Industry Compensation under Relocation Risk: A Firm-level Analysis of the EU Emissions Trading Scheme*

Ralf Martin†

Mirabelle Muûls‡

Laure B. de Preux§

Ulrich J. Wagner**

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Abstract

The need to compensate firms for the adverse profit impact of regulation has far-reaching consequences for policy design. We propose an industry compensation scheme that explicitly accounts for the risk that regulated firms relocate to unregulated jurisdictions and take with them jobs, taxable profits and – in the case of climate policy – the very pollution emissions targeted by the regulation. Our scheme follows the simple economic logic that compensation should be distributed across firms so as to equalize the expected marginal impact of compensation on the government's objective function. We apply this idea to assess the efficiency and distributional consequences of industry compensation rules under the EU Emissions Trading Scheme, which allocates permits for free to industries with high carbon and trade intensities. Drawing on interviews with managers of almost 800 manufacturing firms across Europe, we show that this practice will result in overcompensation on the order of €6.7 billion every year. If instead free permits were allocated across firms according to our proposal, the aggregate risk of job loss could be reduced by more than half without increasing aggregate compensation.

Keywords: industry compensation, emissions trading, permit allocation, EU ETS, firm data

JEL Classifications: H23, H25, Q52, Q54

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† Imperial College Business School, Imperial College London, and Centre for Economic Performance (CEP), London School of Economics and Political Science (LSE). E-mail: r.martin@imperial.ac.uk

‡ Imperial College Business School and Grantham Institute for Climate Change, Imperial College London, and CEP, LSE. Email: m.muuls@imperial.ac.uk

§ Centre for Health Economics, University of York, and CEP, LSE. Email: l.b.dePreux@lse.ac.uk

** Departamento de Economía, Universidad Carlos III de Madrid. Email: uwagner@eco.uc3m.es

1 Introduction

Government intervention in the marketplace is often justified as a means to increase net social welfare. When imposing welfare-improving regulation, a benevolent government may be able to tax part of the welfare gains and use the revenue to compensate industry for the cost of compliance. But when should compensation be offered, to whom, and how much? Should firms that pollute the environment be offered compensation for the cost impact of a regulation that forces them to internalize the environmental damage? Should financial institutions be offered compensation for a tax levied on financial transactions?

The distributional effects of regulation have far-reaching consequences for policy design. If no compensation is offered, industry has incentives to spend large amounts on raising political support against the policy, and to lobby for exemption clauses that weaken its effectiveness. Worse, when the policy is not harmonized across jurisdictions, firms may find it profitable to relocate to an unregulated one. As the head of a leading financial transactions company recently told the BBC: "If [the financial transaction tax] really happened, we would have to move our business to New York or Singapore or Hong Kong. Our business would continue. [It is] just sad it wouldn't continue in London."[1] The threat of relocation – if credible – is a powerful argument to extract concessions from politicians of all stripes, as regulation-induced job losses are likely to cloud their re-election prospects.

In the realm of climate policy, the threat of relocation is aggravated by "carbon leakage", i.e. the phenomenon that industrial relocation shifts greenhouse gas (GHG) emissions to places beyond the regulator's reach. Since GHG emissions are a global public bad, relocation not only costs jobs at home but also weakens the environmental effectiveness of the policy. It is therefore not surprising that generous compensations are

[1] BBC interview with Michael Spencer, Group Chief Executive Officer of ICAP, available online at http://www.bbc.co.uk/news/business-16990025.

pervasive in this area.[2] For example, numerous European countries have implemented carbon taxes since the 1990ies, and virtually all of them grant rebates or exemptions to energy-intensive firms, even though doing so runs counter to the polluter-pays principle underlying environmental policy-making in the EU.

This paper puts forth the simple but so far little appreciated economic logic that compensation should be offered first to those firms where it leads to the highest marginal improvement of the government's objective function associated with the policy. This is different from compensating the firms with the highest propensity to relocate. Rather, an efficient compensation rule equalizes, across firms, the firms' *marginal* propensity to relocate, weighted by how damaging their relocation is to the government's objectives.

We analyze the implications of this idea in the context of industry compensation rules established under the European Union Emissions Trading System (EU ETS), the largest cap-and-trade system worldwide. The EU ETS imposes an overall cap on CO_2 emissions from stationary sources – mostly power stations and industrial plants – in 30 countries. Emitters with heterogeneous abatement costs can trade permits amongst each other or with third parties so as to lower their total abatement cost and hence, the total cost of the cap on CO_2. Since the beginnings of the EU ETS in 2005, industrial emitters have been compensated for the cost of compliance by receiving fairly generous allocations of free permits based on their past CO_2 emissions. Contrary to its initial plan of phasing in auctioning of permits from 2013, the EU Commission (EC) decided in 2009 that free permit allocation would be continued for industries deemed at a heightened risk of carbon leakage. Determining which industries are at risk is complicated by asymmetric information about compliance costs. Regulated firms face an incentive to exaggerate these costs in order to extract more rents in the form of free permits, or to lobby for a more lenient

[2] The evidence on whether the threat of relocation is credible is very scant when it comes to climate policy. Martin, de Preux, and Wagner (2011) find no evidence that the UK Climate Change Levy caused output reductions or plant exit among treated firms. The literature on FDI and more broadly-defined environmental regulation suggests that relocation decisions in some industries are indeed deterred by environmental regulatory stringency(e.g. Wagner & Timmins, 2009; Hanna, 2010).

overall cap. The EC decided to exempt from permit auctions industries that are either very carbon intensive or very trade-exposed, or exceed certain threshold values on both measures. There is, however, no empirical evidence that these exemption criteria are in any way related to actual relocation or downsizing risk, let alone the marginal impacts of compensation on such risk.

This paper provides the first evidence on this topic based on new firm-level data we gathered in telephone interviews with managers of 770 manufacturing firms in six European countries. We applied a new survey tool developed recently by Bloom & van Reenen (2007) with the objective to mitigate known types of bias arising in conventional survey formats. An obvious bias to be concerned about in our context would be that firms overstate their vulnerability to future carbon pricing, along the lines of the financial executive quoted above. This is not supported by the data. In all countries and in most industries, the average downsizing risk remains well below a 10% cut in production or employment. In none of the industries we studied did we find that the average firm will close down entirely and relocate to a non-European country. There is, however, substantial variation in the reported vulnerability between sectors as well as individual firms.

We correlate the vulnerability measure derived from the interview responses with the sector-level criteria for free permit allocation devised by the EU. While carbon intensity is a good predictor of vulnerability, trade intensity is not. This is a reason for concern because most exemptions from auctioning will be granted on the basis of the trade intensity criterion alone. We propose two simple improvements to the EU criteria, based on the principle that free permits should only be given to industries where the average relocation risk 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 on the order of €6.7 billion every year. Second, 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 definition of the trade intensity criterion along these lines would raise an additional €2.8 billion in auction revenues per year.

The large heterogeneity in relocation risk in our data suggests that further efficiency gains could be reaped by allocating free permits at the firm level. We thus develop a normative framework for industry compensation under the threat of relocation. The key idea is that free permits should be given to those firms where they have the highest *marginal* impact on aggregate CO_2 leakage or job risk. Using the interview data, we show that this marginal impact varies substantially across firms and sectors, and that it is not necessarily correlated with the impact *level*. We employ dynamic programming techniques to minimize the aggregate risk of either job loss or CO_2 leakage for a given amount of permits to be allocated for free. Counterfactual simulations reveal that optimal allocation dramatically reduces this risk, even when compared to the situation where all permits are handed out for free. We also consider the dual problem of minimizing the number of permits handed out for free while constraining the aggregate risk. We find that the aggregate risk of job loss or carbon leakage resulting from an application of the current EU criteria could be achieved with just a fraction of the amount of permits that will be handed out for free. The mismatch between optimal and actual allocations is particularly severe when it comes to minimizing the risk of job loss. This means that, contrary to their official justification, the current exemption criteria do too little to mitigate the risk to jobs that arises from carbon pricing.

In view of these inefficiencies, we use the normative framework to examine the distributional consequences of the EC criteria. We find that Germany is the country in our sample which benefits, by far, the most from the deviation from optimal allocations. Moreover, we show evidence that the latest EU rules do little to narrow a gaping inequality in the distribution of subsidies per employee across firms, which were embodied in free permit allocations so far.

Finally, we derive various rules for assigning optimal allocations at the firm-level under a 'feasibility constraint' which ensures that these allocation rules are based on easily observable firm characteristics. We find that even simple rules, based only on firm-level employment and carbon emissions, yield substantial reductions in the risk of carbon leakage and job losses due to relocation.

Our paper adds to a rapidly growing literature that collects firm-level data on management practices in large-scale, cross-country surveys and links them to performance data from commercial and administrative sources in order to better explain firm-level productivity, energy efficiency and organizational structure (Bloom and van Reenen, 2007; Bloom, Genakos, Martin, and Sadun, 2010a; Bloom, Sadun, and van Reenen, 2010b, 2012; Martin, Muûls, De Preux, and Wagner, 2012).

Furthermore, our analysis provides new evidence on the competitiveness impacts of the EU ETS. While the existing literature on this topic (reviewed in detail in the following section) analyzes intensive-margin adjustments to production, employment and profits, we focus on the extensive-margin impact relevant for the risk of offshoring and relocation.

Not least, this paper also links to a series of papers that use general equilibrium models to recover the welfare costs of industry compensation under different environmental policy instruments (Bovenberg and Goulder, 2002; Bovenberg, Goulder, and Gurney, 2005; Bovenberg, Goulder, and Jacobsen, 2008). While our partial-equilibrium approach allows us to recover only *monetary* costs of industry compensation, we are able to calculate these costs with much greater sectoral detail, and to explicitly account for the rich heterogeneity across individual firms. Furthermore, the compensation scheme we propose is different from the one in this literature, in that it explicitly aims at preventing relocation and carbon leakage, in line with the EC's official justification for those transfers.

The remainder of this paper is organized as follows. Section 2 provides the relevant

institutional background and summarizes the literature on the EU ETS and competitiveness. Section 3 describes the data collection and matching, giving particular attention to how we measure firm-level vulnerability to carbon leakage. Section 4 analyzes the EU criteria and Section 5 presents our framework for optimal permit allocation under the risk of relocation. Section 6 concludes.

2 Permit allocation, carbon leakage and competitiveness

Designing a cap-and-trade scheme inevitably requires a choice to be made about the initial allocation of permits. Unless all permits are auctioned off, the regulator has to determine the micro-allocation of permits across firms, across sectors, and – in an international emissions trading scheme such as the EU ETS – across countries. According to the independence property of emissions trading (Montgomery, 1972), the permit price only depends on the stringency of the overall cap, but not on the initial allocation. An implication of this is that the permit allocation *per se* does not condition firm behavior at the intensive margin, because firms factor the opportunity cost of using a permit into their marginal cost – regardless of the initial cost of acquiring permits. Independence need not hold in the presence of market power (Hahn, 1984) or transaction costs (Stavins, 1995), but existing research has not rejected the independence property in the EU ETS (Convery & Redmond, 2007; Reguant & Ellerman, 2008).

In contrast, the extensive-margin behavior of firms is affected by both the overall stringency and the initial permit allocation. This is because variable profits are decreasing in the permit price and total profits decrease with the total cost of permits. Thus, full auctioning of emission permits might lower firm profits to the point where exit or relocation to non-EU countries are worthwhile considering. Likewise, a more stringent cap may have similar effects as it sustains a higher carbon price. An economic rationale behind allocating permits for free is thus to mitigate the risk of relocation and carbon

leakage by compensating industry for the adverse profit impacts of emissions trading.

Initial permit allocation in phases I and II of the EU ETS has followed a decentralized process. Countries were called upon to draw up National Allocation Plans (NAPs) that both fixed the national cap and determined the sectoral allocation.[3] Emission permits were handed out for free ("grandfathered") to existing business sites based on their historical emissions, on growth projections and on the Kyoto obligations of the countries they were located in. For phase III, beginning in 2013, the EC aimed to drastically increase the share of permits to be auctioned off, thereby transferring the ownership of emissions from incumbent polluters back to governments and, ultimately, taxpayers.[4] This objective was met with strong opposition from the affected industry associations who convinced EU law makers that full auctioning of permits would exacerbate the detrimental impact of the EU ETS on their competitiveness. The EC decided to mitigate the detrimental impacts of a more stringent cap in trading phase III by continuing to allocate free permits to sectors at significant risk of carbon leakage. Directive 2009/29/EC establishes this risk based on (i) carbon intensity (CI), defined as direct and indirect CO_2 costs relative to the value added of a sector, and (ii) trade intensity (TI), defined as the sector's trade volume with third countries divided by the total market size in the EU. The directive also stipulates threshold values for these metrics according to which a sector is exempt from permit auctioning or not.[5]

How do these metrics relate to the profit impact of the EU ETS? Conceptually, one can identify as relevant aspects (i) the cost impact of regulation, (ii) the demand response to higher product prices, and (iii) the factor specificity of production. The cost impact

[3]Based on a detailed account of the development of the NAPs under phase I in 10 European countries, Ellerman et al. (2007) show that the principles guiding this development were rather consistent across national governments, as most opted for free permit allocations based on existing emissions. NAPs submitted for phase II exhibited more stringent caps but retained the allocation scheme. Ellerman & Joskow (2008) point out that the use of auctioning in phase II remains far short of what is allowed and that the use of benchmarking remains an exception.

[4]This was decided in the revision of the Emission Trading Directive, agreed on 17 December 2008.

[5]The construction of these metrics by the EC is discussed in Section 3.4 below.

stems from the fact that previously grandfathered firms will be forced to pay the market price for the right to pollute. The cost burden tends to be higher for firms with a higher ratio of direct and indirect emissions to gross value added. However, CI defined in this way is an incomplete measure of the cost impact because it fails to account for how easily carbon intensive inputs can be replaced by less carbon intensive ones.

