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Abstract

Concerns about the potential negative effects on domestic firms' international competitiveness and ensuing carbon leakage are the main obstacle to the unilateral use of carbon pricing for reducing greenhouse gas emissions. Since 2005, the EU Emissions Trading System (EU ETS) has put a price on about half of the EU's overall emissions and presently remains the largest cap-and-trade scheme in the world. Monitoring the competitiveness effects of the EU ETS is vital for evaluating the cost effectiveness of the policy instrument and for amending it if needed. This paper surveys the econometric literature that tests for the occurrence of competitiveness effects and carbon leakage under the EU ETS. Emphasised is the specific or more general relevance of estimation results for sectors, countries and years. Organised in this way, the empirical evidence may better inform policy. The review also covers several studies analysing the competitiveness effects of the EU ETS through the lens of stock markets. By far, the most frequently encountered conclusion is that no evidence was found of negative statistically significant effects on firms' competitiveness (nor, therefore, of carbon leakage). Among the few adverse effects, those concerning increased FDI activity in certain regulated sectors deserve special consideration.

Keywords

EU ETS, Competitiveness effects, Carbon leakage, Empirical evidence

1. Introduction

The EU Emissions Trading System (EU ETS) is the cornerstone of the EU's strategy for decarbonising its economy. In operation since 2005, it presently remains the largest cap-and-trade scheme in the world. The EU ETS imposes a cap on overall emissions of carbon dioxide, nitrous oxide and perfluorocarbons from over 11,000 heavy energy-using and electricity-generating installations and airlines, covering about 45% of the EU's overall greenhouse gas (GHG) emissions. At any given moment, the market of emission allowances sets a single price for the emissions falling under the scheme. This, in theory, guarantees that cheaper opportunities for emission abatement are exploited first[1].

Whether implemented through carbon taxation or through emissions trading, as with the EU ETS, the main rationale for carbon pricing is indeed cost effectiveness in reducing emissions (Baumol and Oates, 1971). However, the experience with the implementation of carbon pricing has generally proved difficult or contentious at the least. Most notably, concerns about the potential negative effects on domestic firms' international competitiveness, due to increased production costs, are a major obstacle to the unilateral use, or to the deeper unilateral use, of carbon pricing. Competitiveness deterioration also implies that the environmental effectiveness of the policy is affected, as in some measure additional emissions will be generated overseas. The mere displacement of emissions, due to their regulation, is called carbon leakage[2]. The EU ETS is no exception in facing these challenges. Their importance is well reflected in the history of the EU ETS, its working and the relevant policy debate[3].

While the concerns about detrimental effects on international competitiveness and related carbon leakage are perfectly legitimate, economic theory itself is not unequivocal as to whether such effects are certain outcomes of unilateral carbon pricing. The negative impact of tightening environmental regulation on exports or, over the longer term, on industry location is known as Pollution Haven Effect. In contrast with it, the Porter Hypothesis (Porter and van der Linde, 1995) suggests that market-based environmental policies, by spurring new production processes and products, may in fact lead to improved competitiveness. Does empirical evidence generally support the Porter Hypothesis? There is no consensus (Brännlund and Lundgren, 2009; Ambec *et al.*, 2013; Dechezleprêtre and Sato, 2017). In any case, however, carbon pricing can be accompanied by specific measures to guard against potentially adverse effects. In the EU ETS, the free allocation of emission allowances is used for just this purpose.

In the last decade, a large econometric literature has accumulated examining evidence of competitiveness effects caused by the EU ETS. Only two studies (Dechezlepretre *et al.*, 2015 and Naegele and Zaklan, 2017), as far as we are aware, directly test for evidence of carbon leakage; that is, for whether emissions increased outside the EU as a consequence of the EU ETS. While the Pollution Haven Effect vs Porter Hypothesis debate permeates this whole literature, the same studies necessarily deal in some way with the more specific question of whether the EU ETS net-of-free-allowances has affected businesses. Free allocation remains a central feature of the EU ETS and a determinant of its performance. Its calibration, including the progressive replacement with auctioning, has been a matter at the heart of most regulatory interventions. Thus, it is important to understand whether different sectors have suffered any loss of competitiveness due to the EU ETS, despite free allocation, or viceversa, have benefited from regulation, possibly (but not necessarily) thanks to free allocation.

