Ecological Economics, September 2014, v. 105, pp.78-88

DOI: 10.1016/j.ecolecon.2014.05.010

ON THE EMPIRICAL CONTENT OF CARBON LEAKAGE CRITERIA IN THE EU EMISSIONS TRADING SCHEME*

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April 2014

Abstract

The EU Emissions Trading Scheme continues to exempt industries deemed at risk of carbon leakage from permit auctions. Carbon leakage risk is established based on the carbon intensity and trade exposure of each 4-digit industry. Using a novel measure of carbon leakage risk obtained in interviews with almost 400 managers at regulated firms in six countries, we show that carbon intensity is strongly correlated with leakage risk whereas overall trade exposure is not. In spite of this, most exemptions from auctioning are granted to industries with high trade exposure to developed and less developed countries. Our analysis suggests two ways of tightening the exemption criteria without increasing relocation risk among non-exempt industries. The first one is to exempt trade exposed industries only if they are also carbon intensive. The second one is to consider exposure to trade only with less developed countries. By modifying the carbon leakage criteria along these lines, European governments could raise additional revenue from permit auctions of up to €3 billion per year, based on a permit price of €30.

Keywords: Carbon leakage, industrial relocation, emissions trading, EU ETS, permit allocation, firm data

JEL Classifications: H23, H25, Q52, Q54, F18

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* Part of the analysis in this paper was previously circulated as NBER Working Paper 19097. We are indebted to Barry Anderson, Jörg Leib and Marty McGuigan for their invaluable help at different stages of this research, and to Felix de Bousies, Pieter De Vlieger, David Disch, Eszter Domokos, Lorenz Elsasser, Helen Franzen, Maite Kervyn, Zsofia Kopetka, Oliwia Kurtyka, Anne-Lise Laurain, Emeric Lujan, Nicole Polsterer, Antoine Martin-Regniault, Maxence Snoy, Joanna Romanowicz, Bartosz Vu, Julia Wittig, Joanna Wylegala for their help with the interviews. Melanie Hermann and Antonin Cura provided excellent research assistance. Olivier Sartor, Stephen Lecourt and Clément Pallière graciously provided data on National Implementation Measures. We thank two anonymous referees for insightful comments and suggestions that have improved the paper. We have also received helpful comments from Stephen Boucher, Alex Bowen, Denny Ellerman, Sam Fankhauser, Tom Foxon, Andy Gouldson, Mark Jacobsen, Stéphanie Monjon, and from staff members at DECC, at DG Climate, and at the Environmental Committee of the European Parliament. All remaining errors are our own. The interviews were funded through grants from the European Climate Foundation and the ESRC. The Centre for Economic Performance and the Grantham Institute on Climate Change provided generous logistical support. The authors gratefully acknowledge financial support from the British Academy (Martin), from the Leverhulme Trust (Muûls) and from the Spanish Government, reference numbers SEJ2007-62908 and ECO2012-31358 (Wagner).

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1 Introduction

It is widely recognized that the problem of carbon leakage poses a major challenge for designing effective unilateral policies aimed at mitigating global climate change. In its most direct manifestation, carbon leakage occurs when polluting plants that are subject to climate policy relocate to an unregulated jurisdiction. Since carbon emissions are a global pollutant, their "leaking" to unregulated places reduces the environmental benefits from the policy. In addition, carbon leakage creates an excess burden for those countries that regulate emissions to the extent that relocation reduces output, employment, and taxable profits at home.

Not surprisingly, carbon leakage takes the center stage whenever new climate change regulation is up for debate. So far, the most common deterrent against carbon leakage has been to either compensate or to exempt those industries deemed to be most adversely affected by the policy. For instance, virtually all of the numerous carbon taxes that have emerged in Europe since the 1990's grant rebates or exemptions to energy-intensive firms in order to prevent them from relocating.[1] While this practice may be justified from the point-of-view of industrial policy, it runs counter to the polluter-pays principle underlying environmental policy-making in the EU. It also gives way to rent-seeking behavior, as regulated firms have an incentive to exaggerate their compliance costs in order to receive more generous compensation. Addressing carbon leakage is therefore a difficult and controversial policy issue.

This paper empirically analyzes the current scheme to prevent carbon leakage implemented in the European Union Emissions Trading System (EU ETS), the world's first and largest regional cap-and-trade system for greenhouse gas emissions. During the first eight years of the EU ETS, leakage was addressed by offering manufacturing firms generous compensation in the form of allocating most emission allowances free of charge. In the current, third trading phase, which runs from 2013 until 2020, the European Commission (EC) gradually reduces the proportion of free allowances allocated to manufacturing firms. At the same time, and contrary to its stated objective of achieving full auctioning of emission allowances, the EC exempts from this transition more than three quarters of the regulated emissions from manufacturing, on the

[1] Contrary to this view, a recent study of the UK Climate Change Levy finds no causal impact of carbon taxation on output, employment or plant exit among manufacturing firms (Martin et al., 2011).

grounds that the firms accounting for those emissions are at risk of carbon leakage. Exemptions are granted according to two simple criteria, namely the carbon intensity of value added and trade exposure, both measured at the level of the 4-digit industry code.

Our paper assesses the accuracy of these criteria based on a novel firm-level measure of leakage risk we gathered in telephone interviews with managers of 390 manufacturing firms in six European countries which are regulated under the EU ETS. The flexibility of the interview based approach, along with the bias-reducing format of the survey tool developed by Bloom and van Reenen (2007) and adapted to the climate policy context in Martin et al. (2012, 2014), allows us to elicit valuable information on politically contentious issues such as a firm's vulnerability to carbon pricing, defined as the firm's propensity to downsize or relocate in response to climate change policy.

We show that carbon intensity is strongly correlated with our interview-based measure of vulnerability whereas trade intensity is not. This is a reason for concern because most exemptions from auctioning are granted on the basis of the trade intensity criterion alone. We propose two simple improvements to the exemption criteria, based on the principle that free permits should only be given to industries where the average relocation propensity is significantly higher than that of non-exempt industries. First, by not exempting trade intensive sectors but the ones that are at least moderately carbon intensive as well, European governments could raise additional auction revenue of up to €3 billion every year, based on the carbon price of 30€/tCO_2 which is used in the official economic analysis that justifies the leakage criteria (EU Commission, 2009). Alternatively, we show that a sector's intensity of trade with less developed countries such as China is a better proxy for vulnerability than the overall trade intensity. A change in the current trade intensity criterion along these lines could raise €430 million in auction revenues per year in addition to the revenue under the current auction rules.

In extending the normative analysis of industry compensation rules in the EU ETS by Martin et al. (2014), this paper contributes further evidence of practical value on this controversial aspect of climate policy. This will be relevant for the impending revision of the carbon leakage criteria by the EU Commission, but our findings also inform climate policy far beyond the European context. This is because criteria similar to the ones used by the

EC have been adopted in actual and proposed legislation underlying half a dozen regional carbon trading schemes world wide. For instance, emission intensity and trade intensity are used to determine eligibility for compensation in the recently implemented carbon trading schemes in California and Switzerland, in Australia's Carbon Pollution Reduction Scheme and in New Zealand's ETS. Moreover, these metrics were proposed for a US wide cap-and-trade scheme under the 2009 Waxman-Markey Bill, and will be applied in a future South Korean ETS (`http://www.ieta.org/worldscarbonmarkets`). In view of this, it is worthwhile to study how these criteria relate to leakage risk, as assessed by the very managers who decide on relocation.

The next section describes the policy background and summarizes the relevant literature. Section 3 describes the data set and explains our regression based test. Section 4 presents the results and Section 5 discusses their implications for the auction revenues forgone by the actual policy. Section 6 concludes.