The demand response conditions a firm's ability to pass on the cost impact to its consumers in the form of higher prices. Doing so will be more difficult for a firm whose customers can easily substitute to relatively cheaper products from competitors located outside the EU. The import component of the TI metric picks up this kind of demand response; in fact import penetration is a widely used proxy for firms' ability to pass-through cost increases to customers. The export ratio contained in TI will have two opposite effects on the demand response. While the firm might be competing with non-EU firms for customers in its exports destinations, a higher export intensity also reflects the factor specificity of production which tends to mitigate the profit impact of permit auctioning. For instance, a firm that benefits a lot from country specific factors – e.g. a skilled labor force, natural resource deposits, or externalities from industrial agglomeration – is less likely to relocate in response to full auctioning than a firm that can easily set up shop elsewhere. If factor specificity creates an absolute advantage (think of Swiss watches), TI will be high because of strong exports, not imports. Consequently, the sector looks vulnerable according to EU criteria even though it can easily pass-through the cost of permit auctioning in international product markets.[6]

There is little empirical evidence linking the EU criteria to a sector's vulnerability to carbon leakage. A large number of *ex-ante* studies evaluates the impact of the EU ETS on competitiveness – defined as either production or profitability – using simulation or

[6]The same is true if aggregation to the sector level lumps together many different products. Then domestic firms may be able to pass-through the costs in some product markets that are less competitive due to concentration or product differentiation, in spite of a high import penetration at the sector level (Clò, 2010).

economic modeling (McKinsey & Ecofys, 2006a; Demailly & Quirion, 2006, 2008).[7] While they predict a negative impact on production in most manufacturing industries, these studies also show that profitability is not adversely affected under free permit allocation. In fact, grandfathering overcompensates many industries (Smale et al., 2006). An exception to this is primary aluminum production which – although not directly regulated under ETS phase I – suffers adverse impacts on production and profitability due to its exposure to higher electricity prices (Reinaud, 2005; McKinsey & Ecofys, 2006a; Smale et al., 2006). Based on this literature, Sato, Grubb, Cust, Chan, Korppoo, and Ceppi (2007) propose to use trade intensity, carbon intensity and electricity intensity as proxies for the competitiveness impact of the EU ETS.

Survey evidence shows that EU ETS companies are strongly opposed to more permit auctioning after 2012 (McKinsey & Ecofys, 2006b). So far, however, the EU ETS seems to have neither resulted in significant costs, nor induced a fundamental shift in strategy such as relocation or reduction of the workforce (Kenber et al., 2009).

A few *ex-post* evaluation studies of the competitiveness effects of the EU ETS have been completed to date, chiefly based on the first trading phase. Anger & Oberndorfer (2008) find no significant correlation between the degree of overallocation of German firms and their revenues or employment. Using balance-sheet data from more than 2,700 European companies for the period between 2005 and 2008, Abrell, Ndoye, and Zachmann (2011) find small negative impact of the EU ETS on employment, but no significant impact on value added or profit margins. Commins, Lyons, Schiffbauer, and Tol (2011) also use balance-sheet data for a large sample of European firms and find that phase I of the EU ETS had a negative effect on productivity and profits, but not on employment. Since treatment status is determined at the sector level, however, these effects are possi-

[7] A widespread approach to assessing aggregate leakage effects has been to calibrate computable general equilibrium models that are capable of predicting the consequences of differential carbon pricing across regions. We do not review these models here as they are not informative about individual NACE industries. Models with exogenous technical change predict carbon leakage rates between 5 and 35% for the Kyoto Protocol commitments (Paltsev, 2001).

bly confounded with those of sector-level shocks to the outcome variables.[8] Going one step further, Bushnell, Chong, and Mansur (2011) argue that some firms and sectors were profiting from regulation, as the stock prices of ETS companies – particularly in carbon- and electricity-intensive industries – fell significantly in response to a precipitous decline in the permit price which occurred in April 2006. In sum, the existing evidence 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.

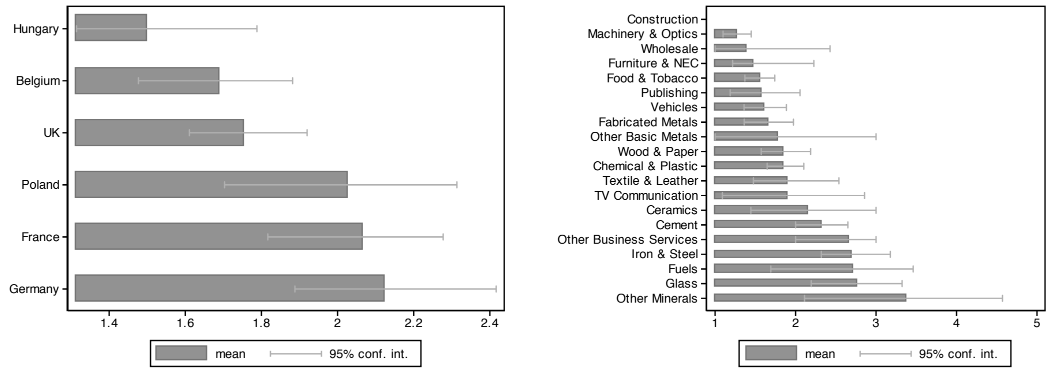
3 Data

This paper combines three principal sources of data into a unique firm-level data set suitable for analyzing the link between permit allocation and carbon leakage. First, we collect data on vulnerability to carbon pricing – as well as on management practices relating to climate policy more generally – by interviewing managers of manufacturing firms in six European countries: Belgium, France, Germany, Hungary, Poland and the UK.[9] Second, we augment this information with "hard" data on economic performance from the ORBIS database maintained by Bureau Van Dijk. Third, we obtain data on CO_2 emissions from the official EU ETS registry, known as the Community Independent Transactions Log (CITL). Additional EU data sources are used to calculate carbon emissions, CI and TI at the sector level. This section describes the data collection and matching processes and summarizes our core data set.

[8] In addition, none of these studies addresses a possible selection issue at the sector level.

[9] Scheduling of interviews began in late August 2009 and the last interview was given in early November 2009.

Figure 1: Average vulnerability score by country and industry



(a) by country (b) by sector

Notes: The bars show the average the average score in a given country (a) or 3-digit sector (b). Bootstrapped confidence bands are calculated at the 95% level. NEC: Not elsewhere classified.

3.1 Measuring vulnerability to carbon leakage

3.1.1 Vulnerability score derived from interview responses

To obtain a measure of the expected impact of future climate policies on outsourcing and relocation decisions, we asked managers:

> "Do you expect that government efforts to put a price on carbon emissions will force you to outsource part of the production of this business site in the foreseeable future, or to close down completely?"

The answers to this question were translated into an ordinal 'vulnerability score' (VS) on a scale from 1 to 5. Analysts were instructed to assign a score of 5 if the manager expected the plant to be closed completely, and a score of 1 if the manager expected no detrimental impacts at all. A score of 3 was given 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.

VS across all firms in the sample has a mean of 1.87 and a standard deviation of 1.29. ETS firms expect a significantly higher impact of 2.14 than non-ETS firms (1.49). Inspection of the raw data suggests that carbon pricing will affect German and French

and Polish firms more strongly than British, Belgian and Hungarian firms (cf. Figure 1a). However, in no country does the 95%-confidence band include outsourcing of more than 10% of production in response to regulation. Looking across different industries, Fuels and Other Minerals, Glass, Iron and Steel are the most vulnerable (cf. Figure 1b). In all other industries, the average VS is rather low. In no industry do we find that plant closure and complete relocation are in the 95% confidence interval.[10]

In further results, reported in Table A.5 in the appendix, we show that only French firms expect significantly stronger-than-average impacts after controlling for industrial composition and interview noise.[11] Hence the bulk of the heterogeneity in the responses is driven by sectoral differences. Again controlling for interview noise, we find that Other Minerals, Glass, Iron & Steel, and Cement are the most vulnerable industries, irrespective of employment size. Other energy intensive industries such as Food & Tobacco, Fabricated Metals, and Vehicles are significantly less vulnerable than the average.

3.1.2 Validity of the vulnerability score

Given the importance of the VS measure for the analysis to follow, we now describe key aspects of the interview design and the sampling procedure which help to minimize potential sources of bias. Additionally, we present evidence that our measure is *internally* valid, based on other interview results, and that it is *externally* valid, based on energy price elasticities of employment in a large sample of firms in Europe and other OECD countries.

Interview design We adopt a survey tool based on structured telephone interviews pioneered by Bloom & van Reenen (2007) and designed to avoid several sources of bias common in conventional surveys (Bertrand & Mullainathan, 2001). Unlike other survey

[10] Figure A.1 in the appendix shows the full distribution of the vulnerability score, by country and industry. Summary statistics are reported in Table A.4.

[11] The set of interview noise controls is described in the next subsection.

formats, the interviewer engaged the interviewee in a dialog with specific questions for discussion.[12] On the basis of this dialog, the interviewer then assessed the company along various aspects of management relevant for climate policy, including VS. We provided exemplary responses that interviewers could consult when in doubt about giving a high versus a medium or low score for the relevant dimension. The goal was to benchmark the practices of firms according to common criteria. For instance, rather than asking the manager for a subjective assessment of the management's awareness of climate change issues we gauged this by how formal and far-reaching the discussion of climate change topics was in current management.

As in Bloom & van Reenen (2007), the interview process was "double blind". Interviewees were not told that their answers would be scored, so as to avoid giving them an incentive to provide biased information. Conversely, interviewers were given no information about the firm except the contact details,[13] so as to minimize the chance that the interviewer's preconceptions about the firm could influence the scoring process (see also Bloom & van Reenen, 2010).

For consistency checks of interviewer scoring, a subset of randomly selected interviews were double-scored by a second team member who listened in. In the regression analysis below, we control for possible bias on the part of the interviewers by including interviewer fixed effects. In addition 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).

Random sampling Our sampling frame comprised all manufacturing firms with more than 50 but less than 5,000 employees contained in ORBIS for the countries under study.

[12] See Anderson et al. (2011) for a comprehensive list of questions asked.

[13] Given our focus on medium-sized firms, the graduate students conducting the interviews were unlikely to have prior knowledge about the firm they were interviewing.

Out of a total of 44,605 such firms, possible interview partners were drawn at random and contacted via phone until an interview was given or explicitly denied. We oversampled EU ETS firms by drawing firms at random from the EU ETS registry so that between 50% and 70% of managers contacted in each country worked at an EU ETS firm. In total, we contacted 1,451 firms in the six countries and interviewed 761 of them (134 firms in Belgium, 141 in France, 139 in Germany, 69 in Hungary, 78 in Poland, and 209 in the UK). Of all firms we interviewed, 446 (57%) were in the EU ETS. In spite of a relatively high response rate of 53%, sample selection bias might arise if interviewed firms differ in systematic ways from firms that declined to be interviewed. We compare the principal firm characteristics available in the ORBIS database – turnover, employment and capital – between firms interviewed and not interviewed, conditional on a firm's participation in the EU ETS. These comparisons are reported in Section A.1.2 of the appendix and show no statistically significant evidence of sample selection on observable characteristics.

Internal validity Table 1 shows that VS correlates in expected ways with other interview responses that also capture vulnerability to carbon pricing in some way but may be deemed less subjective. A low VS is strongly associated with a high cost pass-through as well as with a low share of non-EU competitors. Both circumstances enable firms to pass the cost of carbon pricing on to their customers and thus help to protect them against the detrimental effects of carbon pricing. Moreover, we find a strong positive association between VS and a number of management practices relevant for climate change, such as the setting, monitoring and enforcement of targets for energy consumption or GHG emissions, as well as process innovation in areas related to climate change. This is plausible as the firms most adversely affected by carbon pricing have stronger incentives to monitor and reduce their carbon intensity and permit liability. When the sample is restricted to include only EU ETS firms, similar qualitative findings emerge although the statistical significance on some of the management variables is lower. In sum, these results

Table 1: Correlations between vulnerability score and other interview variables

	(1) All firms	(2) EU ETS firms
Cost pass through (%)	-0.107***	-0.109*
Share of non-EU competitors (%)	0.141***	0.135**
Non-EU competitors	0.02	-0.06
Total competitors	0.02	-0.14
Share of sales exported to non EU (%)	-0.08	-0.03
Customers are other businesses (D)	0.105***	0.166***
Multinational firm (D)	0.01	-0.06
CC related products (S)	0.01	0.01
CC related product innovation (S)	-0.02	-0.04
CC related process innovation (S)	0.132***	0.108*
Energy monitoring (S)	0.169***	0.179***
Greenhouse gas monitoring (S)	0.168***	0.1
Energy consumption targets (S)	0.074*	0
Greenhouse gas targets (S)	0.207***	0.160***
Enforcement of targets (S)	0.120***	0.1
Employment	0.02	-0.06
EU ETS firm (D)	0.623***	

Notes: Coefficients of correlation between the vulnerability score and other interview variables. Variables refer to numbers unless indicated otherwise; D denotes a dummy variable and S another interview score constructed in a way similar to the vulnerability score. CC stands for “climate change”. Results in column 1 are based on the full sample wheras those in column 2 are calculated using only firms in the EU ETS. Asterisks indicate statistical significance at the 10% (*), 5%(**) and 1%(***) level.

establish the internal validity of VS as a measure of the firm's vulnerability to carbon pricing.

External validity If VS is a valid measure of a firm's propensity to outsource jobs in response to higher carbon prices, one would expect that they respond to higher energy prices in a similar fashion. To test this hypothesis, we estimate the elasticity of employment with respect to energy prices using more than 500,000 firm-year observations from ORBIS. We recover a separate elasticity estimate for firms in vulnerable sectors, defined as those for which the average employment-weighted VS is above the median, and test whether it is negative in a statistically significant way.

The regression equation is estimated in first-differences and includes a full set of country-year effects. This controls for unobserved heterogeneity across firms and transitory shocks at the macro level, respectively. Table 2 reports the elasticity estimates based on data on manufacturing firms for the years 1999 through 2007, separately for a sample of 24 OECD countries and a sample of 18 EU countries.[14] In addition to OLS estimates, the table reports IV estimates where we instrument for the energy price variable and its interaction with the "High VS" dummy using the corresponding variables in levels, lagged either once or twice. This corrects for bias that arises if energy prices are predetermined or endogenous, respectively.[15]

The OLS estimates imply that firms in sectors with low VS increase employment by 3.5% in response to a doubling of energy prices. In contrast, firms in sectors with high VS would reduce employment by 2.2% in the EU sample and by 1.8% in the full sample if energy prices doubled. These effects are small but statistically significant at the 1% level.