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[1] All official documentation and any relevant information on the functioning of the EU ETS can be found on the website of the European Commission's DG Clima (www.ec.europa.eu/clima/).

[2] 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.

[3] Ellerman *et al.* (2010) is the reference book for the genesis and the development of the EU ETS in its first five years of operation.

This chapter offers a comprehensive review of the literature at hand. Any studies that present relevant econometric estimations and meet acceptable quality standards are considered[4]. The main goal of the review is to identify robust findings, while qualifying for the generality of individual results. Unlike previous literature reviews with a focus on the competitiveness effects of the EU ETS (notably, Martin *et al.*, 2016), we emphasise the specific or more general relevance of estimation results for sectors, countries and years. We deem that by making these distinctions as clearly as possible, better weighted and hence more accurate conclusions can be drawn based on the different outcomes. Organised in this way, the existing empirical evidence may better inform policy. Moreover, it may make more obvious where empirical evidence is limited or missing.

The first part of the review covers several works that, taken together, consider a range of economic performance indicators (e.g., exports, profits, sales, number of employees and productivity measures) and employ various econometric approaches. As Dechezleprêtre and Sato (2017) point out, there is, as yet, no single accepted test or measure of the competitiveness effects of environmental regulation, so the literature continues to use a variety of outcome measures linked to competitiveness. The second part of the review covers, by contrast, a rather homogenous body of literature that specifically infers investors' appraisal of the influence of the EU ETS on firm competitiveness. It does so by analysing the effects of changes in the price of European Emission Allowances (EUAs) on returns on company stock prices. The EU ETS can be valued either as a net extra cost or as an opportunity for increased profits. The sector's and firm's characteristics and the extent of free allocation will determine which of these two. Unlike other competitiveness indicators, which measure realised outcomes, stock returns reflect investors' expectations. For this reason, we refer to the first as conventional indicators and to the second as unconventional ones. As most of the works looking at stock returns are quite recent, only a few of them have been covered in previous literature reviews.

The rest of the chapter is organised as follows. Section 2 reviews the literature considering conventional competitiveness indicators and the two studies testing for carbon leakage. Section 3 reviews the literature analysing stock returns. Section 4 discusses the findings and concludes.

2. Effects on conventional competitiveness indicators and evidence of carbon leakage

The econometric literature assessing the competitiveness effects of the EU ETS is very diverse with respect to the variables used for measuring economic performance. It is also diverse with respect to the data, the methods and both the time and country coverage of the applications. With reference to the identified studies that consider conventional competitiveness indicators (in the sense specified), the first part of this section illustrates the choices made by the authors in each of these respects. For expository convenience, the two studies found that directly test for carbon leakage (Dechezleprêtre *et al.*, 2015 and Naegele and Zaklan, 2017) are considered together with this literature.

Detailed accounts of the contents and the results of the same literature are subsequently provided[5]. The studies are presented according to whether the respective estimated effects are *a)* sector-generic, country-generic, *b)* sector-generic, country-specific, *c)* sector-specific, country-generic, or *d)* sector-specific, country-specific[6]. We deem that the distinction between sector-generic and sector-specific effects is particularly expedient for policymaking. As understood in the rules for free allocation, the EU

[4] Our search of the literature, which was carried out through the Google Scholar web search engine, terminated in December 2017.

[5] A broader discussion of the evidence and of the relative implications of this literature is left to the paper's conclusive section.