2 Policy background: Carbon Leakage and the EU ETS

2.1 Carbon leakage

Although the objective of the EU ETS is the mitigation of a global environmental problem, the policy limits greenhouse gas emissions only in the EU – not globally. In the Carbon Leakage Decision,[2] the European Commission acknowledges that this "could lead to an increase in greenhouse gas emissions in third countries where industry would not be subject to comparable carbon constraints ('carbon leakage') and undermine the environmental integrity and benefit of actions by the Union". Matthes (2008) distinguishes between two forms of leakage. Investment leakage occurs in the medium-to-long run as firms do not expand their production facilities in Europe or fail to reinvest in facilities that have reached the end of their economic lifetime. Operational leakage denotes the short-term phenomenon of production activity being decreased or shut down completely in Europe and its possible relocation to other countries without carbon

[2] Cf. Commission Decision 2010/2/EU determining, pursuant to Directive 2003/87/EC of the European Parliament and of the Council, a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage (2010) OJ L 1/10 (Carbon Leakage Decision).

pricing. Since our empirical analysis relies on interviews with managers of existing facilities, the results are most pertinent to operational leakage.

The evident economic solution to the leakage problem is to adjust the price of goods for the implicit carbon cost when they cross the border (see e.g. Monjon and Quirion, 2010). However, such border adjustments – in addition to raising a number of practical issues – may collide with the rules of the World Trade Organization (e.g. Quirion and Monjon, 2011; Jouré et al., 2013). The EU ETS has been relying on free permit allocation as the principal instrument to avoid leakage. Incentives for investment leakage are mitigated by granting free emission permits to new facilities (the EU ETS sets aside permits for this purpose in a 'new entrant reserve'). Conversely, all freely allocated emissions allowances are cancelled when a regulated facility closes, thereby penalizing operating leakage. If properly designed and enforced, this plant closure provision deters carbon leakage because free allocation is contingent on the continued activity of the plant.[3] The drawback of this is a distortion of productive efficiency because free permits act like an output subsidy (Fischer and Fox, 2007; Quirion, 2009, discusses this in the EU ETS context).[4] Specifically, the plant closure provision may render the operation of otherwise inefficient plants profitable (Matthes and Monjon, 2008).[5]

2.2 Permit allocation

In phases I and II of the EU ETS, each member state drew up a National Allocation Plan (NAP) that fixed the national cap and determined the sectoral permit allocation. In developing their

[3]This deterrent for carbon leakage hinges on free allowance allocation and hence loses bite during the transition to full auctioning, unless low carbon innovation creates a lock-in effect (Schmidt and Heitzig, 2014).

[4]Extending earlier work by Demailly and Quirion (2006) on the cement sector, Monjon and Quirion (2011) use a computable partial equilibrium model to compare border adjustments and output based allocation. They find that the most efficient way to prevent carbon leakage in the EU ETS is by combining full auctioning of emissions allowances with border adjustments. In a theoretical analysis, Meunier, Ponssard, and Quirion (2012) show that a combination of output based and capacity based allowance allocation is second-best when border adjustments are not available.

[5]Notice that making permit allocation contingent on the firm's decisions at the extensive (continued operation) or intensive margins (output) leads to outcomes no longer being independent of the initial permit allocation. As Hahn and Stavins (2011) note, this 'independence property' of emissions trading follows from the Coase theorem under certain conditions (a competitive permit market, rational behavior, and lack of transaction costs, regulatory uncertainty or credit constraints). In a recent study of the RECLAIM program in Southern California, Fowlie and Perloff (2013) test and cannot reject the hypothesis that plant-level abatement of nitrogen oxides was independent of the permit allocation. For the EU ETS, Reguant and Ellerman (2008) obtain a similar finding in a study of Spanish electricity generators. In contrast, Abrell et al. (2011) find some evidence that the EU ETS increased employment at firms that received allowances in excess of their verified emissions.

NAPs in phase I most of the countries opted for "grandfathering", i.e. free permit allocations based on historical emissions (Ellerman, Buchner, and Carraro, 2007). In phase II, the member states imposed more stringent caps so as to honor their commitment to the EU's joint emission target under the Kyoto Protocol, but they also retained free allocation. Auctioning fell far short of what was allowed, and benchmarking remained an exception (Ellerman and Joskow, 2008).

Since the beginning of phase III, the allocation of all allowances has been relegated from national governments back to Brussels. The amended Emissions Trading Directive 2009/29/EC[6] advances the transition toward full auctioning of permits as the basic principle of allocation and stipulates a harmonized allocation scheme to reduce competitive distortions among producers of similar products across member states. The two main features that lead the way to this scheme are (i) the use of benchmarks which rewards operators who have taken early action to reduce the emission intensity of production, and (ii) the continued free allocation to sectors considered at risk of carbon leakage.[7]

To the extent possible, benchmarks are defined in tons of CO_2 equivalent per unit of output of a specific product.[8] They reflect the average greenhouse gas emission performance of the 10% best performing installations in the EU producing that product, based on the average emissions intensity in 2007-2008.[9] The amount of free permits is obtained by multiplying the benchmark with the historical reference activity level, defined as the median activity level over the years from 2005 until 2008 (or from 2009 until 2010, if larger). Total allocations calculated in this way are scaled by a factor that takes a value of 0.8 in 2013 and declines linearly to a factor of 0.3 in 2020.[10] This factor is meant to accomplish the gradual transition to full auctioning foreseen already in the original Emissions Trading Directive 2003/87/EC.

[6]Cf. Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community (2009) OJ L 140/63 (Emissions Trading Directive).

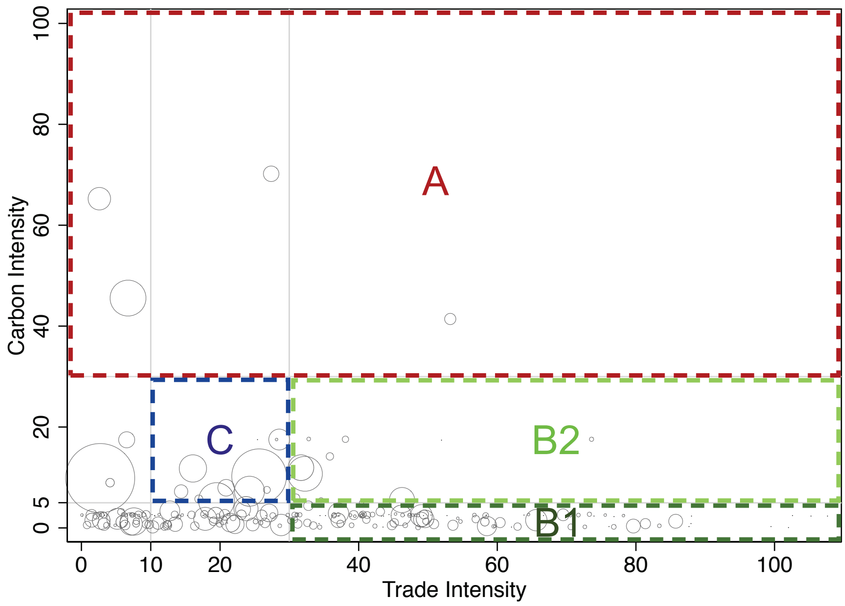
[7]Recall that the focus of this paper is on the manufacturing sector. Operators in the power generation sector no longer receive any free allowances, although some exceptions to this apply in eight of the member states that have joined the EU since 2004.

[8]Where deriving a product benchmark is not feasible, a hierarchy of fallback approaches is applied, as explained in detail by Sartor, Pallière, and Lecourt (2014).

[9]Cf. Commission Decision 2011/87/EU determining transitional Union-wide rules for harmonized free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council (2011) OJ L 130/1 (Benchmarking Decision).

[10]Furthermore, a uniform correction factor is applied if necessary to align the total free allocation to benchmarked installations with the overall cap on emissions.