[14] The EU sample includes Austria, Belgium, Czech Republic, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Spain, Sweden and the United Kingdom. In addition to those countries, the OECD sample includes Canada, Mexico, Japan, Norway, Switzerland, Turkey, and the United States of America, but not Romania.

[15] For example, energy prices are pre-determined if firms adjust their employment because they anticipate a future change in the energy price. Energy prices are endogenous if shocks to employment impact on contemporaneous energy prices as well. See Section A.2 in the appendix for a description of the data and methods used.

Table 2: Estimating the energy-price elasticity of employment in vulnerable sectors

	(1)	(2)	(3)	(4)	(5)	(6)
	Δln(Employment)					
	European Union			OECD		
Δln(Energy price)*(High VS)	-0.057***	-0.242***	-2.426***	-0.052***	-0.237***	-1.763***
	(0.009)	(0.041)	(0.320)	(0.008)	(0.033)	(0.242)
Δln(Energy price)	0.035***	0.065***	1.354***	0.034***	0.039***	0.694***
	(0.006)	(0.013)	(0.265)	(0.005)	(0.013)	(0.200)
High VS	-0.007	-0.180**	-1.066***	0.070	0.030	-0.172***
	(0.024)	(0.080)	(0.157)	(0.071)	(0.051)	(0.061)
Number of firms	93,831	93,831	93,831	129,867	129,867	129,867
Number of observations	407,905	407,905	407,905	516,128	516,128	516,128
R-squared (OLS and 1st stage)	0.039	0.727	0.718	0.034	0.695	0.682
Method	OLS	IV (1 lag)	IV (2 lags)	OLS	IV (1 lag)	IV (2 lags)

Notes: The dummy variable "High VS" equals one for firms in sectors for which the employment-weighted vulnerability score (VS) exceeds the sector median. Regressions also include a full set of country-year effects as well as interactions thereof with "High VS (not reported). For a predefined set of countries, the dataset contains all ORBIS firms with more than 10 employees. The OECD sample comprises 24 OECD countries listed in appendix A.2. In columns 1 to 3, non-EU countries are excluded from the sample and Romania is included. IV regressions instrument for Δlog(energy price) and Δlog(energy price)·(High VS) using their respective levels, lagged once (cols. 2, 5) or twice (cols. 3, 6). Reported R-squared refers to OLS regressions and first-stage regressions. Robust standard errors, clustered at the firm level, are in parentheses. Asterisks indicate statistical significance at the 10%(*), 5%(**) and 1%(***) level.

While the IV estimations give rise to much larger point estimates, both instrumenting strategies confirm that increases in energy prices are more detrimental to employment in sectors with a high average VS score. In sum, these results provide robust evidence that the VS measure derived from the interviews adequately captures the risk of outsourcing associated with energy price increases and hence higher carbon prices.

3.2 Economic performance

Balance-sheet data on firm performance and other characteristics are obtained from ORBIS. Table 3 summarizes selected variables for the sample of 761 firms we interviewed. The sample is well stratified with respect to age, size, profitability, and ownership. Table A.3 in the appendix compares the sample means of each characteristic between firms in the EU ETS with those that are not and reports the results from a test of equality group means. This reveals that EU ETS firms are older, larger and more profitable than their counterparts outside the EU ETS, and that these differences are statistically significant.

Table 3: Firm characteristics

	Mean	Standard deviation	Percentiles 10th	50th	90th	Obs.
Firm						
Age (years)	37	37	7	22	87	736
Turnover (EUR million)	477.69	2,790.11	9.79	77.20	728.37	696
Number of employees	1,004	3,891	84	298	1,890	699
EBIT (EUR million)	17.18	78.25	-1.85	2.31	41.65	683
Number of shareholders	2	5	1	1	3	761
Number of subsidiaries	4	24	0	1	8	761
Firm's Global Ultimate Owner						
Turnover (USD million)	23,800	54,100	176	5,948	57,500	241
Number of employees	46,804	72,634	492	15,211	107,299	226

Notes: EBIT: Earnings Before Interests and Taxes. Interview data sample of 761 firms. Figures correspond to the year 2007. Source: ORBIS (Bureau Van Dijk).

3.3 Carbon emissions

Data on carbon emissions and permit allocations for all EU ETS firms in the sample are calculated as the average, respectively, of verified emissions and allocated permits between 2005 and 2008 obtained from CITL. We aggregate these installation-level variables up to the firm level before matching them to ORBIS.

EU ETS firms interviewed by us are sampled either from ORBIS or from the CITL. They are subsequently matched to the CITL or ORBIS, by hand (in the case of Germany, Hungary and the UK) or using lookup tables available in the public domain (in the case of France, Belgium and Poland). This also allows us to assign firms in the CITL to 4-digit NACE industrial sectors. To match firms and countries that are not included in our interviews or in official lookup tables, we draw on a mapping from CITL to ORBIS by Calel & Dechezleprêtre (2012).[16] This allows us to match 75% of CITL installations and emissions to ORBIS firms. NACE rev 1.1 classification and employment data is available for 4,254 firms, 71% of which are manufacturing firms. Table A.7 of the appendix summarizes the correspondence between sectoral classifications.

[16] We thank Rafael Calel and Antoine Dechezleprêtre for graciously providing us with NACE code identifiers and employment data based on their mapping. The match comprises 5,037 firms (9,061 installations) with a total of 1,743 million tons of CO_2.

3.4 The EU Commission's definitions and data

The EC aims to exempt the most vulnerable firms from permit auctioning, but takes a 'top-down' approach to evaluating their vulnerability. Exemptions will be granted at the sector level, based on carbon (CI) and trade (TI) intensities computed by the EC in its Impact Assessment (IA) Report (EU Commission, 2009).[17] CI is measured as the sum of the direct and indirect costs of permit auctioning, divided by the gross value added of a sector.[18] The logic behind CI is that it proxies for the cost burden imposed by full auctioning. The direct costs are calculated as the value of direct CO_2 emissions (using a proxy price of 30€/tCO_2). The indirect costs capture the exposure to electricity price rises that are inevitable on account of full permit auctioning in the power sector.[19]

The TI criterion is defined 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). Both CI and TI figures are available at the NACE 4-digit level from the EU Commission (2009).[20] Using the methodology and the same databases from EUROSTAT as in the IA, we also compute sectoral import and export intensity figures, as well as calculate trade intensities with different regions of the world.

The EC uses a combination of thresholds for CI and TI to determine if a sector is at risk of carbon leakage and hence eligible for free permit allocation. Sectors are considered at significant risk of carbon leakage if their CI is greater than 5% and their TI is greater than 10%, or either CI or TI is greater than 30%. For the purposes of the subsequent analysis, we subdivide eligible sectors accordingly into three disjoint categories:

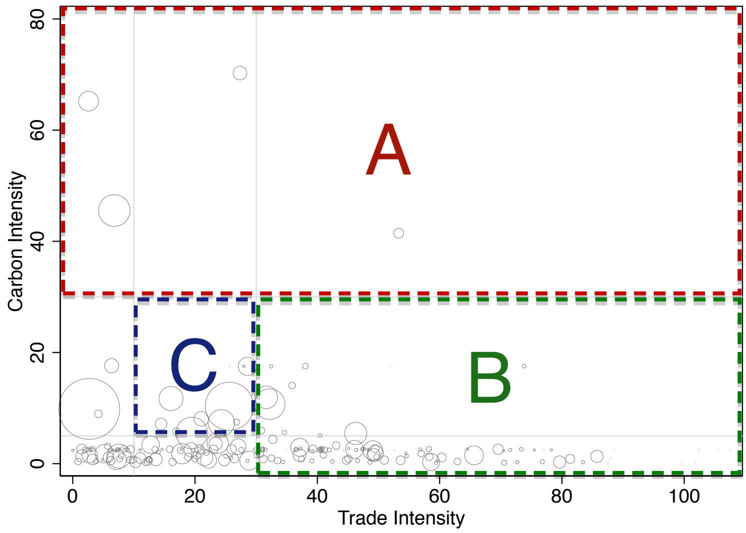
[17] See Juergens, Barreiro-Hurlé, and Vasa (2012) for a detailed explanation of the these calculations. Clò (2010) provides a critical appraisal.

[18] Others, such as Sato et al. (2007) have referred to this ratio as "Value at Stake" (VaS).

[19] They are calculated as electricity consumption (in MWh) multiplied by the average emission intensity of electricity generation in the EU27 countries (0.465 tCO_2/MWh), and applying the same proxy price for an European Union Allowance of 30€/tCO_2.

[20] NACE stands for "Nomenclature statistique des activités économiques dans la Communauté européene" (Statistical Classification of Economic Activities in the European Community).

Figure 2: 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 the full ORBIS-CITL match. The size of the circles is proportional to the number of firms in a given industry. Sectors in areas A, B, and C will continue to be exempt from permit auctions in EU ETS phase III.

A very high carbon intensity: CI>30%

B high trade intensity and low to moderately high carbon intensity: CI≤30% ∩ TI>30%

C moderately high carbon and trade intensity: 5%<CI≤30% ∩ 10%<TI≤30%

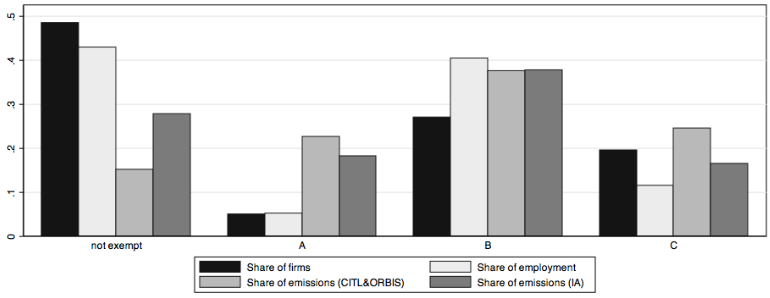
Figure 2 plots the location of 3-digit sectors in a diagram with CI on the vertical and TI on the horizontal axis.[21] This shows that a large number of sectors are in category B, meaning that they are exempt because their TI is higher than 30%. Figure 3 displays the relative size of the exemption category in terms of their share in the number of firms, employment and CO_2 emissions. By all these measures, category B turns out to be the largest group of exempted firms.[22]

The share of CO_2 emissions that is not exempt from auctioning varies, depending on the CO_2 emissions measure used. Based on CITL data we arrive at a figure of 15%

[21]The visualization of the exemption criteria by Clò (2010) is similar but does not show the size of sectors for lack of a match to firm-level data.

[22]Figure A.3 in the appendix shows the size of these groups in (a) the six countries where we interviewed firms and (b) in the interview sample as such. This leads to very similar distributions as for the ORBIS-CITL matched sample, confirming that our interview sample is representative of the underlying population.

Figure 3: The relative size of exemption groups



Notes: The chart displays the relative size of each category of sectors in the EU ETS defined by the exemption criteria. The first bar indicates the category's share of firms, the second bar its share in employment, and the third and fourth bars its share in CO_2 emissions, based on figures from the CITL-ORBIS match and from the EU Impact Assessment (IA), respectively.

whereas the IA data suggest a share of about 27%, as shown in Figure 3. It is likely that the true value lies somewhere in between these figures, due to the way they are computed. In fact, Juergens, Barreiro-Hurlé, and Vasa (2012) arrive at an intermediate value of 23% after backing out direct emissions from the sectoral CI calculations by the EC. They argue that this number is based not only on CITL and IA data but also on confidential data on CO_2 emissions which the member states made available to the EC. In contrast, the IA figures count CITL emissions for regulated sectors, but also emissions from sectors and firms that are currently not regulated by the EU ETS. Since the EU ETS was designed primarily to cover energy intensive sectors and installations, non-regulated sectors and firms tend to have lower CI values and hence fall into the non-exempt category.[23] Therefore, emissions by sectors covered in the IA data and not in the CITL data are likely to increase the estimated share of emissions that are not exempt from auctioning.

[23]The EU ETS was designed to cover CO_2 emissions from large emitters in the heat and power generation industry (i.e. installations with a rated thermal input of more than 20MW) and in selected energy intensive industrial sectors.

Table 4: Vulnerability score and exemption criteria

	(1)	(2)	(3)	(4)	(5)
	Vulnerability Score (VS)				
Sectoral Trade Intensity (TI)	-0.012		0.050	0.051	0.097
	(0.092)		(0.112)	(0.096)	(0.117)
Carbon Intensity (CI)		0.229***	0.454**	0.292***	0.473***
		(0.063)	(0.215)	(0.090)	(0.114)
TI X TI			-0.037		
			(0.037)		
CI X CI			0.007		
			(0.074)		
TI X CI			0.059	0.086	0.063
			(0.106)	(0.091)	(0.134)
Weights	no	no	no	no	employment
Observations	392	392	392	392	392

Notes: OLS regressions in columns 1 to 4 and Weighted Least Squares (WLS) regression in column 5. The dataset is a cross-section of 392 interviewed firms that are part of the EU ETS and for which CITL, 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. 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.

4 Empirical analysis of EU criteria and alternatives

4.1 Assessing the EU criteria

We wish to evaluate whether or not the EU criteria (TI and CI) are indeed good proxies to capture the risk of carbon leakage or job losses. The vulnerability score derived from the interview responses lends itself to this exercise as it provides a direct measure of what the EC can only approximate by using TI and CI . Thus, if the EU criteria of the EC are accurate one would expect them to be positively correlated with VS. We implement this test in the regression

$$VS_{i,s} = \beta_0 + \beta_T TI_s + \beta_C CI_s + \mathbf{x}'_{\mathbf{i,s}}\beta_{\mathbf{x}} + \varepsilon_{i,s} \quad (1)$$

where $VS_{i,s}$ is the vulnerability score of firm i in sector s, TI_s and CI_s are the EC's trade and carbon criteria at the sector level, and $\mathbf{x}_{i,s}$ is a vector of country dummies and interview noise controls.

