)	2005–2008					− (SE, Paper)
Lutz (2016)	2005–2012					0/+ (DE, Basic metals)
Löschel *et al.* (2018)	2005–2012					+ (DE, Paper)

Note: (a) This table only reports estimated positive (+) and negative (−) effects statistically significant at the 10% level or less. Effects that are not statistically significant (0) are reported only if in the same study some statistically significant positive or negative effects are found too. (b) The specific countries and/or sectors to which the reported effects may refer are indicated in brackets.

limited, is very different from the first two trading periods with respect to free allocation (overall way more generous in Phases I and II). Because of such differences, estimates of effects referring to more recent years are needed to judge the current EU ETS.

4.2 *Investment Leakage Deserves More Attention*

The risk of investment leakage is particularly important in that losses of production capacity entail long-term economic losses and long-term carbon leakage. Another reason why looking at investment leakage is of special interest is that it allows to anticipate the effect of the EU ETS – in this context – on future rather than current domestic production activity. In this sense, compared to effects on current competitive performance indicators, investment leakage is akin to an early warning, which the policymaker may want to consider to take more timely countermeasures.

In our review, the few studies dealing with investment leakage find statistically significant results that, for the said reasons, deserve special consideration. Both Borghesi *et al.* (2018) and Koch and Mama (2019) find evidence of some investment leakage, respectively, in more trade-intensive sectors in Italy (more exposed to international competition) and less capital-intensive sectors in Germany (more mobile or footloose). For a certain subset of regulated firms, Aus dem Moore *et al.* (2019) find – consistent with the hypothesis of investment leakage – that very little investment in fixed capital was undertaken in response to the EU ETS. These results quite clearly indicate that some investment leakage has taken place, but it has been limited to specific sectors. For the future, further studies exploring investment leakage are certainly recommendable.

4.3 *A limitation of the DiD Approach*

While for good reasons, the DiD approach has become the most popular in this literature, it is increasingly vulnerable to estimation bias as the lifetime of the EU ETS gets longer. The issue arises because the DiD approach requires sample units with both pre-treatment and post-treatment observations. Accordingly, in existing DiD applications to the EU ETS, only firms surviving the treatment period are considered for estimation, whereas both new and closed firms, any time after the EU ETS started operating, are ignored.[29] This restriction on the sample opens the possibility of estimation biases, which materialize if the EU ETS systematically affects new or closed firms differently from surviving firms. One can imagine reasons for why this could occur. For example, it is not unconceivable that the EU ETS causes new firms to be more energy efficient than incumbents and, if so, it may have weaker negative effects on their competitiveness. In this case, discarding new firms would result in overestimation of negative competitiveness effects. On the other hand, the EU ETS could have sufficiently strong negative effects on the competitiveness of some firms to cause their closure. Here, ignoring closed firms would result in underestimation of negative competitiveness effects.[30]

This estimation bias issue points to a limitation of the DiD approach for applications to the EU ETS, which is failing to account for structural changes caused by the EU ETS itself. As years go by, it becomes increasingly important to assess whether and how the EU ETS – which has now been operative for 14 years – has affected the economy through firm dynamics (i.e. through firm entries and exits). Again, with regard to possible future research, it is also for this reason that studying the effects of the EU ETS on investment leakage is highly desirable.

5. Concluding Remarks

This paper has reviewed the large existing econometric literature assessing the effects of the EU ETS on competitiveness and related carbon leakage. Taken together, the results of these studies tell us that to date there is no evidence of the EU ETS having had widespread negative (or positive) effects on the competitiveness of regulated firms, nor is there evidence of significant carbon leakage. Three caveats are in order, however. Firstly, the evidence we have largely refers to Phases I and II, with a few cases in which it stretches to the first years of Phase III. Econometric evidence referring to the EU ETS today, which sees much higher carbon prices than only two years ago, does not yet exist. Secondly, some heterogeneity of estimated effects is observed, but patterns, notably sectoral patterns, hardly emerge. Indeed, for each of the many sectors covered by the EU ETS, only few sector-specific estimates exist, if any. Thirdly, very little explored is whether the EU ETS has had long-term effects on the economy through notably investment leakage and firm dynamics.

Future research would ideally reduce these knowledge gaps. Often researchers in this area invoke greater support from relevant public authorities (e.g. the European Commission, national statistical offices) in accessing suitable micro-level data, thus enabling or helping speed up the elaboration of useful econometric analyses. Improving the information content and usability of the EUTL for research purposes could be the best place to start. Researchers, on their part, could conduct more analyses that allow identifying sector-specific effects of the EU ETS and, also, they could focus more on said long-term effects. Moreover, as firms can respond to carbon pricing in multiple ways, there is an increasingly recognized value in analyses that combine environmental and economic outcomes (as some studies already do) as well as technological change. Of course, the data requirements of such analyses are very high.

Finally, while the general message extrapolated from the literature is reassuring, the emphasized remaining uncertainties arguably justify what seems a reasonably prudent reduction of free allocation in Phase IV, accompanied by enhanced support to low-carbon innovation.