[6] We do not consider effects referring to the manufacturing sector as being sector-specific, since the manufacturing sector is too heterogeneous. However, effects referring to any manufacturing subsectors (distinguished by output) are considered sector-specific.

ETS legislation needs to carefully consider the different effects that the scheme has on different sectors[7]. This literature review shows, however, that the studies providing estimates of sector-specific effects are relatively few and together only cover few sectors.

2.1 Mapping the literature: dependent variables, levels of analysis, methods, coverage

The econometric applications in the literature presented in this section can vary from one to another across different dimensions. The following five are the main ones:

1. Measure of competitiveness

   Several dependent variables are considered as alternative competitiveness indicators. This is possible because firms can respond to carbon pricing in different ways, notably through pricing-, production- and investment decisions, the effects of which, in turn, are detectable at different levels. These include sales, profits, the number of employees, exports, process or product innovations and changes in production capacity or location[8].

Table 1 – Surveyed literature (conventional competitiveness indicators): measures of competitiveness

Variable	Number of studies
Productivity	7
Trade	7
Employment	6
Profitability	4
Turnover	3
Value added	3
Investment (FDIs included)	3
Production costs	1

2. Level of analysis

   Thanks to the increasing availability of micro-level data, most applications are at the installation level or, more often, at the firm level. Basic information on regulated installations is found in the EU Transaction Log (EUTL);[9] and additional useful information can be drawn from external company databases (typically, private databases provided under license or public ones for administrative purposes) using firm identifiers. Fewer analyses are carried out at the sector level, which typically use time-series techniques.

3. Approach

   Different approaches are used. The difference-in-differences (DiD) approach (with pre-treatment matching) has become by far the most popular. Its main attractiveness lies in the clearcut causal interpretation of the results around the impact of participation in the EU ETS – which in the control-treatment framework is the "treatment" – on the given dependent variable. Moreover, it allows for the capture of the final net effect of the EU ETS without having to specify a relationship (which is empirically difficult to identify) between EUA prices and the dependent

[7] Arguably, heterogeneous effects across countries are easier to evaluate. Moreover, differently from business representatives, national governments participate first hand in the legislative process.

[8] Dechezleprêtre and Sato (2017) put some order into this collection of indicators by classifying the corresponding effects as first, second and third order, and distinguishing between firm responses, on the one hand, and economic, technology, international and environmental outcomes, on the other.

[9] The EUTL records official information both on regulated installations and allowance transactions in the EU ETS. The EUTL is accessible online at: http://ec.europa.eu/environment/ets/.

variable[10]. In the remaining applications, either time-series or panel-data models are employed. In the first case, the effect of the EU ETS is more specifically that of EUA prices. In the second, the effect usually refers to participation in the EU ETS, to EUA prices, or some measure of regulatory stringency.

Table 2 – Surveyed literature (conventional competitiveness indicators): approach and level of analysis

	Level of analysis		
Approach	Firm (/plant)	Sector	Total
Time series	0	4	4
Panel data	3	2	5
DiD	12	0	12
Total	13	5	21

4. Specificity of effects

   Some models provide estimates of sector- and/or country-specific effects, whereas others offer estimates of more general average effects. Importantly, models fitted to data from multiple countries or sectors do not necessarily provide estimates of multiple country- or sector-specific effects. While including binary variables controlling for country or sector fixed effects, they often limit themselves to estimating more general average effects that correspond to the scope of the sample.

Table 3 – Surveyed literature (conventional competitiveness indicators): specificity of effects

	Sector dimension		
Country dimension	Sector-specific	Sector-generic	Total
Country-specific	5	4	9
Country-generic	7	5	12
Total	12	9	21

5. Time coverage

   Models are estimated using data spanning different time periods. This is particularly relevant considering the dynamic nature of the EU ETS, as reflected in the evolution of EUA prices, in its structure by trading period, as well as in the changes to its regulation. Most studies are based on datasets covering Phase I (2005-2007) or both Phases I and II (2008-2012). By contrast, surprisingly few studies, as of yet, draw on data stretching as far as Phase III (2013-2020).