Table 5: Vulnerability score and exemption categories

	(1)	(2)	(3)	(4)	(5)
	Vulnerability Score			Vulnerability Score>2	
CI>30 (A)	1.032***	1.015***	1.996***	0.714***	1.704***
	(0.303)	(0.312)	(0.523)	(0.242)	(0.448)
TI>30 ∩ CI<30 (B)	0.225				
	(0.258)				
10<TI<30 ∩ 5<CI<30 (C)	0.122	0.139	0.358	0.105	0.271
	(0.248)	(0.240)	(0.241)	(0.233)	(0.292)
B ∩ CI>5		0.596*	1.031***	0.500**	1.267***
		(0.316)	(0.322)	(0.252)	(0.417)
B ∩ CI<5		-0.053	0.056	-0.059	0.121
		(0.243)	(0.329)	(0.233)	(0.389)
Constant	1.623***	1.572***	1.426		
	(0.516)	(0.523)	(0.912)		
Weights	no	no	employment	no	employment
Observations	392	392	392	392	392

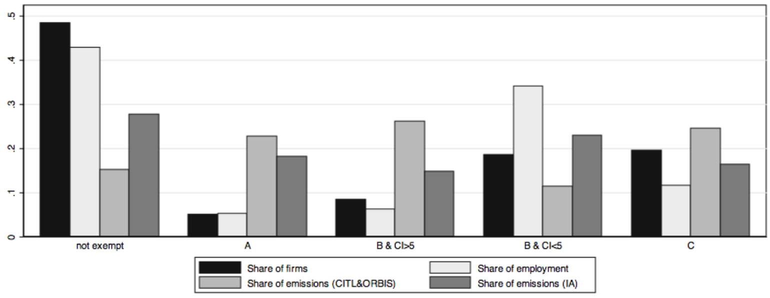
Notes: OLS regressions in columns 1 and 2, WLS in column 3 and Probit regressions in columns 4 and 5. The dataset is a cross-section of 392 interviewed firms that are part of the EU ETS and for which CITL, sectoral trade and carbon intensity data are available. The dependent variable is the vulnerability 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 (B ∩ CI>5) and (B ∩ CI<5). 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.

Table 4 summarizes the results of this regression. In the univariate specifications, we find a strong positive association of vulnerability with CI but no statistically significant association with TI. 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. 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.[24] 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.

It could be argued that the continuous relationship between VS, CI and TI imposed

[24]Employment values used here and in the remainder of the paper are obtained from ORBIS and averaged over the years 2005 through 2008.

Figure 4: Subdividing the high trade intensity category



Notes: The chart displays the relative size of each category of EU ETS sectors defined by the exemption criteria and subdivides category B into low and moderately carbon intensive. The sample includes the 4,254 manufacturing firms participating in the EU ETS and matched to ORBIS. The first bar indicates the category's share of firms, the second bar its share in employment, and the third and fourth bars its share in CO_2 emissions, based on surrendered permits data from the CITL and sectoral emissions from the EU Impact Assessment (IA), respectively.

in equation 1 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 (A,B,C) defined above instead of the continuous variables *TI* and *CI*. The reference category in the new regression is thus given by firms that are not exempt from auctioning. The results are reported in the first column of Table 5. Only the very carbon intensive group (A) has an average VS significantly higher than the reference group. While the average VS in this group is below 3 (which means a reduction of at least 10% in production or employment due to outsourcing) the 95%-confidence band includes the value 3, albeit by a small margin. Thus even in group A there is no dramatically high risk of downsizing or outsourcing for the average firm.

Given that most free permits will be handed out to sectors not in group A, the efficiency of the allocation scheme could be enhanced if the threshold values for exempting sectors from auctioning were changed or if exemption criteria were modified so as to better reflect the actual risk of carbon leakage. The next section proposes two simple modifications to the EU criteria along those lines.

4.2 Two simple improvements

4.2.1 Intensity thresholds

The above results suggest that handing out free permits to prevent carbon leakage is justified only for sectors in category *A*, whereas all others should be subject to auctioning. 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 CI ($5 < CI < 30$), cf. Figure 2. In order to account for this heterogeneity, we further subdivide category *B* into a group with low CI and one with intermediate CI. Figure 4 plots the fraction of firms, employment and CO_2 emissions that fall into those categories. The least carbon intensive sectors in group *B* ($B \cap CI < 5$) account for a larger share of firms, employment and CO_2 emissions than the sectors with intermediate CI ($B \cap CI > 5$).[25]

When these separate groups are included along with groups *A* and *C* in regression equation (1), 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 dramatically high levels for the average firm (cf. columns 2 and 3 of Table 5). This result holds up when the regression is weighted by employment. In fact, the coefficient estimates on groups *A* and $B \cap CI > 5$ both become stronger, indicating that some of the larger firms in those categories are at a higher 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 5, confirm that only groups *A* and $B \cap CI > 5$ present some risk of downsizing.

[25] The ranking for emissions emerges from the IA figures. CO_2 emissions based on the CITL-ORBIS suggest the opposite. The difference is due to the fact that the ORBIS-CITL match was more challenging in the low CI group ($B \cap CI < 5$), which is comprised of many sectors and firms, with the result that emissions of unmatched firms are not included in the total figure for that group.

4.2.2 Trade intensity definition

The evidence shows that the TI criterion is of limited value in 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 might affect 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 (according to the UN classification), (ii) less developed (or developing) countries including China and India, (iii) developed-non EU countries and (iv) EU countries.

Table 6 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 compete with European manufacturing firms and tend to have less stringent environmental regulation standards. The relationship between vulnerability and TI with least developed is negative and significant. This could reflect the lack of competition presented by firms in 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 2). In addition, this reveals that 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.

Table 6: Regressions of the vulnerability score on CI and region specific TI

	(1)	(2)	(3)
	Vulnerability Score		
Sectoral Carbon Intensity (CI)	0.234***	0.547***	0.551***
	(0.060)	(0.169)	(0.166)
Sectoral Trade Intensity (TI)	0.376**	0.695***	1.454***
with LESS developed countries	(0.164)	(0.232)	(0.245)
TI with LEAST developed countries	-0.228***	-0.422***	-0.740***
	(0.076)	(0.157)	(0.174)
TI with Developed non-EU countries	0.117	-0.216	-0.593***
	(0.125)	(0.243)	(0.219)
TI with EU countries	-0.229**	-0.411***	-0.680***
	(0.114)	(0.143)	(0.190)
CI X CI		-0.069**	-0.092**
		(0.030)	(0.045)
TI less X TI less		-0.154	-0.718***
		(0.121)	(0.131)
TI least X TI least		0.047*	0.094***
		(0.027)	(0.029)
TI developed X TI developed		0.074	0.212***
		(0.088)	(0.074)
TI EU X TI EU		0.014	0.305***
		(0.091)	(0.110)
TI less X CI		0.378	0.233
		(0.290)	(0.425)
TI least X CI		0.708***	0.762***
		(0.212)	(0.187)
TI developed X CI		-0.779***	-0.685***
		(0.232)	(0.179)
TI EU X CI		0.167	0.062
		(0.173)	(0.223)
Weights	no	no	employment
Observations	389	389	389

Notes: OLS regressions in columns 1 and 2. WLS regression in column 3. The dataset is a cross section of 389 interviewed firms that are part of the EU ETS and for which CITL 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 or squared.

The coefficient on the quadratic indicates that vulnerability is concave in CI, although this effect is less significant when the regression is weighted by employment (column 3). The weighted regression shows that especially the large firms in sectors that have a high TI with less developed countries are relatively more at risk of downsizing. The coefficients on TI with other regions are negative.

In similar regressions (reported in Table A.8 of the appendix), we decomposed the EC's overall TI measure into export intensity and import intensity. This did not yield more significant results than for the overall TI measure. After differentiating trade intensities by region as above, we found that exports and imports to less developed countries are both positively associated with VS.

4.3 Foregone auction revenue

On balance, the evidence presented thus far suggests that sectors at risk of carbon leakage are either (i) very carbon intensive or (ii) very trade-intensive and moderately carbon intensive or (iii) very trade intensive vis-à-vis less developed countries such as China. This is suggestive of how the efficiency of permit allocation could be improved with minimal changes to the definitions and criteria established by the EC. If exemptions from full auctioning were granted only to groups A and $B \cap CI > 5$ but not to group C, the amount of overall emission permits that could be auctioned would increase by 36 to 39 percentage points, depending on which CO_2 measure is used (cf. Table 7).[26] Whilst having a minimal impact on leakage risk, this modification would generate additional revenue for governments. They could use these for example to fund infrastructure or R&D relevant for GHG abatement as well as to compensate lower income groups for the likely regressiveness of higher energy prices due to carbon pricing. For a back-of-the-envelope calculation of the increase in government revenue due to this change, we

[26] Table A.9 in the appendix lists all sectors we suggest the EC *not* exempt from auctioning.

consider

$$\Delta Revenue = \Delta(CO_2\ share\ not\ exempt) \cdot (CO_2)_{Manufacturing} \cdot AF \cdot P_{CO_2}.$$

That is, we first multiply the change in the share of non-exempt emissions by total manufacturing emissions in the EU ETS to get the amount of emissions not exempt from auctioning any longer. To translate this into a revenue estimate, we need to make assumptions regarding (i) the auctioning factor (AF), which specifies the share of emissions in the non-exempt sector actually auctioned and (ii) the allowance price P_{CO_2}.In keeping with the Carbon Leakage IA Report (EU Commission, 2009), we assume an auctioning factor of 0.75 and an allowance price of €30.[27] This leads to an estimate of €6 billion when using the emission shares based on the CITL-ORBIS match and €7.4 billion when using shares based on the IA figures. Since actual emissions are likely in between CITL-ORBIS and IA figures, we choose the midpoint of €6.7 billion as our preferred estimate.

The second proposal, i.e. maintaining the exemption categories but using TI with less developed countries rather than the general TI measure of the EC, would lead to savings of between €1.8 billion based on the CITL-ORBIS data and €3.8 billion when using the IA figures. The mid-point is €2.8 billion. While these revenue estimates are subject to intrinsic uncertainty about future carbon emissions and allowance prices, their order of magnitude makes it clear that the EU is prepared to hand out profit subsidies to polluting firms on an enormous scale without getting anything in return.

It is worth noting that, even after changing the TI criterion or splitting up group B, there still remains much heterogeneity in the policy impact within groups. Each of the groups defined on the basis of the CI and TI thresholds contains some firms with the

[27] Directive 2009/29/EC stipulates that free permit allocation in non-exempt sectors will fall linearly from 80% of *benchmark* emissions in 2013 to 30% in 2020. The AF of 0.75 results for 2013-2014 when these rules are combined with the estimated amount of emissions exceeding the benchmark, cf. EU Commission (2009, p. 8).

Table 7: Shares of emissions exempt from auctioning

	Impact Assessment Data Direct Emissions	CITL/ORBIS Data Verified Emissions
Current EU criteria (*A*, *B* and *C*)	72.3%	84.8%
A and *B* & *CI>5*	32.9%	48.9%
A, *B* and *C* – but TI with less developed countries only	51.7%	73.9%
Total emissions from non-power sectors [$MtCO_2$ eq]	833.98	748.19

Notes: Each row reports the share of manufacturing emissions exempt from auctioning under a different rule. A, B and C refer to the EU criteria defined in Section 3.1. The third row uses trade intensity (TI) with less developed countries in the definition of groups B and C. Column 1 uses data from the EU Impact Assessment for sectors that are also included in the ORBIS-CITL match. Column 2 uses data from the ORBIS-CITL match. A conservative estimate of total manufacturing emissions in CITL is computed as the sum of emissions from matched manufacturing firms and emissions of unmatched installations that are not in the combustion sector of CITL, as this would include primarily (but not exclusively) power plants. $MtCO_2eq$ stands for million metric tons of CO_2 equivalent.

highest VSs and others that report no impact of future policy at all (cf. Figure A.4 in the appendix). This implies that much could be gained by a more fundamental overhaul of the criteria that exempt firms from auctioning. Regardless of how well sector-level criteria for free allocation are defined, the efficiency of these allocations could be improved if vulnerable firms were targeted directly instead of targeting the entire industry. The next section will explore this idea in more detail.

5 Optimal permit allocation

5.1 The model

In a cap-and-trade scheme, the permit price is determined by the total cap and the marginal cost schedules of all regulated firms. Therefore, the way in which the total cap is allocated across firms should have no bearing on marginal production decisions. However, permit allocation directly affects firm behavior at the extensive margin through its impact on firm profits. This section develops a simple normative model of permit allocation where the government's principal concern is to avoid the relocation of production and jobs to places where carbon regulation is less stringent.