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Notes

1. China's national ETS is expected to be operative by 2020. In emissions terms, the coverage of the Chinese ETS will be about twice that of the EU ETS (ICAP, 2018).
2. All official documentation and relevant information on the functioning of the EU ETS can be found on the European Commission's website (www.ec.europa.eu/clima/).
3. On the assessment of allowance market efficiency, see Hintermann *et al.* (2016). On the related assessment of cost-effectiveness of an ETS, distinguishing between short-term and long-term perspectives, see Fuss *et al.* (2018).
4. Competitiveness deterioration is not the only channel through which carbon leakage may occur. If the region adopting more stringent carbon regulation is sufficiently important in terms of demand for fossil fuels, carbon leakage may also result from lower global fossil fuel prices.
5. Ellerman *et al.* (2010) is the reference book for the genesis and the development of the EU ETS in its first 5 years of operation. For a monographic work covering more recent years of the EU ETS, see Gronwald and Hintermann (2015).
6. Admittedly, the requisite of high quality is somewhat subjective. A more objective requisite for a study to be considered was that it offers a fully developed analysis, including robustness checks or at least a clear indication of its limitations.
7. Technically, in the EU ETS legislation, installation is not a synonym of plant, as there can be multiple installations being part of a single plant. In the following, however, we refer to installations or plants interchangeably.

8. In the context of DiD applications, firms are preferable to installations as statistical units because they allow to derive more credible counterfactuals. Since participation in the EU ETS is based on installation-level production capacity thresholds, it is indeed difficult to imagine, especially for some sectors, non-regulated installations being similar to regulated ones. In turn, this implies a higher risk of estimation bias caused by unobserved time-variant differences between regulated and non-regulated installations. Furthermore, firms as statistical units conveniently account for centralized decision-making across installations. Colmer *et al.* (2018) (see below) provide evidence that proves the relevance of this specific point.
9. The EUTL records information both on regulated installations and allowance transactions in the EU ETS. The EUTL can be accessed at: http://ec.europa.eu/environment/ets/.
10. The DiD approach is robust to unobserved time-invariant differences between treated and control entities (Heckman *et al.*, 1997).
11. For a regulated firm, its *Y*-level conditional on non-participation in the EU ETS is not observed.
12. Depending on their specification, models estimated using data from multiple sectors or countries do not necessarily provide estimates of multiple sector- or country-specific effects. While controlling for sector or country fixed effects, such models often limit themselves to estimating more general average effects.
13. We do not consider sector-specific the effects referring to the manufacturing sector as such, as this is too heterogeneous. However, effects referring to any manufacturing subsector are considered sector-specific.
14. Indeed, in a given sector, some firms participate in the EU ETS, while others do not. Notably, firms operating installations with production capacity below the relevant threshold do not come under the EU ETS.
15. Anger and Oberndorfer (2008) estimate the impact of relative allowance allocation, this being the ratio of allocated allowances to emissions, on revenues and on the employment of German regulated firms in 2005. The perspective is therefore slightly different from that of the studies surveyed here, which consider the effects of participation in the EU ETS, and not of relative allocation among regulated firms. The results indicate that relative allocation had no statistically significant effect on revenues or employment.
16. The data do not allow for the disentangling of quantity and price variations.
17. Four sector subsamples are considered: ‘Paper and paper products’, ‘non-metallic mineral products’, ‘basic metals’ and ‘electricity and heat’.
18. In the primary production process, aluminium oxide is produced from bauxite and further processed to aluminium via electrolysis. Secondary aluminium is produced using recycled scrap. Its electricity intensity is about 5% of that required to produce primary aluminium.
19. The authors state that the results with matching are similar, but they are not shown in the paper (they are available from the authors upon request).
20. The Luenberger indicators are computed based on directional distance functions using data envelopment analysis, which is a non-parametric linear programming technique.
21. A negative effect represents a move towards the efficient production frontier (i.e. an increase in production efficiency).
22. The analysis only considers firms that have invested abroad.
23. Process sectors are those regulated through process-specific capacity thresholds. The non-process sectors are regulated due to combustion activities.
24. Perhaps, even 22 companies may seem a small number to some. However, those considered by Veith *et al.* (2009) represent almost two-thirds of total electricity generation in Europe and account for about one third of all emissions under the EU ETS.
25. This is unexpected as, even in the short term, carbon-free generators benefit from higher electricity prices by reaping inframarginal rents.

26. On 25 April, the first reports on country-level emissions began to leak into the market. As the excess supply of allowances became obvious, carbon prices fell from €28/tCO_2 on 25 April to €14 on 28 April.
27. In Phase I (and in subsequent Phase II), almost all allowances were given away for free.
28. The refining sector is characterized by very high-cost pass-through rates, close to 100% (see, e.g. de Bruyn *et al.*, 2010 and de Bruyn *et al.*, 2015).
29. For new firms, pre-treatment observations do not exist. For closed firms, (most recent) post-treatment observations do not exist.
30. In the relevant DiD literature, Marin *et al.* (2018) is, to our knowledge, the only study to empirically examine the importance of discarding new and closed firms.

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