Figure 1: Sectors exempt from permit auctions



Notes: The figure shows a scatter plot of the carbon and trade intensities of 4-digit (NACE 1.1) manufacturing industries, based on 9,061 EU ETS installations. The size of the circles is proportional to the number of firms in a given industry. Sectors in areas A, B1, B2 and C will continue to be exempt from permit auctions in EU ETS phase III. Source: Martin et al. (2014).

2.3 Carbon leakage sectors

To mitigate the competitiveness impacts of permit auctioning, the European Commission grants 100% of benchmark allocations for free to firms in sectors that are considered at risk of carbon leakage. The Carbon Leakage Decision stipulates that leakage risk of a sector or subsector be assessed on the basis of its carbon intensity (CI) and/or trade intensity (TI). The former proxies for the cost burden imposed by full auctioning, and is measured as the sum of the direct and indirect costs of permit auctioning, divided by the gross value added of a sector. The direct costs are calculated as the value of direct CO_2 emissions, where a proxy price of 30€/tCO_2 is used. Indirect costs measure the exposure to electricity price increases that are inevitable on account of full permit auctioning in the power sector. To calculate indirect costs, electricity consumption (in MWh) is multiplied by the average emission intensity of electricity generation in the EU27 countries (0.465 tCO_2/MWh), and by the same proxy price of 30€/tCO_2 for one European Union Allowance. The TI metric is calculated as "the ratio between the total value of exports to third countries plus the value of imports from third countries and the total market size for the Community (annual turnover plus total imports from third countries" (EU Commission, 2009, p. 24).

In addition, a combination of thresholds for CI and TI is used to establish carbon leakage risk. For a sector to be considered at significant risk of carbon leakage, its CI must be greater than 5% and its TI greater than 10%, or else its CI or TI is greater than 30%. Following this, we classify carbon leakage sectors into four mutually exclusive categories:[11]

- **A**: high carbon intensity ($CI > 30\%$)
- $\mathbf{B_1}$: high trade intensity and low carbon intensity ($CI \leq 5\% \cap TI > 30\%$),
- $\mathbf{B}_2$: high trade intensity and moderate carbon intensity ($5\% < CI \leq 30\% \cap TI > 30\%$),
- **C**: moderate carbon and trade intensities ($5\% < CI \leq 30\% \cap 10\% < TI \leq 30$).

Figure 1 plots the location of 4-digit sectors in a diagram with CI on the vertical and TI on the horizontal axis.[12] Two facts are immediate from this graph: First, category B_1 contains most of the sectors the EC considers at risk of carbon leakage. Second, most of these carbon leakage sectors are not carbon intensive at all, as their carbon intensity is less than 5%. Figure 2 plots the relative size of the resulting five categories in terms of the shares in the number of firms, in employment and in CO_2 emissions.[13] B_2 is the largest group of exempted firms in terms of employment, but B_1 has the largest share of exempted emissions. The share of CO_2 emissions that is not exempt from auctioning amounts to only 15% of permits surrendered on average in 2007 and 2008. Using an alternative approach, Juergens et al. (2013) obtain a somewhat higher estimate of 23%.[14] Both these estimates highlight that the Carbon Leakage Decision leaves most pollution rights with European industry, not tax payers, and hence undermines the principle of full auctioning established in the amended ETS directive.

In view of such far-reaching distributive consequences, it is imperative that the criteria for identifying carbon leakage sectors be as accurate as possible. This aspect has received much

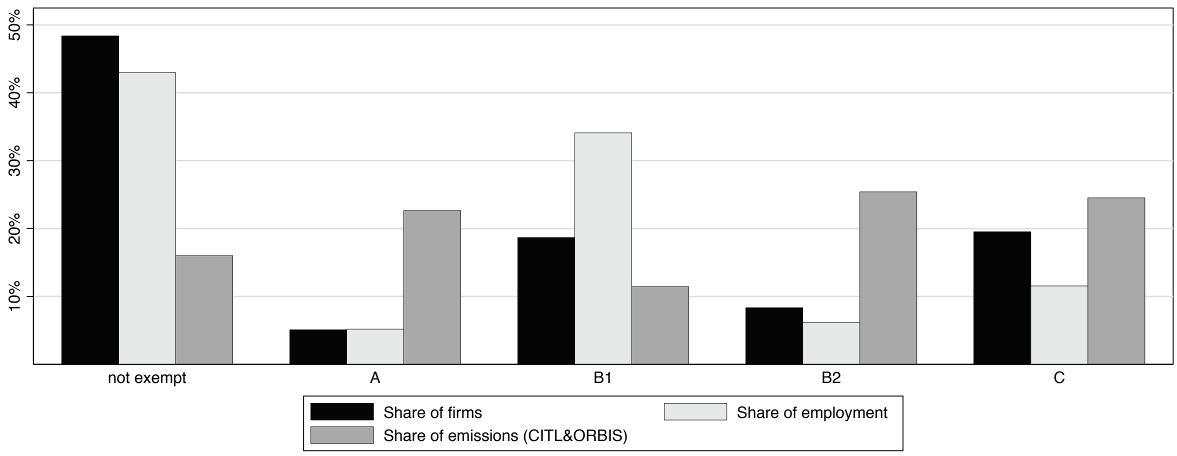
[11] This follows Directive 2009/29/EC's categorization except that category B is here further divided in two.

[12] Similar graphical representations have been used by Clò (2010) and Martin et al. (2014). The EUTL-ORBIS data used here are described in Section 3.1.

[13] As described in Section 3.1, installation-level data is aggregated at the firm level and only firms for which employment and sector are available are kept in the sample.

[14] The discrepancy between their estimate and ours arises because theirs is based not only on data from EUTL and the Impact Assessment Report accompanying the Carbon Leakage Decision (EU Commission, 2009), but also on confidential data on CO_2 emissions which the member states made available to the EC but which are not available to us. It is likely that the true value lies somewhere in between these figures.

Figure 2: Relative size of the non-exempt and different exemption groups



Notes: The chart displays the relative size of each group of NACE industries which are defined by the exemption criteria. Category B (very trade intensive sectors) is subdivided into low (B1) and moderate carbon intensity (B2). The sample includes the 3,247 manufacturing firms participating in the EU ETS and matched to ORBIS employment and sector data. The first bar indicates a group's share in the total number of firms, the second bar its share in employment, and the third bar its share in CO_2 emissions, based on the number of surrendered permits recorded in the EUTL. To compute CI and TI figures at the NACE 4-digit level, we follow the methodology and databases used by the EU Commission (2009). Source: Martin et al. (2014).

less attention in the economic literature thus far than the analysis of policy instruments to prevent leakage discussed in Section 2.1 above.[15] Ex ante evaluations have suggested that the EU ETS adversely impacts on production in most regulated industries while rising electricity prices lower the profitability of highly exposed industries such as primary aluminum production (e.g. Demailly and Quirion, 2008; Reinaud, 2005). These studies also show that free permit allocation offsets negative profit impacts in most industries, and can even lead to overcompensation (Smale et al., 2006). In a review of this literature, Sato et al. (2007) propose to use trade intensity, carbon intensity and electricity intensity as proxies for the competitiveness impact of the EU ETS.

There is, however, little empirical evidence to date that directly links cross-sector variability in CI and TI to heterogeneity in the relocation response to carbon pricing. In fact, a nascent literature on the *ex-post* analysis of the impact of the EU ETS on international competitiveness (reviewed in detail by Martin et al., 2013) does not suggest that industrial firms on the whole suffered strong adverse impacts when permits were allocated for free in the first years of the EU ETS (e.g. Abrell et al., 2011; Commins et al., 2011; Bushnell et al., 2013; Chan et al., 2013;

[15] Another strand of the literature assesses aggregate leakage effects by calibrating computable general equilibrium models that are capable of predicting the consequences of differential carbon pricing across regions. Branger and Quirion (2014) review 25 studies from 2004 to 2012 and report that typical carbon leakage estimates range from 5% to 25%. These figures do not speak, however, to the leakage risk in specific industries, which is the focus of this paper.