5.1.1 Model setup

We consider a firm i that is located in a regulated country and earns a profit of $\pi_i(p,q_i)$ which depends on the number of free permits q_i allocated to the firm and on the prevailing permit price p. Since free permits can be regarded as a lump-sum subsidy to the firm we assume that $\frac{\partial \pi_i(p,q_i)}{\partial q_i} > 0 \ \forall \ p > 0$. By relocating to an unregulated country f, firm i would obtain profit π_{if} and incur relocation cost κ_i. The firm relocates if

$$\pi_i(p,q_i) < \pi_{if} - \kappa_i. \tag{2}$$

We assume that the government has accurate information on the firm's profits at home but cannot observe the net cost of relocation $\varepsilon_i \equiv \kappa_i - \pi_{if}$. The government only knows that ε_i is an *iid* random variable with mean μ_ε and standard deviation σ_ε and that it follows a continuously differentiable distribution function $\Phi(\cdot)$. Given the binary relocation variable

$$y_i \equiv \mathbf{1}\{\varepsilon_i < -\pi_i(p,q_i)\} \tag{3}$$

the government's assessment of the probability that firm i relocates is thus given by

$$\Pr(y_i = 1|p,q_i) = \Phi\left[-\pi_i(p,q_i)\right]. \tag{4}$$

In line with the EC's official justification for granting compensation to polluting industries, we assume that the government seeks to minimize the risk of carbon leakage and the risk of domestic job losses. For individual firm i with free permit allocation q_i, this risk is given by

$$\begin{aligned} r_i(q_i) &= \mathbb{E}\left[y_i \cdot (\alpha l_i(p) + (1-\alpha)e_i(p))\right] \\ &= \Phi\left[-\pi_i(p,q_i)\right] \cdot \left[\alpha l_i(p) + (1-\alpha)e_i(p)\right] \end{aligned} \tag{5}$$

where $l_i(p)$ and $e_i(p)$ denote the level of employment and emissions at firm i at permit price p, respectively, and α their relative weight in the government's risk assessment. Thus, it is assumed that, when firm i relocates to a non-EU country, all of its jobs are lost and all of its emissions "leak" to non-regulated countries. In what follows, we take the total cap $\bar{Q}$ to be exogenously fixed. Therefore, the carbon price is constant and will be omitted hereafter for ease of notation.[28]

The government chooses how many permits q_i to allocate to each firm i so as to minimize aggregate risk $R = \sum_{i=1}^{n} r_i(q_i)$ subject to the sum of allocated permits not exceeding the overall cap $\bar{Q}$:

$$\min_{\{q_i \geq 0\}} \sum_{i=1}^{n} r_i(q_i) \text{ s.t. } \sum_i q_i \leq \bar{Q}. \tag{6}$$

The Lagrangian to this problem is given by

$$\mathscr{L} = -\sum_i \Phi\left[-\pi_i(p, q_i)\right]\left[\alpha l_i + (1-\alpha)e_i\right] + \lambda\left(\bar{Q} - \sum_i q_i\right) + \sum_i \mu_i q_i \tag{7}$$

where λ is the Lagrange multiplier on the permit constraint and μ_i are Kuhn-Tucker multipliers. Given the assumptions on Φ, an additional free permit always brings about a marginal reduction in the probability of relocation. Hence the shadow price of the permit, λ, is positive and the permit constraint holds with equality. The first-order condition for an interior solution is given by

$$\Phi'\left[-\pi_i(q_i)\right]\frac{\partial \pi_i(q_i)}{\partial q_i}\left[\alpha l_i + (1-\alpha)e_i\right] = \lambda \qquad \forall i. \tag{8}$$

Equation (8) requires the regulator to equalize, for each firm, the reduction in expected job losses and carbon leakage brought about by the last free permit allocated to that firm.

[28] The carbon price could vary if relocating firms could sell off their targets. However, in most countries those permits are revoked and cancelled, so that the stringency of the cap is preserved. There could be an effect on price due to the different distribution of abatement costs after exit. The direction of this effect is hard to analyze without placing additional assumptions on the model. Since our primary concern is with the elasticity of profits toward free permit allocation, we leave this as a topic for future research.

To appreciate the emphasis on the marginal relocation probability, consider two firms with identical levels of employment and abatement at price p^c but with different relocation probabilities. Optimality requires that the government allocate the bulk of free permits not to the firm with the highest relocation propensity but rather to the firm where these permits bring about the largest *reduction* in the relocation probability, weighted by a convex combination of jobs and emissions at the firm. Although this important insight follows immediately from straightforward economic reasoning, it seems to have gotten lost in the heat of the public debate on free permit allocation.

Consider now the dual of program (6) which seeks to minimize the amount of free permits allocated to the firms subject to the constraint that the risk to jobs and competitiveness does not exceed the level $\bar{R}$:

$$\min_{q_i \geq 0} \sum_{i=1}^{n} q_i \text{ s.t. } \sum_{i=1}^{n} r_i(q_i) \leq \bar{R} \tag{9}$$

It is easily seen that the first-order condition for an interior solution to this program requires that the impact on risk of the last free permit be equal across all firms receiving positive amounts of permits, as was shown above for the primal program.

5.1.2 Numerical solution

In solving for the optimal permit allocation we want to allow for firm-specific relocation probability functions $\Phi_i(\cdot)$ and for corner solutions that can arise when the marginal impact of the first permit on relocation risk at a firm falls short of its shadow value. We thus use dynamic programming to solve programs (6) and (9). The structure of the problem is akin to a dynamic 'cake eating' problem (see e.g. Adda & Cooper, 2003), with the difference that the 'cake' is not distributed over time but across firms.

Specifically, given an arbitrary yet fixed ordering of firms the recursive formulation

of program (6) has the Bellman equation

$$V_i(s_i) = \min_{0 \leq q_i \leq s_i} \Phi[-\pi_i(q_i)][\alpha l_i + (1-\alpha)e_i] + V_{i+1}(s_i - q_i) \quad (10)$$

where s_i is the amount of total permits left when reaching firm i in the sequence and $V_{i+1}(s_i - q_i)$ is the value of leaving $s_i - q_i$ permits to all remaining firms in the sequence. It is straightforward to solve eq. (10) numerically, starting with the last firm n in the sequence whose value function is given by

$$V_n(s_n) = \Phi[-\pi_n(q_n)][\alpha l_n + (1-\alpha)e_n] \quad (11)$$

For firms earlier in the sequence, we recursively use eq. (10) to choose the optimal q_i for each possible s_n.[29] This approach can be applied to a broad class of specifications for the relocation probability and objective functions. Importantly, it allows us to solve the dual problem (9) as well. Since $\Phi_i(-\pi_i(\cdot))$ is strictly monotonic in q_i we can invert eq. (5) to get $q_i = \pi_i^{-1}\left[-\Phi_i^{-1}\left(\frac{r_i}{\alpha l_i + (1-\alpha)e_i}\right)\right]$ and rewrite the dual program (9) as

$$\min_{\{r_i \geq 0\}} \sum_{i=1}^{n} \pi_i^{-1}\left[-\Phi_i^{-1}\left(\frac{r_i}{\alpha l_i + (1-\alpha)e_i}\right)\right] \text{ s. t. } \left(\sum_i r_i \leq \bar{R}\right). \quad (12)$$

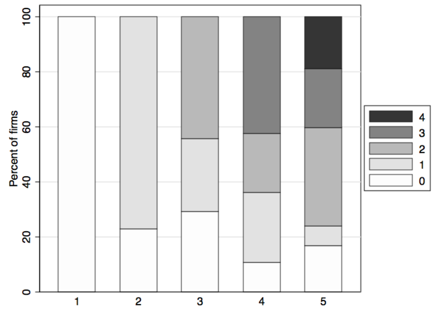
That is, rather than allocating the pieces of a fixed pie of free permits so as to reduce total risk, we now allocate the pieces of a fixed pie of relocation risk so as to minimize total permits. The analogue to Bellman equation (10) is given by

$$W_i(s_i) = \min_{0 \leq r_i \leq s_i} \pi_i^{-1}\left[-\Phi_i^{-1}\left(\frac{r_i}{\alpha l_i + (1-\alpha)e_i}\right)\right] + W_{i+1}(s_i - r_i) \quad (13)$$

and can be solved recursively in the same fashion as described above.

[29]We implement the dynamic programming algorithm in a STATA ado file using MATA language. The ado-file is available upon request.

Figure 5: Impact of free allocation on the vulnerability score



Notes: The chart shows the conditional distribution of the reduction in the vulnerability score when firms receive free permits for 80% of their direct carbon emissions. The conditioning variable is the vulnerability score in the absence of free permits.

5.1.3 Calculating the marginal propensity to relocate

We assume that the unobserved net cost of relocation follows a logistic distribution and consider a linear approximation to the profit function $\pi_i(q_i) = \delta_{0i} + \delta_{1i}q_i$. This yields the relocation probability

$$\Pr(y_i = 1|q_i) = \Phi_i\left(-\pi_i(q_i)\right) = \frac{1}{1+\exp\left(\beta_{0i} + \beta_{1i}q_i\right)} \tag{14}$$

with parameters $\beta_{0i} \equiv \frac{\delta_{i0}+\mu_\varepsilon}{\sigma_\varepsilon}$ and $\beta_{1i} \equiv \frac{\delta_{1i}}{\sigma_\varepsilon}$. We calibrate these parameters for each firm based on the interview responses. We asked the manager to assess (i) the likely future impact of carbon pricing on their businesses (cf. Section 3.1.1) and (ii) how this impact would change if the company was granted permits for 80% of its emissions at no cost. Figure 5 shows the distribution of the change in vulnerability conditional on the initial VS. For example, the fifth bar represents firms that responded that climate change policies were likely to force them to close down or relocate. One fifth of these firms reported that receiving free permits would have no impact on this decision whereas another fifth reported that this would neutralize any negative impact on domestic production.

To map vulnerability scores into relocation probabilities, we follow the scoring grid in assigning probabilities of 0.01, 0.10 and 0.99 to scores 1, 3 and 5, respectively. We interpolate between these numbers and assign probabilities of 0.05 and 0.55 to scores 2 and

4, respectively. For each firm, we evaluate the relocation probability with no free permits, $\Pr_i(y_i = 1|q_i = 0)$ as well as with 80% free permits $\Pr_i(y_i = 1|q_i = 0.8e_i)$ and use these to back out the parameters $\beta_{0i} = \ln\left[\frac{1-\Pr_i(y_i=1|q_i=0)}{\Pr_i(y_i=1|q_i=0)}\right]$ and $\beta_{1i} = \frac{1}{0.8e_i}\ln\left[\frac{1-\Pr_i(y_i=1|q_i=0.8e_i)}{\Pr_i(y_i=1|q_i=0.8e_i)} - \beta_{0i}\right]$ in equation (14).

The marginal impact on firm exit of an additional unit of free permits for firm i is given by

$$\frac{d\Phi_i\left[-\pi_i(q_i)\right]}{dq_i} = \beta_{1i}\frac{-\exp\left(\beta_{0i}+\beta_{1i}q_i\right)}{\left[1+\exp\left(\beta_{0i}+\beta_{1i}q_i\right)\right]^2} \tag{15}$$

which is strictly negative for $\beta_{1i} > 0$.[30] Since the marginal impact of free permits on the relocation probability is declining in absolute value, the government should allocate free permits first to firms with the highest absolute impact of the first free permit, $\frac{\beta_{1i}\exp(\beta_{0i})}{[1+\exp(\beta_{0i})]^2}$.

5.2 Simulation of counterfactual allocations

We compute optimal allocations under different assumptions about the government's objective function and its ability to allocate free permits at the firm or sector level. Counterfactual permit allocations provide a benchmark against which to compare de facto permit allocations. This allows us to precisely identify the efficiency losses associated with the non-optimality of de facto allocations, either in terms of excessive relocation risk for a given amount of free permits, or in terms of excessive amounts of free permits given away to achieve a fixed reduction in relocation risk. Furthermore, we will identify which countries stand to gain from these deviations from optimality.

We calculate optimal permit allocations for different scenarios that result from exhausting the set of possible combinations of the following four characteristics:

1. Program: minimize risk subject to reference cost (eq.(6)) vs. minimize cost subject to reference risk (eq. (9))

[30] This is the case if allocating more permits for free strictly reduces the relocation probability, i.e. $\Phi_i(0) > \Phi_i(0.8e_i)$.

2. Risk weights: $\alpha = 1$ (job loss only) vs. $\alpha = 0$ (emission leakage only)

3. Reference allocation defining the constraint: grandfathering vs. EC proposal

4. Level of allocation: firm level vs. sector level

5.2.1 Minimizing relocation risk

Table 8 reports the minimal relocation risk under the constraint that the total number of free permits does not exceed the amount handed out under grandfathering or under the EC proposal, and compares this with the actual risk under these allocations.[31] The first row shows that job risk under free allocation can be reduced from 4.8% to 3.5% of ETS employment when permits are allocated optimally across firms. This is regardless of the risk criterion used, i.e. there is no trade-off between protecting jobs and preventing carbon leakage. The EC proposal, however, assigns exemptions from permit auctions in such a way that the job risk more than doubles to 10.6% of ETS employment. Optimal redistribution of permits brings the risk back down to the previous level of 3.5%. The new permit constraint is not binding because many firms that would not change their propensity to relocate if given free permits are allocated zero permits.

The third row of Table 8 reports the risk of carbon leakage as a share of total emissions covered by the ETS for the same six allocations. The results are qualitatively similar to the ones reported for job risk. Efficient allocation results in a leakage risk of 12.7% for both permit constraints considered, regardless of whether minimization is with respect to job risk or emission leakage. Differences arise in the baseline risk, which at 15.1% is higher than the job risk, and in the much smaller increase in leakage risk of only 2.2 percentage points when going from grandfathering to the EC proposal. This is because the EC proposal is explicit about exempting carbon intensive sectors from permit auctioning but does not target employment directly. Again there is no trade-off between these two

[31] We do not account for benchmarking but assume that in a sector that is eligible for free permits all firms receive allocations corresponding to their current emissions.

Table 8: Risk of job loss and carbon leakage (in %) under various scenarios

	Free allocation			EC proposal		
Program	Actual	Minimal risk		Actual	Minimal risk	
Risk criterion	-	Jobs	CO_2	-	Jobs	CO_2
A. Percentage share of ETS employment at risk						
Firm allocation	4.8	3.5	3.5	10.6	3.5	3.5
Sector allocation	4.8	3.9	5.0	10.6	4.0	5.3
B. Percentage share of ETS emissions at risk						
Firm allocation	15.1	12.7	12.7	17.3	12.7	12.7
Sector allocation	15.1	15.0	13.8	17.3	17.7	14.4

Notes: Share of jobs (panel A) or CO_2 emissions (panel B) at risk of relocation in total employment or emissions across ETS firms in our sample. Columns 1 and 4 report the risk associated with free allocation and the allocation implied by the EC proposal, respectively. Relocation risk is minimized either w.r.t. jobs only ($\alpha = 1$, columns 2 and 5) or to CO_2 emissions only ($\alpha = 0$, columns 3 and 6). Minimized risk is subject to the constraint that the total number of free permits not exceed the amount under free allocation (columns 2 and 3) or under the EC proposal (columns 5 and 6). The first row of each panel reports optimal allocations at the firm level and the other row at the sector level.

risk measures; the allocation that minimizes job risk also achieves minimal leakage risk, and vice versa.

In practice, it might be difficult for the regulator to implement optimal permit allocations at the firm level. Doing so could provide firms with an incentive to strategically manipulate their reported impact of free permits on the propensity to relocate. Moreover, one can think of legal and political obstacles to fully differentiating free permit allocations across firms in different sectors and countries. It is plausible that such difficulties contributed to the EC's decision of determining allocation rules at the 4-digit sector level.