Table 4 – Time coverage of surveyed literature (conventional competitiveness indicators)

Study	Phase I			Phase II					Phase III			
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Reinaud (2008)	■	■	■									
Commins *et al.* (2011)	■	■	■									
Abrell *et al.* (2011)	■	■	■	■								
Costantini and Mazzanti (2012)	■	■	■									
Sartor (2012)	■	■	■	■	■	■	■					

10 Typically, in the studies using the DiD approach, regulated firms or installations are first paired through statistical matching (e.g., through propensity score matching) with similar non-regulated counterparts. The model for the variable of interest is then fitted, including a binary variable among the regressors. This indicates whether the firm or installation participates in the EU ETS. The estimated coefficient of this variable measures the estimated effect of the EU ETS. For a technical overview of this and similar methods for policy evaluation, the reader is referred to Imbens and Wooldridge (2009).

Chan *et al*. (2013)	■	■	■	■	■							
Yu (2013)	■	■										
Petrick and Wagner (2014)	■	■	■	■	■	■						
Wagner *et al.* (2014)	■	■	■	■	■	■						
Lundgren *et al.* (2015)	■	■	■	■								
Dechezleprêtre *et al*. (2015)*			■	■	■	■	■	■	■	■		
Marin *et al.* (2015)	■	■	■	■	■	■	■	■				
Jaraite and Di Maria (2016)	■	■	■	■	■	■						
Branger *et al.* (2016)	■	■	■	■	■	■	■	■				
Klemetsen *et al.* (2016)	■	■	■	■	■	■	■	■	■			
Lutz (2016)	■	■	■	■	■	■	■	■				
Borghesi *et al.* (2016)	■	■	■	■	■	■						
Koch and Basse Mama (2016)	■	■	■	■	■	■	■	■	■			
Löschel *et al*. (2016)	■	■	■	■	■	■	■	■				
Boutabba and Lardic (2017)	■	■	■	■	■	■	■	■	■	■	■	
Naegele and Zaklan (2017)*			■				■					

* Study directly testing for carbon leakage.

2.2 Detailed review

2.2.1 Sector-generic, country-generic effects

Using a large firm-level longitudinal dataset, mainly sourced from the Amadeus global company database (Bureau van Dijk), 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)* tangible investment; *c)* total factor productivity (TFP); and *c)* 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 is positive (1.5%). All these effects, however, are statistically significant only at the 10% level. Moreover, since participation in the EU ETS is defined at the sector level[11], measurement error is incurred and sectoral shocks may also confound estimations of the effects. The authors warn that the results are indicative.

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 indicates that the EU ETS increased exports of medium-low technology sectors which roughly correspond to those covered by the EU ETS: thus, an outcome consistent with the Porter Hypothesis. The authors themselves, however, qualify this finding as being far from conclusive, stating that further sector disaggregation and longer time series are required to infer on the impact of the EU ETS on the competitiveness of regulated firms.

Using firm-level data and applying the DiD approach, Marin *et al.* (2015) estimate the effects of the EU ETS on a large set of competitiveness indicators: value added; number of employees; turnover; investment; labour productivity; wages; return on investment (ROI); TFP; and markup. As in other studies in this literature, the Amadeus database is the main data source, providing information on the EU ETS firms and on matched counterparts. The samples used for estimation comprise between approximately 700 and 800 regulated firms (or fewer depending on any missing values of the variable analysed), from 2002 to 2012. The EU ETS appears to have positively influenced the scale of firms, as measured by turnover, employment and value added (14.9%, 8.2% and 6%, respectively, in Phase II). By contrast, negative effects, smaller in magnitude, are found for two scale-free variables, namely -2.4%

[11] In a given sector, some firms participate in the EU ETS, while others do not. Notably, firms operating installations whose capacity is below the relevant threshold do not come under the EU ETS.

and -0.5% for, respectively, TFP and ROI, in Phase II. Some heterogeneity in effects across sectors and firms is also identified. The interactions with the treatment variable denoting participation in the EU ETS indicate that emission-intensive firms and sectors were generally penalised. On the other hand, consistent with the Porter Hypothesis, positive effects on labour productivity and on ROI are found for the interaction between participation in the EU ETS and (patent-based) environmental innovation.