Wagner et al., 2013; Petrick and Wagner, 2014).

In a recent paper, Martin et al. (2014) analyze the link between free allowance allocation in the EU ETS and carbon leakage. In taking a normative approach to this issue, they propose that free allowances should be distributed across firms so as to minimize leakage, subject to a given amount of foregone auction revenue. They conduct numerical simulations of the efficiency gains of the resulting allocation rule. The focus of the present paper is on the positive analysis of the accuracy of the carbon leakage criteria, and on providing simple rules for improving them.

3 Data and Methods

3.1 Data

We use a unique firm-level data set constructed by Martin et al. (2014) for analyzing the link between permit allocation and the risk of carbon leakage. A key ingredient of this data set is a measure of a firm's propensity to downsize or relocate in response to carbon pricing, collected from 770 interviews with managers of 761 manufacturing firms in six European countries: Belgium, France, Germany, Hungary, Poland and the UK. The interviews ran from late August until early November 2009, and 429 of them were with ETS firms. As in Bloom and van Reenen (2007), interviews were conducted over the telephone and follow a protocol intended to minimize cognitive bias. This was achieved by asking managers open-ended questions and having the interviewers score the answer to each question according to a common benchmark. The large sample size and interviewer rotation means that it is possible to control for possible bias on the part of the interviewers, e.g. by including interviewer fixed effects in regression analysis (see also Bloom and van Reenen, 2010). More details on the interview process and firms' characteristics are provided in Martin et al. (2014).[16]

Our empirical analysis focuses on the managers' response to the question: "Do you expect that government efforts to put a price on carbon emissions will force you to outsource part of

[16]For instance, the web appendix to Martin et al. (2014) corroborates that firms were contacted at random, and that there was no selection on observable characteristics in a firm's decision to concede an interview when contacted.

the production of this business site in the foreseeable future, or to close down completely?". Interviewers recorded the answer as an ordinal 'vulnerability score' (VS) which ranges from 1 to 5. The highest score of 5 was assigned if the manager expected the plant to be closed completely, whereas the lowest score of 1 was given if the manager expected no detrimental impacts at all. A score of 3 was assigned if the manager expected that at least 10% of production and/or employment would be outsourced in response to future policies. Scores of 2 or 4 were given to account for intermediate responses. Table 1 presents the empirical distribution of the vulnerability score (VS) for the cross-section of 390 interviewed firms that are part of the EU ETS and for which data on both carbon intensity and regional trade intensity are available.[17]

Martin et al. (2014) note that none of the principal manufacturing industries in the sample exhibit a significant risk of firm relocation or closure. Only Other Minerals has an average score slightly above 3, and for a few sectors, including Iron and Steel, Ceramics, Glass, and Fuels, the 95% confidence interval includes a score of 3. In no case does the 95% confidence interval around the point estimates include the maximum score, meaning that the possibility of complete relocation in response to carbon pricing seemed very unlikely at the time the interviews were conducted (Martin et al., 2014).

The interview data are augmented with "hard" data on employment and turnover from the ORBIS database (Bureau van Dijk, 1999-2008), which also provides information on 4-digit NACE codes. A mapping from the European Union Transaction Log (EUTL, formerly known as CITL; EU Commission, 2005-2010) to ORBIS by Calel and Dechezleprêtre (2012) allows us to match firms and countries that are not included in our interviews.[18] This results in a sample of 9,061 installations (5,037 firms) which account for 75 percent of EUTL installations and 76 percent of surrendered CO_2 allowances. The EUTL contains data on emissions and allocations for Phases I and II. Employment and sectoral NACE rev 1.1 classification is available for 4,254 firms, of which 3,810 are manufacturing firms. Data from EUROSTAT (2010a,b,c) were used

[17]The criteria defining sectors at risk of carbon leakage were published on June 5, 2009 (Directive 2009/29/EC), i.e. two months before the first interviews were conducted. It is therefore possible that some managers correctly anticipated that they would receive free permits, and that this could have biased their reported VS. Martin et al. (2014) test and cannot reject the hypothesis that the available information on free permit allocation did not influence the responses to the hypothetical question underlying VS.

[18]We thank Rafael Calel and Antoine Dechezleprêtre for graciously providing us with NACE code identifiers and employment data based on their mapping.

Table 1: Descriptive statistics of the vulnerability score

	Mean	Standard deviation	Min	P25	Median	P75	Max	Firms
Overall vulnerability score	2.15	1.46	1	1	1	3	5	390
A. by country								
Belgium	1.86	1.21	1	1	1	3	5	74
France	2.15	1.47	1	1	1	4	5	88
Germany	2.53	1.72	1	1	1	5	5	85
Hungary	1.71	1.12	1	1	1	3	4	34
Poland	2.37	1.48	1	1	2	4	5	54
UK	2.00	1.33	1	1	1	3	5	55
B. by 3-digit sector								
Cement	2.50	1.56	1	1	2	4	5	54
Ceramics	2.80	1.79	1	1	3	4	5	5
Chemical & Plastic	2.15	1.42	1	1	1	3	5	66
FabricatedMetals	2.33	1.15	1	1	3	3	3	3
Food & Tobacco	1.71	1.16	1	1	1	2	5	68
Fuels	2.71	1.59	1	1	3	4	5	14
Furniture & NEC	1.00	.	1	1	1	1	1	1
Glass	2.82	1.56	1	1	3	4	5	28
Iron & Steel	3.00	1.60	1	1	3	5	5	23
Machinery & Optics	1.56	1.13	1	1	1	1	4	9
OtherBasicMetals	1.50	0.84	1	1	1	2	3	6
OtherMinerals	3.29	1.80	1	1	3	5	5	7
Publishing	1.20	0.45	1	1	1	1	2	5
TVCommunication	2.00	2.00	1	1	1	3	5	4
Textile & Leather	1.67	1.63	1	1	1	1	5	6
Vehicles	1.55	1.06	1	1	1	1	4	22
Wood & Paper	1.93	1.41	1	1	1	3	5	69

Notes: Summary statistics of the overall vulnerability score (first row), by country (panel A) and by 3-digit NACE sector (panel B). The score ranges from 1 (no impact) to 5 (complete relocation). A score of 3 is given if at least 10% of production of employment would be outsourced in response to future carbon pricing. NEC: Not elsewhere classified.

to reproduce as closely as possible the EC's calculation of the sector-level variables CI and TI. Finally, firm-level data on permit allocations for Phase III was obtained from the the National Implementation Measures (NIM).[19] For a more comprehensive description of the dataset, the interested reader is referred to Martin et al. (2014), which also contains further evidence that the VS is a reliable measure of firms' downsizing risk.

3.2 A regression based test

To evaluate the accuracy of the EC's carbon leakage criteria, we examine how they correlate with VS. In particular, CI and TI should be positively correlated with VS. We test this hypothesis by estimating partial correlations in a regression framework that controls for possible confounders at the firm and sector levels. The basic regression equation is given by

$$VS_{i,s,c} = \beta_0 + \beta_T TI_s + \beta_C CI_s + \mathbf{x}'_{\mathbf{i,s,c}}\beta_{\mathbf{x}} + \delta_c + \varepsilon_{i,s,c} \tag{1}$$

where $VS_{i,s,c}$ is the vulnerability score of firm i in sector s and country c, TI_s and CI_s are the trade and carbon criteria at the sector level, and $\mathbf{x}_{i,s,c}$ is a vector including higher order terms of these variables and interviewer fixed effects to control for possible bias on the part of the interviewers. Moreover, we control for interview noise due to the manager's characteristics – by including the tenure in the company, dummies for gender and professional background (technical or law) – and due to the time of the interview – by including dummies for month, day of week and time of day (am/pm). As a robustness check, we also include firm-level employment and capital. All specifications include a full set of country dummies δ_c.