We thus calculate minimal relocation risk under the additional constraint that the government cannot assign free permits at the firm level but only at the sector level.[32] We assume that firms receive permits according to their share in the sector's total emissions and aggregate the resulting relocation risk across firms within sectors. The results in the second and fourth row of Table 8 show that both job and leakage risks are higher than with firm-level allocations. A moderate trade-off between minimizing job risk vs.

[32]Unlike the EC proposal which either assigns zero free permits or grandfathers the entire sector, we assume that any non-negative amount of free permits can be allocated to a sector, subject to the constraint on the number of total permits.

carbon leakage risk arises. The constraints on the number of free permits are binding now because grandfathering individual firms with a high marginal impact of free permits is more costly under sector-level allocation as all other firms in the sector must be given free permits as well. Clearly, those permits are then not available anymore to grandfather more vulnerable firms in other sectors. The trade-off between jobs and carbon leakage is also evident from the fact that minimization with respect to one risk criterion may give a worse outcome, in terms of the other criterion, than under sub-optimal allocations.[33]

5.2.2 Cost minimization

Minimizing the amount of free permits subject to a given relocation risk can be regarded as the tax payer's cost minimization program because it minimizes the amount of foregone auction revenue for a given outcome. Table 9 displays the share of permits handed out for free under different allocation schemes. The first row shows that optimal allocation at the firm level gives rise to drastic efficiency gains. The relocation risk associated with full grandfathering could be achieved by handing out only between 17.1% and 26.1% of permits for free, depending on whether job risk or carbon leakage risk is held fixed. Two mechanisms drive this result. First, the majority of firms in our sample report that their propensity to relocate does not vary with the amount of free permits. It is optimal to assign zero free permits to those firms. Second, among the remaining firms, free permits are allocated in such a way as to equalize the marginal propensity to relocate, weighted by jobs or carbon emissions, as required by the first-order condition (8).

Under the EC proposal, a large number of sectors and particularly the carbon-intensive ones will continue to be exempt from permit auctioning. As a consequence, 92.8% of emissions will continue to be allocated for free.[34] As was pointed out above, the EC

[33]For example, minimizing job risk subject to the total number of permits under the EC proposal leads to 17.7% of emissions being at risk which is larger than the 17.3% put at risk by the EC proposal. Moreover, minimizing carbon leakage risk subject to the total number of permits under free allocation results in 5% of jobs at risk, i.e. slightly more than the 4.8% of jobs at risk when all sectors are grandfathered.

[34]This is roughly consistent with the estimate of 84.8% derived in the previous section using a larger

Table 9: Percentage share of emissions allocated for free

	Free allocation			EC proposal		
Program	Actual	Minimal cost		Actual	Minimal cost	
Risk constraint	-	Jobs	CO_2	-	Jobs	CO_2
Firm allocation	100.0	17.1	26.1	92.6	0.3	21.0
Sector allocation	100.0	28.1	27.6	92.6	15.3	26.0

Notes: Columns 1 and 4 report the share of free permits in total emissions under free allocation and under the EC proposal, respectively. Minimal cost allocations are calculated subject to the constraint that the total relocation risk not exceed the one under free allocation (columns 2 and 3) or under the EC proposal (columns 5 and 6). Relocation risk is measured in terms of job loss ($\alpha = 1$, columns 2 and 5) or CO_2 emissions leakage ($\alpha = 0$, columns 3 and 6). Free permits are allocated optimally at the level of the firm (row 1) or sector (row 2).

proposal propels the job risk to a level so high that it could be achieved by handing out a mere 0.3% of total permits for free. In contrast, carbon leakage risk increases only slightly under the EC proposal. Obtaining this level of leakage risk at minimal cost would still require 21.0% of free permits to be allocated for free.

The second row of Table 9 shows that allocating free permits at the sector level instead of the firm level is somewhat less efficient. Large changes arise in the allocations that maintain job risk fixed whereas sector level allocations under fixed carbon leakage risk are almost as cost effective as their counterparts at the firm level. This is because (i) the EC proposal explicitly targets carbon intensive sectors and (2) carbon intensive firms get a large weight in the objective function when minimizing carbon risk. Overall, the simulations show that under no allocation or weighting scheme would it be optimal to allocate more than 30% of total emissions in the ETS sector for free.

5.3 Distributional implications of the EC proposal

The question of who benefits and who loses out when some sectors are exempted from permit auctions is politically loaded, especially in times of strained budgets and increasing skepticism about European integration. Importantly, this question cannot be answered by simply looking at the raw data as this would fail to control for differences in the

sample of firms and countries.

propensity to relocate which justify non-uniform allocation of free permits across firms, sectors and countries. The model developed at the outset of this section provides us with benchmark permit allocations that take into account both a firm's extensive-margin response to permit auctions as well as its contribution to overall relocation risk. This yielded the result that at least 70% of free permits allocated under the EC proposal can be regarded as a profit subsidy to the eligible sectors. We now examine the distribution of these excess profits and identify winners and losers.

5.3.1 Which countries gain?

From a political perspective, this is a first-order question arising in the context of international emissions trading. Panel A of Table 10 reports the amount of emissions exempt from permit auctioning under the EC Proposal in each country, both in absolute terms and as a share of the country's total manufacturing emissions. These numbers allow for a 'model-free' analysis of the distributional implications by calculating the difference between each country's share of free permits and the average share across the six countries. That is, we compare the proposed scheme of exempting selected sectors from permit auctions to a counterfactual uniform reduction of free permit allocations across all sectors. Row 3 of panel A identifies Belgium, France and Poland as winners whereas all other countries lose compared to the counterfactual. The largest loss is incurred by Hungary which sees its free allocation reduced by 9.5 percentage points below the proportional reduction. When we restrict the analysis to the interview sample, we arrive at qualitatively very similar findings. The first row of panel B reports the difference in free permits as a percentage of the counterfactual allocation. The only qualitative change is that France now emerges with a moderate loss instead of a moderate gain.

In spite of its political appeal, the proportional reduction scenario is not an economically relevant counterfactual to analyze the distributional implications of the EC proposal because countries are not equally vulnerable to carbon pricing. Rows 2 and 3 of panel

Table 10: Country allocations

	Belgium	France	Germany	Hungary	Poland	UK
A. Free permits allocated under the EC proposal (full sample)						
Million permits	28.2	77.4	125.5	3.5	40.2	69.0
Share of emissions (%)	92.6	91.6	89.6	80.3	92.0	86.1
Deviation from mean (%)	2.9	1.9	-0.1	-9.5	2.3	-3.6
B. Change (%) in free permit allocation: EC proposal vs. various counterfactuals (interview sample)						
Proportional reduction	2.6	-1.3	-0.0	-6.8	2.7	-1.1
Minimal job risk	12.2	-12.4	48.1	9.2	14.1	-17.3
Minimal carbon risk	5.1	-7.4	43.7	-6.5	-2.5	-10.2

Notes: Based on the comprehensive CITL/ORBIS match, Panel A reports the total amount of emissions exempted, the share of exempted emissions in total emissions and the deviation of that share from the mean share of exempt emissions across the six countries. Panel B is based on the interview sample and reports the percentage change in a country's free permit allocation when going from a counterfactual allocation to the EC proposal. The counterfactual allocations are: a uniform quota of 92.7% of the countries carbon emissions (row 1), the sector-level allocation that minimizes relocation risk in terms of jobs (row 2) or in terms of CO_2 emissions (row 3) under the constraint that the total number of free permits is the same as under the EC proposal.

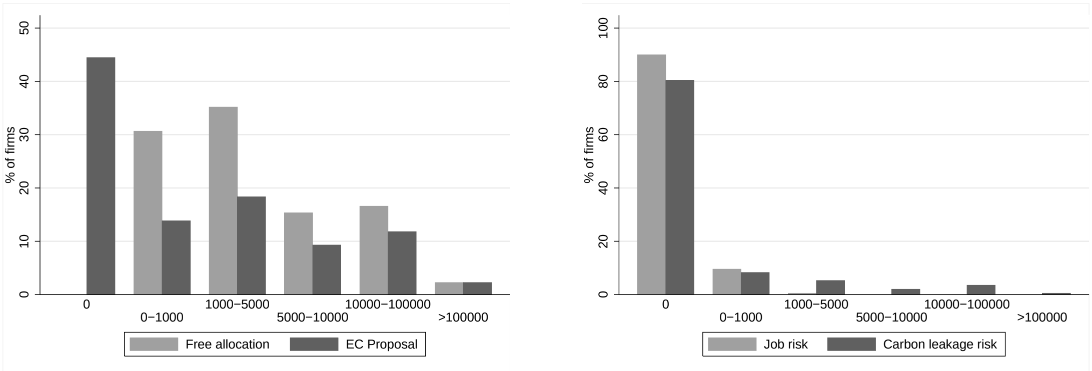
B report by how much the EC proposal differs from permit allocations that minimize the risk of job loss or carbon leakage, respectively, while holding fixed the aggregate number of free permits. Again, the difference is expressed in percent of counterfactual allocations. This confirms that Belgium benefits from the EC proposal whereas France and the UK lose out. Gains and losses in these three countries range between 5.1% and 17.3% (in absolute value) of the free permits they would have obtained in an optimal scenario. These changes are dwarfed, however, by the enormous gains reaped by Germany. The EC proposal grants Germany between 43.7% and 48.1% more free permits than under the allocation minimizing relocation risk, depending on how jobs and carbon emissions are weighted in the objective function. This striking result is completely masked in the naive comparison to the proportional cutback. The distributional effects for Poland and Hungary are ambiguous: they gain compared to an allocation with minimal job risk but lose with respect to an allocation with minimal carbon leakage risk.

5.3.2 Incidence on Labor

The simulations above establish that free permits under the EC proposal comprise a large profit subsidy that is not justified on the basis of firms' relocation risk only. There might

Figure 6: Distribution of subsidies per job

(a) Reference scenarios (b) Minimal cost scenarios



Notes: The figure displays histograms of the distribution of subsidies per job – calculated in € per employee for a permit price of €30 – in the interview sample, comprised of 398 ETS firms, under various allocations. Subfigure (a) compares the implicit distribution of subsidies per job under free permit allocation with the one resulting from the exemption rules proposed by the European Comission. Subfigure (b) juxtaposes the distributions of subsidies per job that result from optimal firm-level allocations of free permits where either the job risk or the carbon leakage risk is fixed at the level implied by the EC proposal.

be other reasons for subsidizing firms, however. For example, if employment generates positive externalities for society – by stabilizing pay-as-you-go social security systems, lowering crime and drug abuse, among other things – then the EC should subsidize labor-intensive firms. In its simplest form, this kind of subsidy would require that firms receive free permits in proportion to the number of employees, maintaining constant the subsidy per employee across firms.

Figure 6 displays histograms of the distribution of subsidies per job, expressed in € per employee, under various allocations. We follow the EC's IA report and assume a permit price of €30 for these calculations. Figure 6a compares the implicit distribution of subsidies per job under free permit allocation with the one resulting from the exemption rules proposed by the EC. It is clear that neither of the two allocation schemes distributes subsidies evenly across employees. This should not come as a surprise because both grandfathering and the EC proposal are designed to give more subsidies to carbon intensive firms. The degree of inequality is striking. Under free permit allocation, 30% of firms receive less than €1,000 per worker whereas 18% receive more than €10,000. The combination of permit auctions and exemption rules proposed by theEC further ex-

acerbates inequality. Almost half of the firms (44%) receive nothing while excessive subsidies to the top ten firms in our sample remain unchanged, ranging from €91,651 to €467,016 per worker. The distribution in the full sample is very similar to the one of the interview sample.[35]

Figure 6b juxtaposes the distributions of subsidies per job resulting from cost minimal allocations at the firm level when either the job risk or the carbon leakage risk is held fixed at the level implied by the EC proposal. While both scenarios allocate no permits to more than 80% of firms, the distribution of subsidies per job among firms receiving free permits differs quite a lot. When job risk is fixed, the distribution is fairly uniform across firms, with a maximum subsidy of €1,468 per employee. In contrast, when carbon leakage risk is fixed the distribution of subsidies per job is more unequal and inherits some of the excesses of the reference allocations, with implicit transfers to the top ten firms in the sample ranging from €20,002 to €394,697 per worker. This suggests that including employment as a criterion for free permit allocation, unlike current criteria based on carbon and trade intensities, could go a long way to mitigate the striking inequalities in the distribution of the subsidies implied by free permit allocation.

5.4 Feasible optimal permit allocation

The previous sections have uncovered several shortcomings of the EC criteria for free permit allocation. First and foremost, too many sectors with a negligible risk of carbon leakage will be exempted, particularly due to the trade intensity criterion. Consequently, a large amount of revenue from permit auctions will be foregone with no corresponding reduction in aggregate relocation risk. Moreover, the EC criteria fail to protect employment effectively and create strong inequality in the distribution of the implicit per-job

[35] In the full sample, 31% of firms receive less than €1,000 per worker whereas 23% receive more than €10,000. Under the EC rules, 46% will receive nothing while excessive subsides to the top ten firms remain unchanged, ranging from €423,000 to €2,770,551. The distribution is displayed in Figure A.5 in the appendix.

subsidies across firms. This section develops a simple allocation rule for free permits based on easily observable characteristics of firms and sectors which brings the allocations closer to the efficiency frontiers derived in the previous section.