2.2.2 Sector-generic, country-specific effects[12]

Wagner *et al.* (2014) assess the impacts of the EU ETS on GHG emissions and employment of regulated manufacturing firms in France. The DiD approach is applied to panels of administrative data comprising 5,957 plants (384 regulated) and 4,589 firms (287 regulated), from 2000 to 2010. Sizeable effects on emissions are found for Phase II, which, however, differ depending on whether the analysis is conducted at the plant or at the firm level. In the first case, the authors find that the EU ETS reduced emissions by almost 20%; in the second, by half as much. Similarly, varying results are found for the effects on employment. At the plant level, Phase II turns out to have reduced employment by 7%; at the firm level, meanwhile, no statistically significant effects are found. Two possible explanations for these differences in results are: within-firm leakage, that is, firms shifting production from regulated to non-regulated plants; and measurement error[13]. The authors find evidence of only modest within-firm leakage, but warn that further testing is required.

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)[14]. 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 5,000 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

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[12] 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.

[13] Participation in the EU ETS is defined at the installation level, not at the firm level.

[14] The data do not allow for the disentangling of quantity and price variations.

manufacturing plants[15]. 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.

Borghesi *et al.* (2016) investigate whether Phases I and II had any effect on outward FDIs of regulated manufacturing firms in Italy. In this study, FDIs are measured by the number of foreign subsidiaries[16]. 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. Results show that, on average, firms in the EU ETS did not increase their presence in other countries. However, the interactions with the treatment variable, denoting participation in the EU ETS, reveal that firms operating in sectors particularly exposed to international competition increased their FDIs towards countries not covered by the EU ETS. This result may reflect a strategy by which regulated firms attempt to stay competitive in the market.

Similarly to Borghesi *et al*. (2016), Koch and Basse Mama (2016) test for whether the EU ETS affected FDI stocks outside the EU of regulated (almost exclusively, manufacturing) firms in Germany[17]. The DiD approach is applied to a panel of firm survey data (Deutsche Bundesbank) spanning 1999-2013 (within which 232 regulated firms are identified). When using the full sample, no statistically significant effects are found across the three trading periods. This is the primary result, which speaks to exaggerated concerns about carbon leakage through relocation. Subsample analysis, however, reveals that the EU ETS increased (by as much as 50%) FDI activity of firms in "non-process" regulated sectors (notably, the machinery, electrical equipment and automotive sectors). Compared to "process" regulated sectors, non-process ones are characterised by lower capital intensities[18]. For this reason, the latter are more geographically mobile.

2.2.3 Sector-specific, country-generic 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 2,000 regulated firms (operating about 3,600 installations), from 2003 to 2008. Separate models for CO_2 emissions, added value, 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 small 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[19]. 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.

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15 Norway joined the EU ETS in 2008.

16 Available information on the economic relevance of the subsidiaries is too scarce to be used.

17 The analysis only considers firms that have invested abroad.

18 "Process" sectors are those regulated through process-specific capacity thresholds. The "non-process" sectors are regulated due to combustion activities.

19 Four sector subsamples are considered: "Paper and paper products", "Non-metallic mineral products", "Basic metals" and "Electricity and heat".

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[20]. 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); 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 be related to compliance costs (i.e. the cost of purchasing allowances) or fuel 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 cointegration 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[21]. 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 cointegration. 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.