It could be argued that the continuous relationship between VS, CI and TI imposed in these regressions is not appropriate for the EC's threshold based approach. We thus modify equation (1) to include a set of dummy variables representing the exemption categories ($\mathbf{A},\mathbf{B},\mathbf{C}$) defined

[19]We thank Oliver Sartor, Stephen Lecourt and Clément Pallière for kindly providing us with the data for 20 of these countries, for which they collected and matched the NIM data on free permit allocation to ORBIS (Sartor et al., 2014). We complemented this dataset with the NIM data for Belgium and Hungary, which we matched to ORBIS by hand. In total, this results in a sample of nearly 8,000 installations covering 95% of the emissions.

above instead of the continuous variables *TI* and *CI*.

$$VS_{i,s,c} = \gamma_0 + \gamma_A \mathbb{I}_{\{i \in \mathbf{A}\}} + \gamma_B \mathbb{I}_{\{i \in \mathbf{B}\}} + \gamma_C \mathbb{I}_{\{i \in \mathbf{C}\}} + \mathbf{x}'_{\mathbf{i,s,c}} \gamma_{\mathbf{x}} + \delta_c + \eta_{i,s,c} \tag{2}$$

The omitted category in this regression comprises all firms that are not exempt under the Carbon Leakage Decision. We estimate these regressions using ordinary least squares and calculate robust standard errors which are clustered at the 4-digit NACE code level.[20]

4 Results

4.1 Baseline specifications

Table 2 summarizes the results of various versions of regression equation (1). In the univariate specifications, we find a strong positive association of VS with carbon intensity, but no statistically significant association with trade intensity. This result is robust when both measures are included in a quadratic form that is better suited to capture possible effects of interactions and non-linearities. For instance, trade exposure could matter for very high values of TI only, or only when it coincides with high CI. There is no evidence of such effects, and the same conclusion arises from a probit specification where the dependent variable indicates that the VS is larger than 2 (reported in column 8). Weighting the regression equation (1) by employment does not change the qualitative findings but gives rise to a larger estimate for the impact on CI. This suggests that CI is a particularly good measure of the risk of downsizing among large firms. In sum, our regression-based test reveals that TI is not a good indicator to measure the risk of downsizing or outsourcing whereas CI is.

We obtain similar results when looking at exemption categories. The first column of Table 3 reports the results obtained for equation (2). Only the very carbon intensive group (**A**) has an average VS significantly higher than the reference category (firms that are not exempt from auctioning). But even in group **A** there is no dramatically high risk of downsizing or outsourcing for the average firm. The 95%-confidence band for the VS in group **A** just about includes

[20] Clustering standard errors at the 3-digit NACE code level does not warrant any changes to the inference drawn below.

Table 2: Vulnerability score and exemption criteria

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Vulnerability Score (VS)					VS>2
Sectoral Trade	-0.013		0.056	0.055	0.098	0.072	0.014	0.031
Intensity (TI)	(0.093)		(0.115)	(0.097)	(0.117)	(0.111)	(0.114)	(0.110)
Carbon Intensity (CI)		0.235***	0.462**	0.295***	0.475***	0.448**	0.405*	0.390**
		(0.060)	(0.213)	(0.089)	(0.114)	(0.220)	(0.237)	(0.194)
TI X TI			0.005			0.002	0.020	0.034
			(0.075)			(0.074)	(0.073)	(0.067)
CI X CI			-0.039			-0.036	-0.024	-0.035
			(0.037)			(0.038)	(0.039)	(0.034)
TI X CI			0.050	0.078	0.060	0.056	0.083	0.048
			(0.106)	(0.091)	(0.133)	(0.103)	(0.095)	(0.093)
Employment (ln)						-0.039	-0.082	
						(0.064)	(0.079)	
Capital (ln)							0.022	
							(0.043)	
Weights	no	no	no	no	employment	no	no	no
Observations	390	390	390	390	390	390	368	389

Notes: OLS regressions in columns 1 to 4 and 6 and 7, Weighted Least Squares (WLS) regression in column 5, and Probit regression in column 8. The dataset is a cross-section of 390 interviewed firms that are part of the EU ETS and for which EUTL, sectoral trade and carbon intensity data are available. The dependent variable is the vulnerability score of the firm given by the interviews data. In column 5, the score is weighted by the firm's employment. As explanatory variables, CI indicates carbon intensity and TI trade intensity which are calculated using data from Eurostat and the EU Commission. X indicates that two variables are interacted. Employment and capital are averages over the years from 2005 to 2008, taken from Orbis. Capital is measured as Fixed Assets and is not available for 22 firms of the sample. All regressions include a constant, interview noise controls and country dummies (not reported). Robust standard errors, clustered by 4-digit NACE sector, are given in parentheses. Asterisks indicate statistical significance at the 10%(*), 5%(**) and 1%(***) level.

the value of 3, which means a reduction of at least 10% in production or employment due to outsourcing.

Taken together, the regression results obtained in equations (1) and (2) suggest that the efficiency of the allocation scheme could be enhanced if the exemption criteria or associated thresholds were modified so as to better reflect the true risk of carbon leakage. The next section considers two simple modifications along these lines.

4.2 Extensions

4.2.1 Modifying intensity thresholds

The result that the average VS in categories **B** and **C** is not significantly higher than in sectors not exempt from auctioning suggests that subjecting sectors in these categories to auctioning would not raise overall relocation risk. However, category **B** is very heterogeneous. While most sectors in this category are not carbon intensive at all ($CI < 5$), there is a small number of sectors with intermediate carbon intensity ($5 < CI < 30$), as shown in Figure 1. In order to

Table 3: Vulnerability score and exemption categories

	(1)	(2)	(3)	(4)	(5)
	Vulnerability Score			Vulnerability Score>2	
CI>30 (A)	1.080***	1.065***	2.015***	0.757***	1.726***
	(0.284)	(0.291)	(0.510)	(0.230)	(0.440)
TI>30 ∩ CI<30 (B)	0.229				
	(0.259)				
10<TI<30 ∩ 5<CI<30 (C)	0.119	0.136	0.360	0.104	0.272
	(0.250)	(0.244)	(0.241)	(0.236)	(0.292)
B ∩ CI<5 (B1)		-0.047	0.059	-0.060	0.125
		(0.244)	(0.329)	(0.235)	(0.389)
B ∩ CI>5 (B2)		0.598*	1.033***	0.508**	1.269***
		(0.317)	(0.322)	(0.252)	(0.418)
Weights	no	no	employment	no	employment
Observations	390	390	390	390	390

Notes: OLS regressions in columns 1 and 2, WLS in column 3 and Probit regressions in columns 4 and 5. The dataset is a cross-section of 390 interviewed firms that are part of the EU ETS and for which EUTL, sectoral trade and carbon intensity data are available. The dependent variable is the vulnerability score (on a scale of 5) of the firm given by the interviews data in regressions 1 to 3, and a dummy indicating whether the score is higher than 2 in regressions 4 and 5. In columns 3 and 5, the firm's employment is used to weight the regression. CI indicates carbon intensity and TI trade intensity, calculated using data from Eurostat and the EU Commission. Based on these, dummies are constructed to represent belonging to categories A, B and C, as well as B1 and B2. These are used as explanatory variables. Columns 4 and 5 report marginal effects of the probit regressions. All regressions include a constant, interview noise controls and country dummies (not reported). Robust standard errors, clustered by 4-digit NACE sector, in parentheses. Asterisks indicate statistical significance at the 10% (*), 5%(**) and 1%(***) level.

account for this heterogeneity, we subdivide category **B** into a group with low CI ($\mathbf{B}_1$) and one with intermediate CI ($\mathbf{B}_2$).