Given a total amount of free permits $\bar{Q}$, an allocation share $\theta_i = f(x_i;\gamma)$ maps a vector $x_i = (x_i^1, \ldots, x_i^k)$ of k observable characteristics for firm i into the unit interval. Suppose that the function $f(\cdot)$ is known up to a parameter vector γ. Upon substituting $\hat{q}_i = \theta_i \bar{Q}$ into the risk minimization program (6)

$$\min_{\gamma \in \Gamma} \sum_{i=1}^{n} r_i \left(f(x_i;\gamma)\bar{Q} \right) \text{ s.t. } \sum_{i=1}^{n} f(x_i;\gamma) = 1 \wedge f(x_i;\gamma) \geq 0 \quad \forall i. \tag{16}$$

we obtain the optimal allocation rule by solving for γ. As this can be seen as a constrained version of the optimization programs considered above, we refer to this as the "feasible optimal allocation". We specify an allocation rule based on a Cobb-Douglas function,

$$f(x_i;\gamma) = \frac{\prod_k (x_i^k)^{\gamma_k}}{\sum_j \prod_k (x_j^k)^{\gamma_k}}$$

where we require that $\sum_k \gamma_k = 1$. This is the generalization of a grandfathering allocation rule based on past emissions e_i, where $f(e_i;\gamma) = \frac{e_i^{\gamma_e}}{\sum_j e_j^{\gamma_e}}$ and $\gamma_e = 1$.[36]

Table 11 reports the parameter vector $\hat{\gamma}$ for program (16) with $\bar{Q}$ equal to the amount of permits allocated for free under the EC proposal. As above, we minimize relocation risk either in terms of jobs or carbon emissions. We first consider allocation rules that use only two firm-level variables. With weighted parameters of 0.19 for employment and 0.81 for emissions, the percentage of ETS employment at risk drops from 10.6% to 3.57% (column 1). This is very close to the "theoretical" minimum of 3.5% reported in Table 8 above. For emission leakage risk in column 4 we find that using an index with a positive weight for emissions of 1.14 and a smaller, negative weight for employment

[36] We implement this using a standard maximum likelihood solver where the "likelihood" contribution of observation (firm) i becomes $r_i \left(f(x_i;\gamma)\bar{Q} \right)$.

Table 11: Feasible optimal allocation rules

Variables	Risk criterion							
	Employment Risk				CO2 Risk			
Firm-level employment	0.19	0.20	0.20		-0.14	-0.13	-0.16	
Firm-level CO2	0.81	0.80	0.80		1.14	1.18	1.19	
CI		0.02	0.02	0.29		-0.06	-0.03	0.28
TI less		-0.02	-0.02	0.59		0.01	0.10	-0.27
CI X TI less			-0.01	0.13			-0.09	0.99
Share of ETS employment at risk	3.6%	3.6%	3.6%	5.2%	7.2%	7.5%	7.5%	6.4%
Share of ETS emissions at risk	18.5%	18.4%	18.4%	28.7%	16.2%	16.1%	16.1%	25.6%

Notes: The table reports the parameters of the optimal feasible allocation rule for different vectors of observable variables. The optimality criterion is minimal risk to jobs (columns 1 to 4) or carbon emissions (columns 5 to 8). The last two rows report the percentage share of EU ETS employment and CO_2 emissions at risk for a given optimal allocation rule. Carbon intensity and trade intensity with less developed countries (TI less) are defined at the 4-digit level.

yields a risk of 16.21%. This is lower than the risk implied by the EC proposal (17.3%), yet the risk reduction does not nearly get as close to the theoretical minimum (12.7%) as in the case of employment risk.

The inclusion of sector-level CI and TI with less developed countries in the allocation rule yields only very small additional reductions in the minimized objective function for both types of risk.[37] Finally, when only sectoral trade and carbon intensities form the basis for the allocation rule, both risk types increase considerably, to 5.22% in terms of jobs and 25.64%in terms of emissions. All of this suggests that allocating free permits on the basis of employment size and CO_2 emissions alone provides a very efficient allocation rule for employment.

It is remarkable that the deviation of employment risk from the optimum when minimizing CO_2 risk is much larger than the deviation of CO_2 risk when minimizing employment risk. It would therefore seem that using an allocation rule based on minimizing the risk to jobs would be more likely to find a general consensus among different stakeholders concerned with either one type of risk, but not the other. Alternatively, policy makers might also consider a convex combination of both risk types when deriving the optimal feasible index.

[37]We use TI less because we find it to be more correlated with the VS than the overall TI used by the Commission, cf. Section 4.

6 Conclusion

The need to compensate industry for the adverse profit impact of regulation has far-reaching consequences for policy design. For example, general-equilibrium effects may change the relative cost effectiveness of different regulatory instruments when industries are fully compensated for the cost of complying (Bovenberg et al., 2005, 2008). In this paper, we propose an industry compensation principle based on the risk that the adverse profit impact triggers a response at the extensive margin: If profits fall by too much, firms have an incentive to relocate to an unregulated jurisdiction. This is undesirable for the regulator because relocating firms take with them jobs, taxable profits and – in the case of climate policy – the very emissions targeted by the regulation. The simple economic logic following from this is that compensation should be distributed across firms so as to equalize the expected marginal impact of relocation on the regulator's objective function.

We have applied this idea in the context of the EU ETS, where job losses due to relocation are aggravated by carbon leakage. Industry compensation is given in the form of free permit allocations, with the stated objective to prevent relocation and carbon leakage. Our analysis has shown that the criteria adopted by the EC to establish the risk of carbon leakage give rise to very inefficient allocations. Optimal allocations yield drastic improvements in relocation risk, and so do simple approximations to optimal allocations based on only a couple of firm characteristics. What is more, we have estimated that by even simpler modifications to the EC criteria, European governments could raise up to €6.7 billion every year in additional permit revenues, without increasing the overall downsizing risk. In view of the economic slump and the debt crises currently prevailing in most European economies, it seems that the cost – both economic and political – of raising public funds to substitute for these foregone revenues is much higher than the cost of changing the exemption rules.

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A Appendix

A.1 Background on the management interviews

A.1.1 Interview practice

Interviews were carried out by graduate and postgraduate students after they had been trained. The interviewers were paid according to the number of interviews conducted, encouraging them to do more interviews and discouraging any firm background research, thus preserving the double-blind nature of the survey. Interviewers made “cold calls” to production facilities (not head offices), gave their name and affiliation and then asked to be put through to the production or environmental manager. In the case of EU ETS firms, interviewers requested to speak to the person responsible for the EU ETS. At this stage, the terms “survey” and “research” were avoided as both are associated with commercial market research and some switchboard operators have instructions to reject such calls. Instead, we told them that we are doing “a piece of work” on climate change policies and their impact on competitiveness in the business sector and would like to have a conversation with the manager best informed.

Once the manager was on the phone, the interviewer asked whether s/he would be willing to have a conversation of about 40-45 minutes about these issues. Depending on the manager’s willingness and availability to do so, an interview was scheduled. If the manager refused, s/he was asked to provide the interviewer with another knowledgeable contact at the firm who might be willing to comment. Managers who agreed to give an interview were sent an email with a letter in PDF format to confirm the date and time of the interview and to provide background information and assure them of confidentiality. A similar letter was sent to managers who requested additional information before scheduling an interview.

All interviewers worked on computers with an internet connection and used VOIP software to conduct the interviews. They accessed a central interview database via a custom-built, secure web interface which included a scheduling tool and the interview application which displayed the questions along with the scoring grid. The interview screen contained hyperlinks to a manual with background information on each question. Interviewers scored answers during the interview. For all interviews, the scheduling history as well as the exact time and date, duration, identity of interviewer, etc. were recorded. All interviews were conducted in the language of the interviewee’s residence.

The interview format follows the design pioneered by Bloom & van Reenen (2007). This approach seeks to minimize cognitive bias by asking open-ended questions and by delegating the task of scoring the answers to the interviewer. In addition, a large sample size and interviewer rotation is exploited to control for possible bias on the part of the interviewers by including interviewer fixed effects in regression analyses. For further details, see Bloom & van Reenen (2010).

Table A.1: Interview response rates by country

	# of Interviews	# of Firms Interviewed	# of ETS Firms Interviewed	# of Non ETS Firms Interviewed	Total Firms Contacted	Refused	Response Rate
Belgium	134	131	85	46	178	47	0.74
France	141	140	92	48	238	98	0.59
Germany	139	138	95	43	337	199	0.41
Hungary	69	69	37	32	90	21	0.77
Poland	78	78	57	21	140	62	0.56
UK	209	205	63	142	468	264	0.44
Total	770	761	429	332	1451	691	0.52

Notes: There are more interviews than interviewed firms as we conducted several interviews with different partners in a small number of firms.

A.1.2 Sample characteristics

Table A.1 provides an overview of the number of interviews and the response rates broken down by country and by EU ETS participation status.[1] The last column shows the response rate i.e. the fraction of firms that were contacted and with whom we successfully conducted an interview. These vary somewhat between different countries. For example, it is particularly low in Germany (38%) and the UK (40%), whereas in Belgium or Hungarian firms were more willing to participate (74% and 78%, respectively). Generally, these figures are very high compared to response rates achieved in postal or online surveys.

It is important for the validity of our analysis to rule out possible selection bias in our sample. EU ETS firms are different from non-ETS firms, but within these two categories, interviewed firms are not significantly different from non-interviewed firms in regards to the most common characteristics available in ORBIS. This is shown in Panel A of Table A.2 where each of the principal firm characteristics available from the ORBIS database (turnover, employment and capital) is regressed on a dummy variable indicating that a firm is part of the EU ETS, a dummy indicating that a firm was contacted, and a full set of sector and year dummies, with the result that the estimated coefficients are small and statistically insignificant. For the set of firms that either conceded or refused an interview, we ran analogous regressions to estimate an intercept specific to firms that granted us an interview. The results in Panel B of Table A.2 show that none of these intercepts is statistically significant. We thus conclude that our sample is representative of the underlying population of medium-sized manufacturing firms in the six European countries covered by our study.

[1]All analysts would first conduct interviews in the UK and only then go on to conduct interviews in another country allowing a common reference, hence the larger number of interviews for this country. This allows us to control for interviewer bias as discussed below and also for UK responses to be used as a benchmark.

Table A.2: Sample representativeness

	(1) Turnover	(2) Employment	(3) Capital
A. All firms			
Firm contacted	-0.0322	-0.0794	0.172
	(0.0786)	(0.0611)	(0.108)
EU ETS firm	2.031***	1.452***	2.530***
	(0.095)	(0.080)	(0.145)
Number of observations	118,874	107,830	113,771
Number of firms	12,322	12,921	118,874
R-squared	0.511	0.364	12322
B. Contacted firms			
Firm granted interview	-0.0983	-0.0373	0.0443
	(0.118)	(0.0957)	(0.150)
EU ETS firm	2.044***	1.547***	2.540***
	(0.124)	(0.107)	(0.160)
Number of observations	26,114	23,933	25,815
Number of firms	1,373	1,420	1,297
R-squared	0.659	0.589	0.618

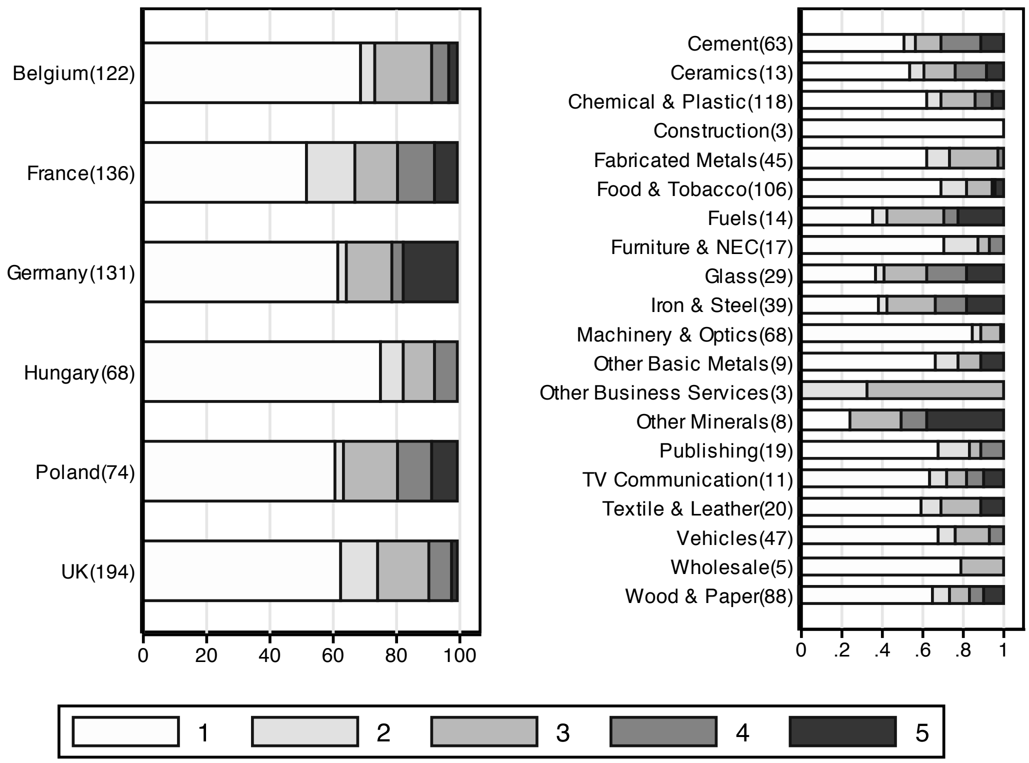
Notes: Regressions in panel A are based on the set of manufacturing firms with more than 50 employees contained in ORBIS for the six countries covered by the survey. Each column shows the results from a regression of the ORBIS variable given in the column head on a dummy variable indicating whether a firm was contacted or not and a dummy variable indicating whether a firm was taking part in the EU ETS at the time of the interviewing. Panel B shows analogous regressions for the set of contacted companies and with an indicator for whether an interview was granted. All regressions are by OLS and include country dummies, year dummies and 3-digit sector dummies. Standard errors are clustered at the firm level and are robust to heteroskedasticity and autocorrelation of unknown form.* significant at 10%; ** significant at 5%; *** significant at 1%.

Table A.3: Firm characteristics by ETS participation status

	ETS Firms			non ETS Firms		
	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Firm						
Age (years) *	40	37	409	33	37	327
Turnover (EUR million) **	725.73	3,611.50	398	146.42	767.93	298
Number of employees **	1,418	5,092	394	469	857	305
EBIT (EUR million) **	26.12	100.54	391	5.22	23.47	292
Number of shareholders	2	5	429	3	5	332
Number of subsidiaries	6	32	429	2	5	332
Firm's Global Ultimate Owner						
Turnover (USD million)	31,695	67,080	142	12,464	21,980	99
Number of employees	50,012	71,864	131	42,381	73,834	95

Notes: Based on 2007 data. Stars next to a variable name indicate that the respective means for ETS and non ETS firms are significantly different at the 10 (*), 5 (**), and 1(***) percent level.