2.2.4 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

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[20] This excludes the risk of estimated effects being biased by different trends in the sectors to which the firms in treatment and control groups would belong. On the other hand, it risks firms which should be in the treatment group ending up in the control group. Abrell *et al.* (2011) warn that this can happen if participating firms are not identified in the company database.

[21] 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.

supply), in 2005 and 2006. The DiD approach (with and without matching[22]) is applied to a panel dataset, extracted from Statistics Sweden's business database, comprising almost 1,000 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[23], 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 to 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.* (2016) 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[24]. Across the array of modeling strategies, no evidence is found of negative effects of the EU ETS on 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 2003-2007 and 2003-2012, respectively) and, in general, on regulated firms during the first year (only) of Phase I.

2.2.5 Carbon leakage

Dechezleprêtre *et al.* (2015) are the first to directly test for carbon leakage caused by the EU ETS. That is, instead of testing for competitiveness effects and assuming that those would have resulted in carbon leakage, shifts in emission locations are directly analysed. An ingenious strategy is put to work, made viable by a special database. The Carbon Disclosure Project (www.cdp.net) 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 1,785 companies (142 regulated), over 2007-2014, the authors test the relationship between changes in firms'

[22] 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).

[23] The Luenberger indicators are computed based on directional distance functions using data envelopment analysis, which is a non-parametric linear programming technique.

[24] A negative effect represents a move toward the efficient production frontier (i.e., an increase in production efficiency).

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 (2017) 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. Effects on stock returns

Taking a radically different approach from the literature reviewed in Section 2, several studies analyse the competitiveness effects of the EU ETS through the lens of stock markets. Assuming that a firm’s stock price reflects its 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. Specifically, a direct (/inverse/no) relationship between carbon prices and stock prices indicates that investors see the EU ETS as having a net positive (negative/no) effect on profits. Crucially, this effect varies across sectors and firms depending on the respective characteristics and on the proportion of emissions covered by free allowances. Indeed, the typical exercise in this literature consists in testing for differing effects across such dimensions.

Considering the mechanisms underlying the Porter Hypothesis, but also more sophisticated ones (e.g., restricting entry, raising rivals’ costs), the impact of carbon pricing on profits is not predictable with any certainty. In this sense, free allocation in a cap-and-trade scheme adds a layer of complexity. Free allocation introduces two channels through which firms can increase revenues and by which it can potentially increase profits; the latter meaning that the revenue increase following carbon pricing exceeds the production cost increase. The first channel is the pass-through of opportunity costs (the costs associated with the use of free allowances for compliance) to output prices. With positive carbon prices, depending on its ability to pass-through (at no expense of market shares or profits) and on its endowment of free allowances relative to emissions, a firm increases revenues and possibly profits. The second channel refers to the extra revenues that can be obtained from selling unused allowances. Thus, an increase in carbon prices will have a positive (/negative) effect on profits if the revenue effects operating through the said two channels dominate (/are dominated by) the increase in production costs. By the same token, a decrease in carbon prices will have a negative (/positive) effect on profits if the negative revenue effects dominate (/are dominated by) the decrease in production costs. Any of these variations in carbon prices equally indicates that investors see the EU ETS as having a net positive (/negative) effect on profits.

The literature in question presents itself as quite homogeneous in methodological terms. The use of the multifactor market model (MMM) is typical, in which daily (or monthly) returns on a firm’s stock are explained by those 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 MMM framework, applied to panel data, has the following form:

$$R_{it} = \alpha + \sum_j \alpha_i D_i^j + \beta_1 R_t^m + \beta_2 R_t^c + \sum_j \gamma_j R_t^j + \varepsilon \quad (1)$$

where: R_i is the return on the stock of firm i; D_i is a firm 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.