When these separate groups are included along with groups **A** and **C** in regression equation (2), the more carbon-intensive sectors in group **B** exhibit a significantly higher risk of outsourcing than the reference group, even though, as is the case for group **A**, the risk of downsizing or closure does not attain very high levels for the average firm (cf. columns 2 and 3 of Table 3). This result holds up when the regression is weighted by employment. In fact, the coefficient estimates on groups **A** and $\mathbf{B_2}$ both become stronger, indicating that some of the larger firms in those categories are at a higher leakage risk.

In order to account for the qualitative difference between a slight increase in downsizing risk and a strong downsizing impact, we also estimate Probit regressions of the binary event that a firm has a VS of 3 or larger. The results, reported in columns 4 and 5 of Table 3, confirm that only groups **A** and $\mathbf{B}_2$ present some risk of downsizing. It would therefore seem justified to adjust the thresholds for exemption accordingly.

Table 4: Vulnerability score and region-specific trade intensities

	(1)	(2)	(3)	(4)
	Vulnerability Score			
Sectoral Carbon Intensity (CI)	0.239***	0.419***	0.555***	0.553***
	(0.057)	(0.094)	(0.167)	(0.166)
Sectoral Trade Intensity (TI)	0.378**	0.606***	0.701***	1.456***
with LESS developed countries	(0.164)	(0.206)	(0.231)	(0.245)
TI with LEAST developed countries	-0.229***	-0.313***	-0.421***	-0.739***
	(0.076)	(0.084)	(0.157)	(0.174)
TI with Developed non-EU countries	0.120	-0.019	-0.212	-0.593***
	(0.125)	(0.160)	(0.243)	(0.219)
TI with EU countries	-0.234**	-0.249*	-0.417***	-0.682***
	(0.114)	(0.132)	(0.142)	(0.189)
$(CI)^2$			-0.069**	-0.092**
			(0.030)	(0.045)
$(TI\ less)^2$			-0.152	-0.718***
			(0.121)	(0.131)
$(TI\ least)^2$			0.046*	0.094***
			(0.027)	(0.029)
$(TI\ developed)^2$			0.073	0.212***
			(0.088)	(0.074)
$(TI\ EU)^2$			0.015	0.305***
			(0.091)	(0.110)
TI less X CI			0.400	0.237
			(0.288)	(0.426)
TI least X CI			0.700***	0.760***
			(0.209)	(0.187)
TI developed X CI			-0.783***	-0.686***
			(0.232)	(0.179)
TI EU X CI			0.152	0.058
			(0.171)	(0.223)
Weights	no	employment	no	employment
Observations	390	390	390	390

Notes: OLS regressions in columns 1 and 3. WLS regression in columns 2 and 4. The dataset is a cross section of 390 interviewed firms that are part of the EU ETS and for which EUTL data, carbon intensity data and geographically precise sectoral trade and carbon intensity data are available. Robust standard errors, clustered by 4-digit NACE sector, in parentheses. Asterisks indicate statistical significance at the 10%(*), 5%(**) and 1%(***) level. Includes a constant, country dummies and interview noise controls (not reported). The dependent variable is the vulnerability score of the firm given by the interviews data. As explanatory variables, CI indicates carbon intensity and TI trade intensity which are calculated from Eurostat and the EU Commission data. X indicates that the two variables are interacted.

4.2.2 Refining the trade intensity definition

We have found that the TI criterion is of limited value for proxying a sector's actual downsizing risk. One reason for this could be that this indicator is not precise enough to capture how exposure to international markets affects downsizing risk. For example, being exposed to competition from China might affect a firm's competitiveness in a very different way than does competition from Australia. Moreover, being export intensive could have different implications than being import intensive. In order to explore whether a refined TI measure would give a better indicator of carbon leakage risk, we regress VS on CI and four separate measures of the intensity of trade with (i) least developed countries, (ii) less developed (or developing) countries including China and India, (iii) developed non-EU countries and (iv) EU countries.[21] These measures are based on figures for the years between 2005 and 2007.

Table 4 summarizes the results of these regressions. Column 1 reveals a strong positive association between vulnerability and TI with less developed countries, which includes China and other countries that tend to have less stringent environmental regulation standards and which compete with European manufacturing firms. The relationship between vulnerability and TI with least developed countries is negative and significant. This could reflect a lack of competition from such countries as they tend to export agricultural products and natural resources rather than manufactured goods. High TI with EU countries is negatively associated with the VS. This is consistent with firms anticipating that their EU competitors will be subject to the same policy constraints. The findings obtained in the quadratic form, which includes interactions of TI with CI and squared terms, are qualitatively similar (column 3). In addition, TI with other developed countries outside the EU only matters in interaction with high CI, in which case vulnerability is lower. Conversely, the negative link between vulnerability and TI for the least developed countries is partially offset for the most carbon intensive firms. The employment-weighted regressions (columns 2 and 4) show qualitatively similar results. The most striking difference is that the coefficient for trade with less developed countries is almost twice as large as in columns 1 and 3. This suggests that using a regionally disaggregated TI measure to assess vulnerability would be particularly important when the objective is to prevent job leakage.

[21] The full list of countries is reported in the Appendix. The grouping follows the 2011 UN classification, available online at http://unstats.un.org/unsd/methods/m49/m49regin.htm#developed.

Table 5: Vulnerability score and export-import intensitites

	(1)	(2)	(3)
		Vulnerability Score	
Carbon Intensity (CI)	0.224***	0.240***	0.457***
	(0.055)	(0.062)	(0.108)
Sectoral Export intensity (EI)	-0.071		
	(0.160)		
Sectoral Import intensity (II)	0.141		
	(0.153)		
EI with LESS developed countries		0.100	0.582***
		(0.145)	(0.193)
II with LESS developed countries		0.298**	0.169
		(0.117)	(0.162)
EI with LEAST developed countries		-0.173*	-0.290**
		(0.096)	(0.118)
II with LEAST developed countries		-0.132**	-0.094*
		(0.059)	(0.048)
EI with Developed non-EU countries		0.147	-0.209
		(0.191)	(0.233)
II with Developed non-EU countries		0.022	0.007
		(0.140)	(0.198)
EI with EU countries		0.216	0.065
		(0.389)	(0.661)
II with EU countries		-0.461	-0.151
		(0.352)	(0.606)
Weights	no	no	employment
Observations	390	390	390

Notes: OLS regressions in columns 1 and 2. WLS in column 3. The dataset is a cross-section of 390 interviewed firms that are part of the EU ETS for which EUTL, geographically precise sectoral trade and carbon intensity data are available. Robust standard errors, clustered by 4-digit NACE sector, in parentheses. Asterisks indicate statistical significance at the 10%(*), 5%(**) and 1%(***) level. Includes a constant, country dummies and interview noise controls (not reported). The dependent variable is the vulnerability score of the firm given by the interview data. In column 3, the firm's employment is used to weight the regression. As explanatory variables, CI indicates carbon intensity, EI export intensity and II import intensity which are calculated from Eurostat and the EU Commission data.

In further specifications, reported in Table 5, we decompose the TI measure into export intensity (EI) and import intensity (II). The first column shows that these variables on their own are not strongly correlated with VS. Columns 2 and 3 reveal an interesting heterogeneity. For the unweighted equation in column 2, the import intensity with less developed countries becomes significant, whereas for the employment-weighted regression it is the export intensity that is more strongly associated with a high VS. However, in both cases the point estimates for both import and export intensity are positive, suggesting that the specifications in Table 4 which consider overall trade intensity, is a reasonable simplification.