Figure A.1: Distribution of vulnerability score by country and industry



Notes: Bar charts show the distribution of the vulnerability score by country (left) and by 3-digit NACE sector (right). The score ranges from 1 (no impact) to 5 (complete relocation). A score of 3 is given if at least 10% of production or employment would be outsourced in response to future carbon pricing. The number of observations in each country and industry is given in parenthesis. NEC: Not elsewhere classified.

Table A.4: 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.

Table A.5: Differences in vulnerability score by sector and country

	(1)	(2)
	Deviations from the overall mean	
A. Countries		
Belgium	-0.034	0.054
France	0.361 **	0.322 *
Germany	0.032	0.021
Hungary	-0.402 *	-0.378
Poland	0.311	0.013
United Kingdom	-0.269	-0.032
3-digit Sector controls	no	yes
B. Sectors		
Ceramics	-0.011	-0.010
Cement	0.379 **	0.382 **
Chemical & Plastic	-0.168	-0.171
Fabricated Metals	-0.268 *	-0.272 *
Food & Tobacco	-0.474 ***	-0.474 ***
Fuels	0.563	0.566
Furniture & NEC	-0.584 ***	-0.583 ***
Glass	0.752 ***	0.752 ***
Iron & Steel	0.703 ***	0.697 ***
Machinery & Optics	-0.731 ***	-0.733 ***
Other Basic Metals	-0.284 **	-0.287
Other Minerals	1.278 **	1.285 **
Publishing	-0.415 *	-0.413 *
Textile & Leather	-0.130	-0.125
TV & Communication	-0.028	-0.025
Vehicles	-0.434 ***	-0.447 ***
Wood & Paper	-0.149	-0.147
Employment control	no	yes
Observations	725	725

Notes: Reported coefficients represent the deviation of a country/sector's intercept from the overall mean vulnerability score. Panel A is based on a regression of the vulnerability score on country dummies with additional controls for interview noise and 3-digit sector (column 2). Panel B is based on a regression of the vulnerability score on broadly defined sector dummies with additional controls for interview noise and employment (column 2). The asterisks indicate statistical significance of a t-test of equality of the country/sector's intercept and the overall mean (* p<0.1, ** p<0.5, *** p<0.01). NEC: Not elsewhere classified.

Table A.6: Descriptive statistics (employment, energy prices)

	Mean	Standard deviation	Min	P25	Median	P75	Max	Firms
A. Europe								
employment	132	668	1	22	42	99	187,586	407,905
energy price	760	428	122	451	604	941	2,726	407,905
log(employment)	3.94	1.14	0.00	3.09	3.74	4.60	12.14	407,905
log(energy price)	6.50	0.50	4.81	6.11	6.40	6.85	7.91	407,905
Δlog(employment)	0.00	0.23	-1.99	-0.05	0.00	0.07	1.99	407,905
Δlog(energy price)	0.08	0.14	-1.12	0.02	0.09	0.15	1.29	407,905
B. OECD								
employment	134	678	1	23	44	103	187,586	516,128
energy price	789	404	122	480	683	1,014	2,726	516,128
log(employment)	3.98	1.13	0.00	3.14	3.78	4.64	12.14	516,128
log(energy price)	6.55	0.48	4.81	6.17	6.53	6.92	7.91	516,128
Δlog(employment)	0.00	0.22	-1.99	-0.04	0.00	0.06	1.99	516,128
Δlog(energy price)	0.06	0.14	-1.33	0.00	0.07	0.13	1.29	516,128

A.2 Background on energy price regressions

A.2.1 Data

We combine ORBIS data for EU and OECD countries with historical energy prices and the VS. Table A.6 summarizes the data.

Employment Our sample covers all firms with at least 10 employees contained in the ORBIS database which provides information on employment and industry at the 3-digit NACE code. The EU sample includes Austria, Belgium, Czech Republic, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Spain, Sweden and the United Kingdom. In addition to those countries, the OECD sample includes Canada, Mexico, Japan, Norway, Switzerland, Turkey, and the United States of America, but not Romania.

Energy prices The "Energy Prices and Taxes Database of Energy End-Use Prices" (Vol. 2009 release 03) maintained by the International Energy Agency provides price data for electricity, gas, liquid and solid fuels for the years 1998-2007. To ensure comparability of prices across fuels we adjust for net calorific value using prices in US$ per ton of oil equivalent (TOE). We compute the sectoral energy price

$$P^e_{sct} = \sum_f \omega^f_s p^f_{ct} \tag{A.1}$$

where p^f_{ct} is the price of fuel $f \in$ {electricity, gas, liquid fuel, solid fuel} in country c and year t, and where ω^f_s is the expenditure share of fuel f in sector c. Since expenditure shares are not available for all countries in the sample, we impute them using UK data at the 3-digit NACE code taken from the Quarterly Fuels Inquiry maintained by the UK

Office for National Statistics. Moreover, we hold these shares fixed at their 2004 values in order to avoid the issue of endogenously changing fuel expenditures.

Vulnerable sectors We define a dummy variable HI_s at the sector level which equals 1 if, in our interview sample, the employment-weighted average VS is above the median VS calculated across all sectors.

A.2.2 Estimation

We estimate the equation

$$\triangle l_{isct} = \beta_0 + \beta_1 HI_s + \beta_2 \triangle p^e_{sct} + \beta_3 \triangle p^e_{sct} \cdot HI_s + \lambda_{ct} + HI_s \cdot \lambda_{ct} + \Delta\varepsilon_{it} \quad \text{(A.2)}$$

where $l = \log(employment)$ and $p^e_{sct} = \log(P^e_{sct})$, ε_{it} is the unobserved error term and λ_{ct} denotes a full set of country-by-year effects.

If energy prices are predetermined, i.e. $\mathbb{E}[p^e_\tau \varepsilon_{it}] \neq 0$ for $\tau > t$, for example if unobserved shocks to employment are a function of predicted future energy price, then the lagged level of the energy price p^e_{sct-1} is a valid instrument for $\triangle p^e_{sct}$. With endogenous energy prices $\mathbb{E}[p^e_\tau \varepsilon_{it}] \neq 0$ for $\tau \geq t$ the twice lagged level of the energy price is available as an instrument. We construct instruments for the interaction term $\triangle p^e_{sct} \cdot HI_s$ in an analogous fashion.

A.3 Additional Tables and Figures

Table A.7: Sector classification

Sector	NACE Sectors	CITL 2008 sectors
Food & Tobacco	15, 16	
Textile & Leather	17, 18, 19	
Wood & Paper	20,21	9
Publishing	22	
Fuels	23	2,3
Chemical & Plastic	24, 25	
Glass	261	7
Ceramics	262	8
Cement	264, 265,266	6
Other Minerals	267, 268	
Iron & Steel	271, 272, 273, 275	5
Other Basic Metals	274	
Fabricated Metals	28	
Machinery & Optics	29, 30, 31,33	
TV & Communication	32	
Vehicles	34,35	
Furniture & NEC	36	

Notes: NACE sectors codes are based on NACE 1.1. NEC: Not elsewhere classified.

Figure A.2: The shape of the exit probability function

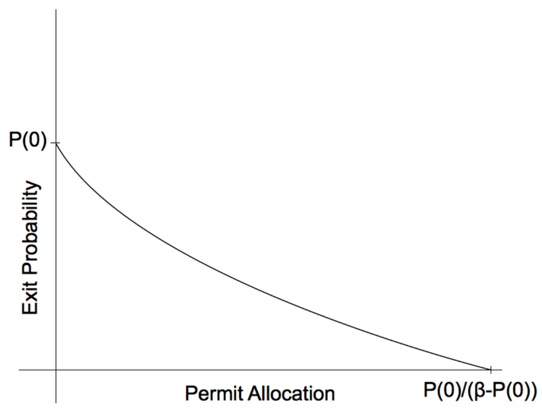
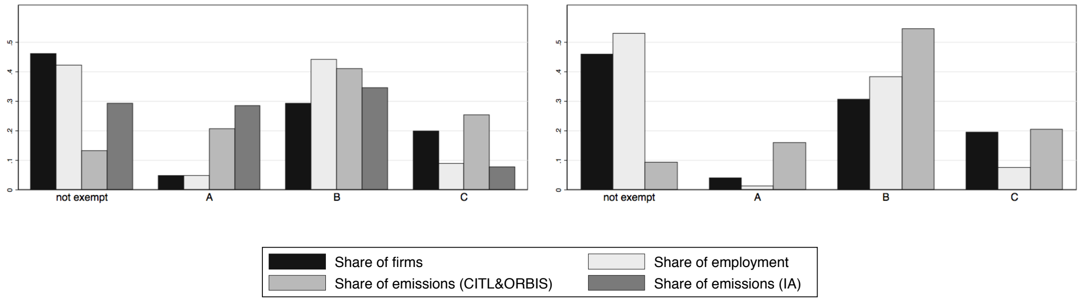


Figure A.3: Relative size of exemption groups in the six countries

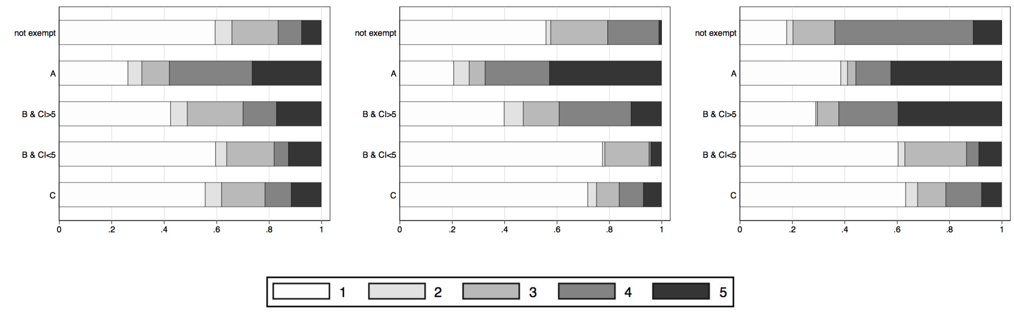
(a) Based on all matched EU ETS firms (b) Based on EU ETS firms interviewed



Notes: We cannot report CO_2 emissions based on EU IA data as these are only available at the sector level and not for individual firms.

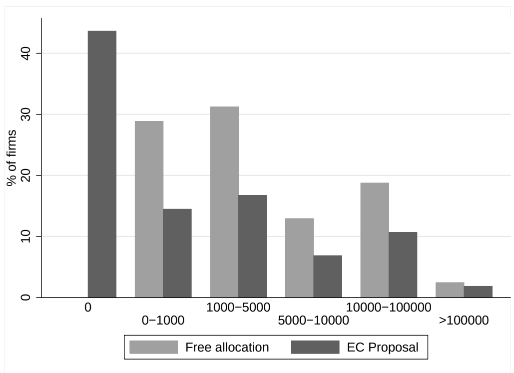
Figure A.4: Distribution of the vulnerability score

(a) Shares in number of firms (b) Shares in employment (c) Shares in CO_2 emissions



Notes: The graphs show the distribution of the vulnerability score for interviewed firms included in the EU ETS and part of each group of sectors defined in Sections 3.4 and 4. Panel a reports the shares of firms, panel b employment shares, and panel c CO_2 emission shares, based on average permits surrendered in 2007 and 2008.

Figure A.5: Distribution of subsidies per job - full sample



Notes: The figure compares the implicit distribution of subsidies per job – calculated in € per employee for a permit price of €30 – under free permit allocation with the one resulting from the exemption rules proposed by the EC. Based on the CITL/ORBIS matched sample of 3,039 firms.

Table A.8: Regressions of the vulnerability score on CI, EI and II

	(1)	(2)	(3)
		Vulnerability Score	
Carbon Intensity (CI)	0.217***	0.611***	0.312
	(0.058)	(0.201)	(0.202)
Sectoral Export intensity (EI)	-0.072		
	(0.160)		
Sectoral Import intensity (II)	0.142		
	(0.153)		
EI with LESS developed countries		0.200	1.613***
		(0.263)	(0.286)
II with LESS developed countries		0.350	0.640**
		(0.225)	(0.273)
EI with LEAST developed countries		-0.476**	-0.833***
		(0.203)	(0.240)
II with LEAST developed countries		0.030	-0.052
		(0.185)	(0.284)
EI with Developed non-EU countries		-0.083	-0.551**
		(0.242)	(0.216)
II with Developed non-EU countries		-0.156	-0.443
		(0.416)	(0.374)
EI with EU countries		0.544	0.016
		(0.544)	(0.675)
II with EU countries		-0.827	-0.901
		(0.579)	(0.682)
EI less X EI less		0.081	-0.467***
		(0.164)	(0.171)
II less X II less		-0.018	-0.363**
		(0.102)	(0.139)
EI least X EI least		0.089***	0.095
		(0.034)	(0.097)
II least X II least		-0.012	0.007
		(0.020)	(0.034)
EI developed X EI developed		0.328**	0.303**
		(0.137)	(0.134)
II developed X II developed		-0.044	0.010
		(0.098)	(0.110)
EI EU X EI EU		-0.926**	-0.243
		(0.361)	(0.386)
II EU X II EU		0.633**	0.695**
		(0.305)	(0.295)
EI less X CI		-0.027	0.918*
		(0.386)	(0.512)
II less X CI		0.262	0.191
		(0.214)	(0.295)
EI least X CI		0.255	0.145
		(0.257)	(0.262)
II least X CI		0.064	0.411*
		(0.169)	(0.233)
EI developed X CI		0.311	0.153
		(0.338)	(0.394)
II developed X CI		-0.354	-1.218***
		(0.292)	(0.410)
EI EU X CI		0.041	-3.959**
		(1.419)	(1.659)
II EU X CI		0.158	3.700**
		(1.479)	(1.692)
Weights	no	no	employment
Observations	389	389	389

Notes: OLS regressions in columns 1 and 2. WLS in column 3. The dataset is a cross-section of 389 interviewed firms that are part of the EU ETS for which CITL, 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 interviewnoise controls (not reported). The dependent variable is the vulnerability score of the firm given by the interviews 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. X indicates that the two variables are interacted or squared.

Table A.9: 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 will be exempted from auctioning under the current EC criteria, but would no longer be exempted under our proposed rule change. The list contains about half of the sectors currently exempted under EU Commission proposals. 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.