Most often daily returns are considered, while only a few studies use monthly data[25]. The number of companies varies greatly, from a dozen to about one hundred. More relevant elements of differentiation concern the estimation of effects that vary across sectors, firms or trading periods. Early contributions tend to focus on the electricity sector, within which they distinguish dirtier from cleaner firms (defined according to the carbon intensity of the generation fuel mix). More recent studies tend to extend the analysis to other sectors and can draw on data covering the first years of the third trading period. This is important, given the fundamental change in the allowance allocation regime brought in with Phase III. Moreover, the most significant variations on the standard MMM approach are represented by event studies (exploiting the April 2006 crash of EUA prices) and the extension to vector co-integration.

In the following, the identified literature (Table 5) is described in greater detail. 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.

Table 5 – Time coverage of surveyed literature (stock market)

Study	Phase I			Phase II					Phase III			
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Oberndorfer (2009)	■	■	■									
Veith *et al.* (2009)	■	■	■									
Mo *et al.* (2012)		■	■	■	■							
Bushnell *et al.* (2013)	■	■	■									
Jong *et al.* (2014)	■	■										
Scholtens *et al.* (2014)				■	■	■	■					
Oestreich and Tsiakas (2015)	■	■	■	■	■	■	■	■				
Venmans (2015)			■	■	■	■	■					
Pereira da Silva *et al.* (2015)									■	■		
Tian *et al.* (2016)	■	■	■	■	■	■	■	■				
Pereira da Silva *et al.* (2016)				■	■	■	■	■	■	■		
Moreno and Pereira da Silva (2016)				■	■	■	■	■	■	■	■	

3.1 Electricity sector (exclusively)

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 MMM approach. Though the samples differ somewhat in the number of companies (12 and 22[26], in Oberndorfer and in Veith *et al.*, respectively), their 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). On a different level, Veith *et al.* (2009) find that increases in carbon prices did not have a positive effect on carbon-free generation companies[27].

[25] Monthly data can be preferable as there is less noise in their information. However, the tradeoff is with the number of available observations, which, of course, are many fewer than with monthly data.

[26] 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.

[27] This is unexpected as, even in the short term, carbon-free generators benefit from higher electricity prices by reaping inframarginal rents.

Mo *et al.* (2012) mainly extend the analysis of previous works by comparing estimated effects across trading periods. The estimation sample covers the years 2006 to 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 former, 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, positive for less carbon-intensive ones. Limiting the analysis to the Spanish stock market, but crucially drawing on data straddling Phases II and III, Pereira da Silva *et al.*'s (2016) extend the standard MMM approach to vector cointegration. Applying a cointegrated 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 above positive relationship is found to be significantly stronger for the subset of clean energy producers.

3.2 Multiple sectors

Bushnell *et al.*'s (2013) study stands out in this literature for adapting the standard MMM 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[28], 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[29], 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.

Also the studies not restricted to the energy sector mostly use the standard MMM approach. Prominent among them is Oestreich and Tsiakas (2015). Using monthly data from the German stock market, the authors provide compelling evidence on the role of the allocation method in affecting the relative financial performance of different firms. 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.

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

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[28] 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.

[29] In Phase I (and in subsequent Phase II), almost all allowances were given away for free.

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 emphasises 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 MMM 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 MMM 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. The only sector for which positive effects are found in both trading periods is the refining sector[30].

4. Discussion and conclusions

The empirical literature on the competitiveness effects of the EU ETS and related carbon leakage is wide and growing. Yet, only two studies were found directly testing for carbon leakage; that is, testing for whether emissions increased outside the EU as a consequence of the EU ETS[31]. This is the case principally because econometric identification of carbon leakage presents additional empirical challenges (greater data requirements to begin with) compared to identification of competitiveness effects. Within the reviewed literature, two main sets of works have been identified. The first considers a range of conventional indicators measuring economic outcomes linked to competitiveness, such as profits, exports, sales, employment and productivity. The second looks at the stock market to infer whether investors believe the EU ETS is beneficial or detrimental to profits. Though the respective approaches are very different, the two bodies of literature complement each other nicely. Their recurring findings are largely consistent, thus, allowing for some robust conclusions. Nevertheless, especially considering the information needs of policymakers, significant gaps remain.