5 Discussion

Our analysis of the correlation between a measure of carbon leakage risk based on managers' responses, and the carbon leakage criteria applied by the EC has revealed that carbon intensity is a good proxy for leakage risk whereas trade intensity is not. This mismatch gives rise to overly generous compensation in the form of free permits granted to trade-exposed industries that are not really at risk of relocating due to carbon pricing. Based on our results, we have identified two simple modifications of the carbon leakage criteria that might inform the EC's impending review of carbon leakage sectors, scheduled for 2014. The first one is to consider trade intensive sectors at risk only if they are also carbon intensive. The second modification suggests the adoption of a more specific TI measure which is based on trade only with less developed countries rather than with all non-EU countries.

If exemptions from permit auctioning were granted according to these modified criteria, more emission permits could be auctioned without a significant increase in leakage risk. Given the scale of the EU ETS, it is worthwhile to perform a back-of-the-envelope calculation of the resulting increase in auction revenue. To this end, we compile installation-level data on benchmarking allocations, available for 22 countries, and match in the information on the NACE industry code, which is needed to assign installations to exemption groups. When computing the amount of emissions no longer exempt from auctioning under an alternative rule, we take into account that installations in non-exempt sectors get free permits for only 80% instead of 100% of their benchmark emissions in 2013, and that this proportion falls linearly to 30% until

Table 6: Reduction of free permit allocation and additional revenue

	Reduction of free permit allocation (22 countries) [$MtCO_2$ eq]	Reduction of free permit allocation, whole EU ETS [$MtCO_2$ eq]	Additional revenue with price of €30 per ton [M€]	Additional revenue with price of €5 per ton [M€]
A and *B2*	82.27 [70.78; 95.54]	100.29 [86.51; 115.54]	3,008.78 [2,595.35; 3,466.17]	501.46 [432.56; 577.69]
A, *B1, B2* and *C* – but TI with less developed countries only	8.29 [6.32; 10.17]	14.35 [9.47; 20.11]	430.4 [284.11; 603.41]	71.73 [47.35; 100.57]

Notes: Each row reports the reduction of free permit allocations and additional revenue under a different rule on average per year over 2013-2020. A, B1, B2 and C refer to the EU criteria defined in Section 2.3. The second row uses trade intensity (TI) with less developed countries in the definition of groups B and C. $MtCO_2$eq stands for million metric tons of CO_2 equivalent. The numbers in brackets report two-sided 95% confidence intervals of the reductions of free permit allocation and additional revenue obtained from a bootstrap with resampling based on 200 replications.

2020. The results of this exercise are reported in Table 6.

Consider first a modification of the carbon intensity threshold for trade intensive sectors, as described above. Table 7 lists all sectors that would cease to be exempt from auctioning under this proposal. For our sample, we calculate that this would yield an additional 82.3 million emission rights to be auctioned on average per year. The bootstrapped confidence intervals at the 95% level indicate that the sampling error surrounding this estimate interval is quite small.[22] The point estimate is a lower bound as it does not include (i) a small proportion of installations that could not be matched to industry codes and (ii) installations in seven countries for which the NIM data were not publicly available.[23] Using aggregate data on emissions in 2009, we scale up the initial estimate to the entire EU ETS and obtain a total of 100.3 million permits to be auctioned.[24] Finally, we translate emissions into revenues using two alternative allowance prices. The higher price of €30 is considered in keeping with the price used by the EU Commission (2009) to calculate the carbon intensity of value added. A lower price of €5 is closer to the market price observed during 2012 and 2013. This leads to an estimate of additional auction revenue of either €0.5 billion or €3 billion per year, with uncertainty of $\pm 15\%$.

When the exemption categories are maintained but TI with less developed countries is used

[22]The bootstrap with resampling is based on 200 replications.

[23]The Czech Republic, Latvia, Liechtenstein, Lithuania, Malta, Norway and Slovenia.

[24]This is done in two steps. First, for each EUTL sector in each of the 22 countries, extra auctioning is scaled up by the proportion of matched 2009 allocations for the respective sector-country pair. Second, for each EUTL sector, additional auctioned permits were divided by the share of the 22 countries in the total, EU ETS wide allocation for that sector in 2009.

Table 7: List of additional sectors *not* to be exempted from auctioning

Sector Description	***NACE sector code (Rev 1.1)***	***Sector Description***	***NACE sector code (Rev 1.1)***
Processing and preserving of fish and fish products	152	Manufacture and processing of other glass including technical glassware	2615
Manufacture of crude oils and fats	1541	Manufacture of non-refractory ceramic goods other than for construction purposes; manufacture of refractory ceramic	262
Manufacture of starches and starch products	1562	Manufacture of ceramic tiles and flags	263
Manufacture of sugar	1583	Production of abrasive products	2681
Manufacture of distilled potable alcoholic beverages	1591	Manufacture of tubes	272
Production of ethyl alcohol from fermented materials	1592	Precious metals production	2741
Manufacture of wines	1593	Lead, zinc and tin production	2743
Manufacture of other non-distilled fermented beverages	1595	Manufacture of cutlery	2861
Preparation and spinning of woollen-type fibres	1712	Manufacture of tools	2862
Preparation and spinning of worsted-type fibres	1713	Manufacture of fasteners, screw machine products, chain and springs	2874
Preparation and spinning of flax-type fibres	1714	Manufacture of other fabricated metal products, n.e.c.	2875
Throwing and preparation of silk, including from noils, and throwing and texturing of synthetic or artificial filament yarns	1715	Manufacture of machinery for the production and use of mechanical power, except aircraft, vehicle and cycle engines	291
Manufacture of sewing threads	1716	Manufacture of furnaces and furnace burners	2921
Preparation and spinning of other textile fibres	1717	Manufacture of non-domestic cooling and ventilation equipment	2923
Textile weaving	172	Manufacture of other general purpose machinery n.e.c.	2924
Manufacture of made-up textile articles, except apparel	174	Manufacture of agricultural and forestry machinery	293
Manufacture of other textiles	175	Manufacture of machine- tools	294
Manufacture of knitted and crocheted fabrics	176	Manufacture of other special purpose machinery	295
Manufacture of knitted and crocheted articles	177	Manufacture of weapons and ammunition	296
Manufacture of other wearing apparel and accessories	182	Manufacture of electric domestic appliances	2971
Dressing and dyeing of fur; manufacture of articles of fur	183	Manufacture of office machinery and computers	300
Tanning and dressing of leather	191	Manufacture of electric motors, generators and transformers	311
Manufacture of luggage, handbags and the like, saddlery and harness	192	Manufacture of electricity distribution and control apparatus	312
Manufacture of footwear	193	Manufacture of insulated wire and cable	313
Sawmilling and planing of wood, impregnation of wood	201	Manufacture of accumulators, primary cells and primary batteries	314
Manufacture of articles of cork, straw and plaiting materials	2052	Manufacture of lighting equipment and electric lamps	315
Manufacture of pulp, paper and paperboard	211	Manufacture of other electrical equipment n.e.c.	3162
Manufacture of wallpaper	2124	Manufacture of electronic valves and tubes and other electronic components	321
Other publishing	2215	Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy	322
Manufacture of refined petroleum products	232	Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and associated goods	323
Processing of nuclear fuel	233	Manufacture of medical and surgical equipment and orthopaedic appliances	331
Manufacture of dyes and pigments	2412	Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment	332
Manufacture of pesticides and other agro-chemical products	242	Manufacture of optical instruments and photographic equipment	334
Manufacture of pharmaceuticals, medicinal chemicals and botanical products	244	Manufacture of watches and clocks	335
Manufacture of perfumes and toilet preparations	2452	Building and repairing of ships and boats	351
Manufacture of essential oils	2463	Manufacture of aircraft and spacecraft	353
Manufacture of photographic chemical material	2464	Manufacture of motorcycles and bicycles	354
Manufacture of prepared unrecorded media	2465	Manufacture of other transport equipment n.e.c.	355
Manufacture of other chemical products n.e.c.	2466	Manufacture of jewellery and related articles	362
Manufacture of man-made fibres	247	Manufacture of musical instruments	363
Manufacture of rubber tyres and tubes	2511	Manufacture of sports goods	364
Manufacture of flat glass	2611	Manufacture of games and toys	365
Manufacture of hollow glass	2613	Miscellaneous manufacturing n.e.c.	366

