

OECD Environment Working Papers No. 87

Impacts of Carbon Prices on Indicators of Competitiveness: A Review of Empirical Findings

Johanna Arlinghaus

https://dx.doi.org/10.1787/5js37p21grzq-en

OECD

Unclassified **ENV/WKP(2015)8**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **27-Mar-2015**

English - Or. English

ENVIRONMENT DIRECTORATE

ENV/WKP(2015)8
Unclassified

IMPACTS OF CARBON PRICES ON INDICATORS OF COMPETITIVENESS: A REVIEW OF EMPIRICAL FINDINGS - ENVIRONMENT WORKING PAPER No. 87

by Johanna Arlinghaus (1)

OECD Working Papers should not be reported as representing the official views of the OECD or of its member countries. The opinions expressed and arguments employed are those of the author(s).

(1) OECD Centre for Tax Policy and Administration and Environment Directorate.

Authorised for publication by Simon Upton, Director, Environment Directorate.

JEL Classification: H23, H32, Q54, Q58,

Keywords: Environmental Tax; Carbon Tax; Emissions Trading; Competitiveness; Policy Evaluation

OECD Environment Working Papers are available at www.oecd.org/env/workingpapers.htm

JT03373258

Complete document available on OLIS in its original format
This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

English - Or. English

OECD ENVIRONMENT WORKING PAPERS

OECD Working Papers should not be reported as representing the official views of the OECD or of its member countries. The opinions expressed and arguments employed are those of the author(s).

OECD Working Papers describe preliminary results or research in progress by the author(s) and are published to stimulate discussion on a broad range of issues on which the OECD works.

This series is designed to make available to a wider readership selected studies on environmental issues prepared for use within the OECD. Authorship is usually collective, but principal author(s) are named. The papers are generally available only in their original language –English or French- with a summary in the other language.

Comments on Working Papers are welcomed, and may be sent to:

Environment Directorate
OECD, 2 rue André-Pascal, 75775 Paris Cedex 16, France
or by e-mail: env.contact@oecd.org

OECD Environment Working Papers are published on
www.oecd.org/env/workingpapers.htm

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.
The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

© OECD (2015)

You can copy, download or print OECD content for your own use, and you can include excerpts from OECD publications, databases and multimedia products in your own documents, presentations, blogs, websites and teaching materials, provided that suitable acknowledgment of OECD as source and copyright owner is given.

All requests for commercial use and translation rights should be submitted to rights@oecd.org.

TABLE OF CONTENTS

ABSTRACT 4

RÉSUMÉ 5

FOREWORD 6

IMPACTS OF CARBON PRICES ON INDICATORS OF COMPETITIVENESS: A REVIEW OF EMPIRICAL FINDINGS 7

1. Introduction 7
2. Competitiveness, market structure and sector vulnerability 9
3. Impacts of carbon and energy taxes on indicators of competitiveness 12
4. Impacts of the EU ETS on indicators of competitiveness 15
   - 4.1 CO_2 emissions effects 16
   - 4.2 Effects on employment, output and profits 16
   - 4.3 Evidence on cost pass-through 18
   - 4.4 Effects on trade 20
5. Impacts of energy price fluctuations on indicators of competitiveness 21
6. Concluding remarks 23

ANNEX I: OVERVIEW OF PAPERS, METHODS AND RESULTS 24

ANNEX II: METHODOLOGIES AND ASSOCIATED CAVEATS 29

REFERENCES 32

ABSTRACT

Concerns around potential losses of competitiveness as a result of unilateral action on carbon pricing are often central for policy makers contemplating the introduction of such instruments. This paper is a review of literature on *ex post* empirical evaluations of the impacts of carbon prices on indicators of competitiveness as employed in the literature, including employment, output or exports, at different levels of aggregation.

Most studies reviewed find that carbon prices cause emissions abatement, but fail to measure any economically meaningful competitiveness effects as a consequence of these policies. In their majority, the papers evaluate systems featuring exemptions and free allocation of emissions permits, but a few papers compare firms benefitting from preferential treatment to firms having to pay the full rate, without finding a difference in the competitive position of either group. In these cases, therefore, providing preferential treatment was likely not necessary to maintain the competitive position of the firms concerned.

The small number of papers considering *ex post* evidence of the competitiveness impacts of carbon taxes find significant decreases in energy intensity, but identify small impacts on competitiveness, if any. The literature performing *ex post* evaluations of the EU ETS is in broad agreement that the EU ETS caused lower emissions. Taking into account methodological challenges, the *ex post* literature on the competitiveness effects of the EU ETS finds no causal effects of the system on employment or output. Employment is found to decrease, but it is difficult to attribute this result causally to the ETS.

Material cost and profits in the power sector are found to increase, consistent with the finding that the power sector manages to pass on emission permit prices into product prices. There also is evidence that the power sector can pass on the opportunity cost of free permits to consumers. Results for industries listed on the EUROSTOXX 600 confirm these results, as investors are seen to expect the profitability of emissions-intensive firms to be damaged if CO_2 prices decrease. CO_2 cost pass-through in the power sector is found to be substantial with rates from 60% in off-peak to 117% in peak hours. Pass-through rates vary between manufacturing industries, ranging from no cost pass-through to more than 100% of the carbon price. While these relatively high pass-through rates may alleviate the competitiveness impacts of the EU ETS on producers, they may add to the indirect effects of the EU ETS.