By far, the most frequently encountered conclusion is that no evidence was found of negative statistically significant effects of the EU ETS on firms' competitiveness (nor, therefore, of carbon leakage). Moderate to very low carbon prices are the first obvious suspect for this outcome. However, the role of generous free allocation, especially considering firms' differing abilities to pass through opportunity costs of emission allowances, is not less important. A few negative effects have been found, but most of them are characterised by uncertainty greater than ideal (i.e. estimated effects are statistically significant only at the 10% level) or are accompanied by words of caution due to specific data or methodological issues. Besides, a large diversity in the competitiveness indicators deployed means that a particular variable for which negative effects are more frequently detected does not exist. Nevertheless, while any significant effects should be carefully considered, two recent studies prompt a warning that, perhaps, should receive special attention. Namely, Borghesi *et al*. (2016) and Koch and Basse Mama

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[30] The refining sector is characterised by very high cost pass-through rates, close to 100% (see, e.g., de Bruyn *et al.*, 2010 and de Bruyn *et al*., 2015).

[31] None of these applications can produce empirical estimates of carbon leakage rates (i.e., the share of locally abated emissions compensated by increased emissions overseas). To do this, one would need a structural model allowing for the simulation of a counterfactual world without carbon pricing (Aichele and Felbermayr, 2015).

(2016), both find evidence of greater FDI activity, respectively, in Italy's and Germany's regulated sectors most exposed to international competition and less capital intensive.

Positive effects are more frequently found, but, crucially, they are almost exclusively explained by windfall profits (whether via pass-through of carbon costs, allowance overallocation or inframarginal rents) rather than by increased productivity and larger market shares. Indeed, it remains unclear whether the EU ETS made firms in any sectors or subsectors more competitive through innovation or efficiency improvements, the mechanisms underlying the Porter Hypothesis[32]. By contrast, some of the studies analysing stock returns are particularly effective in showing that the combination of free allocation and the pass-through of opportunity costs resulted in profit increases. They do so through comparisons of estimated effects: *a)* between regulated and non-regulated sectors; *b)* between dirtier and cleaner producers within the electricity sector; and *c)* across the first two trading periods and Phase III, Phase III marking the switch from almost full free allocation to auctioning as the main allocation method.

Finally, the conclusions that can be drawn from this literature present three orders of limits, all of which are, at least in part, explained by empirical difficulties. First, most empirical analyses still only refer to Phases I and II. This delay might have some relevance considering the changes that have taken place since the start of Phase III, notably the changed allocation regime. But developments external to the EU ETS (e.g., the economic context, technology, climate policies in other world regions) need also to be taken into account. Second, distinct estimates of sector-specific effects are few. With reference to the literature considering conventional competitiveness indicators, we found: three estimates for the cement sector; three for the iron and steel sector; three for the energy sector (for which carbon leakage risk is minimal); two for aluminium; two for paper; and one or, more often, none for all other sectors[33]. While scarce in number, sector-specific estimates seem to us particularly valuable, as they are suited to inform policy, not least possible revisions of the EU ETS. Third, with few exceptions, existing estimates of competitiveness effects refer only to short-term effects. However, the most relevant economic losses that unilateral carbon pricing might cause would unfold over the long term, if expected or protracted competitiveness deterioration affected investment decisions. In other words, through industry relocation or what is commonly referred to as investment leakage.

[32] Some studies notably, Calel and Dechezleprêtre (2015), find that the EU ETS had significant positive effects on low-carbon innovation (for a survey of the relevant literature, see Rogge, 2016). However, whether these resulted in net gains in competitiveness is a different question.

[33] In some cases, two-digit NACE sectors are still too heterogenous for the corresponding estimates to be of real use for policy.

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