Notes: The table lists sectors that are exempt from auctioning under the current carbon leakage criteria, but would no longer be exempted under the first of our proposed rule changes, which is to apply an additional carbon intensity threshold of 5% to trade intensive industries. The list contains about half of the sectors currently exempted. The EC criteria apply at the 4 digit (NACE Rev. 1.1) sectoral level. For conciseness, we report the 3-digit sector if all 4-digit sub sectors in a 3-digit sector would cease to be exempted.

instead of overall TI, the increase in auction revenue is lower, €71 million to €430m million per year, depending on the allowance price, and estimated somewhat less precisely. While these revenue estimates are also subject to uncertainty about future carbon emissions and allowance prices, their order of magnitude shows that the EU is prepared to hand out profit subsidies to polluting firms on an enormous scale without getting anything in return. This is in line with the findings by Martin et al. (2014) who compare free permit allocation under the Carbon Leakage Decision to counterfactual scenarios that (i) minimize the total leakage risk subject to a maximum amount of free permits or (ii) minimize the amount of free permits subject to a maximum tolerable leakage risk. Like the present paper, they find a large potential for improving the efficiency of compensation offered to avoid leakage, even when compensation rules are based on relatively simple criteria, such as firm-level employment or carbon emissions. Their normative approach is based on the gradient of the vulnerability score with respect to free permits, whereas in the present paper we suggest simple improvements based on the correlation between the level of the vulnerability score and the carbon leakage criteria.

6 Conclusion

While auctioning is poised to become the predominant scheme for allocating emission permits during the current third trading phase of the EU ETS, free allocation continues at a substantial scale. The evidence presented in this paper substantiates concerns that the European Commission compensates polluting industries too generously at the expense of European taxpayers. Clearly, subsidizing "carbon fat cats"[25] in times of deep cuts in public spending could undermine political support for emissions trading. However, our analysis also points to a window of opportunity for European governments to improve the design of the EU ETS significantly while raising additional revenue in the hundreds of millions of euros annually. Rather than providing an unspecific subsidy for industry, governments could earmark this money to finance investments in infrastructure and R&D which are costly but crucial for the transition to a low-carbon economy. Furthermore, part of the additional revenue could be used to mitigate possibly regressive effects of higher carbon prices on low-income groups. Not least, more permit revenue

[25] http://www.sandbag.org.uk/maps/companymap/

would help to balance strained government budgets in those European countries most affected by the grand recession.

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Appendix

List of countries

The least developed countries Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Democratic Republic Of Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Maldives, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Samoa, Sao Tome And Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Sudan, United Republic Of Tanzania, Timor-Leste, Togo, Tuvalu, Uganda, Vanuatu, Yemen, Zambia

The less developed or developing countries Algeria, American Samoa, Anguilla, Antigua and Barbuda, Argentina, Armenia, Aruba, Azerbaijan, Bahamas, Bahrain, Barbados, Belize, Bolivia, Botswana, Brazil, Brunei Darussalam, Cameroon, Cape Verde, Cayman Islands, Chile, China, Colombia, Congo, Cook Islands, Costa Rica, Cote D'Ivoire, Cuba, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Falkland Islands, Fiji, French Polynesia, Gabon, Georgia, Ghana, Grenada, Guam, Guatemala, Guyana, Honduras, Hong Kong, India, Indonesia, Islamic Republic Of Iran, Iraq, Israel, Jamaica, Jordan, Kazakhstan, Kenya, North Korea, South Korea, Kuwait, Kyrgyz Republic, Lebanon, Libyan, Arab, Jamahiriya, Macao, Malaysia, Marshall, Islands Mauritius, Mayotte, Mexico, Federated States Of Micronesia, Mongolia, Montserrat, Morocco, Namibia, Nauru, Netherlands Antilles, New Caledonia, Nicaragua, Nigeria, Niue, Northern Mariana Islands, Occupied Palestinian Territory, Oman, Pakistan, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Pitcairn, Qatar, Saint Helena, Saudi Arabia, Seychelles, Singapore, South Africa, Sri Lanka, St Kitts And Nevis, St Lucia, St Vincent And The Grenadines, Suriname, Swaziland, Syrian Arab Republic, Tajikistan, Thailand, Tokelau, Tonga, Trinidad And Tobago, Tunisia, Turkey, Turkmenistan, Turks And Caicos Islands, United Arab Emirates, Uruguay, Uzbekistan, Venezuela, Viet-Nam, Virgin Islands (US), Virgin Islands (UK), Wallis And Futuna, Zimbabwe.

The developed non-EU countries Albania, Andorra, Australia, Belarus, Bermuda, Bosnia And Herzegovina, Canada, Croatia, Faroe Islands, Former Yugoslav Republic Of Macedonia, Gibraltar, Greenland, Holy See, Iceland, Japan, Kosovo, Liechtenstein, Republic Of Moldova, Montenegro, New Zealand, Norway, Russian Federation, Saint Pierre And Miquelon, San Marino, Serbia, Serbia And Montenegro, Switzerland, Taiwan, Ukraine, United States.

Table 1: Descriptive statistics of the vulnerability score

	Mean	Standard deviation	Min	P25	Median	P75	Max	Firms
Overall vulnerability score	1.87	1.29	1	1	1	3	5	725
A. by country								
Belgium	1.69	1.13	1	1	1	3	5	122
France	2.07	1.34	1	1	1	3	5	136
Germany	2.12	1.58	1	1	1	3	5	131
Hungary	1.50	0.95	1	1	1	2	4	68
Poland	2.03	1.40	1	1	1	3	5	74
UK	1.75	1.12	1	1	1	3	5	194
B. by 3-digit sector								
Cement	2.33	1.52	1	1	1	4	5	63
Ceramics	2.15	1.46	1	1	1	3	5	13
Chemical & Plastic	1.86	1.26	1	1	1	3	5	118
Construction	1.00	0.00	1	1	1	1	1	3
Fabricated Metals	1.67	0.93	1	1	1	3	4	45
Food & Tobacco	1.56	1.01	1	1	1	2	5	106
Fuels	2.71	1.59	1	1	3	4	5	14
Furniture & NEC	1.47	0.87	1	1	1	2	4	17
Glass	2.76	1.57	1	1	3	4	5	29
Iron & Steel	2.69	1.56	1	1	3	4	5	39
Machinery & Optics	1.26	0.68	1	1	1	1	4	68
Other Basic Metals	1.78	1.39	1	1	1	2	5	9
Other Business Services	2.67	0.58	2	2	3	3	3	3
Other Minerals	3.38	1.69	1	2	4	5	5	8
Publishing	1.58	1.02	1	1	1	2	4	19
TV Communication	1.91	1.45	1	1	1	3	5	11
Textile & Leather	1.90	1.33	1	1	1	3	5	20
Vehicles	1.62	0.99	1	1	1	2	4	47
Wholesale	1.40	0.89	1	1	1	1	3	5
Wood & Paper	1.85	1.36	1	1	1	3	5	88

Notes: Summary statistics of the overall vulnerability score (first row), by country (panel A) and by 3-digit NACE sector (panel B). The score ranges from 1 (no impact) to 5 (complete relocation). A score of 3 is given if at least 10% of production of employment would be outsourced in response to future carbon pricing. NEC: Not elsewhere classified.