JEL Classification: H23; H32; Q54; Q58;

Keywords: Environmental Tax; Carbon Tax; Emissions Trading; Competitiveness; Policy Evaluation

RÉSUMÉ

Le risque que des mesures unilatérales de tarification du carbone induisent des pertes de compétitivité constitue souvent un sujet d'inquiétude majeur pour les responsables publics qui envisagent de mettre en place de tels instruments. Ce document passe en revue les travaux consacrés aux évaluations empiriques *ex post* des effets des prix du carbone sur les indicateurs de la compétitivité communément utilisés, dont l'emploi, la production ou les exportations, à différents niveaux d'agrégation.

La plupart des études examinées concluent que les prix du carbone entraînent une réduction des émissions, mais omettent de mesurer les effets économiquement significatifs que de telles dispositions peuvent avoir sur la compétitivité. Dans leur majorité, les études évaluent des systèmes prévoyant des exemptions et une allocation gratuite des permis d'émission, mais quelques-unes comparent les entreprises qui bénéficient d'un traitement préférentiel aux entreprises assujetties au taux plein, sans déceler de différence en termes de positionnement compétitif entre les deux. Dès lors, il n'était probablement pas nécessaire d'accorder un traitement préférentiel pour préserver la position compétitive des entreprises concernées.

Les rares études qui effectuent une analyse *ex post* des effets des taxes sur le carbone sur la compétitivité constatent que l'intensité énergétique a beaucoup baissé, mais relèvent peu d'impact sur la compétitivité, voire aucun. Les travaux consacrés aux évaluations *ex post* du système d'échange de quotas d'émission de l'Union européenne (SEQE-UE) s'accordent globalement pour conclure que ce système a permis de réduire les émissions. Compte tenu des difficultés méthodologiques, ces évaluations ne décèlent aucun lien de cause à effet entre le système SEQE-UE et l'emploi ou la production. L'emploi accuse une baisse, mais il est difficile de l'imputer au SEQE.

Le coût des matières premières et les bénéfices dans le secteur de l'électricité augmentent, ce qui est conforme au fait que le secteur de l'électricité répercute les prix des permis d'émission sur les prix du produit. Des éléments montrent également que le secteur de l'électricité parvient à répercuter le coût d'opportunité des permis gratuits sur les consommateurs. Les résultats pour les industries couvertes par l'indice EUROSTOXX 600 le confirment, car les investisseurs s'attendent généralement à ce que la rentabilité d'entreprises à forte intensité d'émission soit pénalisée si les prix du CO_2 diminuent. Le phénomène de répercussion du coût du CO_2 dans le secteur de l'électricité est très marqué, avec des tarifs qui vont de 60 % en heures creuses à 117 % en heures de pointe. Les taux de répercussion varient entre industries manufacturières, allant de zéro à plus de 100 % du prix du carbone. Ces taux de répercussion relativement élevés peuvent atténuer les effets du SEQE-UE sur la productivité des producteurs, mais ils peuvent aussi alourdir les effets indirects du SEQE-UE.

Codes JEL : H23; H32; Q54; Q58;

Mots-clés: Environmental Tax; Carbon Tax; Emissions Trading; Competitiveness; Policy Evaluation

FOREWORD

This paper is a review of literature on *ex post* empirical evaluations of the impacts of carbon prices on indicators of competitiveness as employed in the literature, including employment, output or exports, at different levels of aggregation.

It was drafted by Johanna Arlinghaus during a joint stage with OECD's Centre for Tax Policy and Administration and OECD's Environment Directorate, and forms a part of the work programme of OECD's Joint Meetings of Tax and Environment Experts.

IMPACTS OF CARBON PRICES ON INDICATORS OF COMPETITIVENESS: A REVIEW OF EMPIRICAL FINDINGS

1. Introduction

This paper summarises and evaluates *ex post* evidence on the impacts of carbon pricing on indicators of competitiveness as employed in the literature. The review also considers the environmental effects of carbon prices, so as to keep track of the policies' primary objective.

Carbon pricing here refers to policy measures that put a price on CO_2 emissions, including but not limited to carbon taxes and emissions trading schemes (e.g. the EU ETS). Energy or fuel taxes can also price carbon by relating to the carbon content of the different tax bases. Not all taxes discussed here are explicit carbon taxes, for example the UK Climate Change Levy, but all raise the cost of emitting CO_2. The introduction of carbon taxes began in the 1990s and has continued since,[1] but rigorous evaluations of their effects remain scarce. The EU ETS is the world's largest cap-and-trade system, covering most industries in 31 countries. Created in 2005, data availability for the EU ETS is increasing, and some partial evaluations are available. These are reviewed here. The effects of carbon prices can also be approximated by studying the impacts of fluctuations in energy prices, and we discuss some studies that take this approach. As will be shown, comparisons between analyses of carbon taxes, the EU ETS, and energy price fluctuations are to be made with caution as the characteristics of the instruments differ. For example, energy price fluctuations and explicit carbon pricing mechanisms can differ in terms of their visibility to consumers and hence responses can differ too.

Competitiveness, as treated in the literature reviewed here, considers the effects of carbon prices on several variables at the firm, sector and national level, including employment and output or exports at different levels of aggregation. The possibility that putting a price on emissions of carbon dioxide (CO_2) in the form of a tax or emissions trading scheme (ETS) has adverse effects on sector or country competitiveness is often a major concern for policy makers contemplating the introduction of such instruments. Model-based studies, mostly using computable general equilibrium (CGE) models, often find rather small competitiveness impacts in different directions. Results differ according to the choice of the reference scenario and modelling assumptions, whether revenue recycling is taken into account and according to what dependent variables are considered (e.g. GDP growth, employment, investment or trade).[2] Such studies are not reviewed here. Instead, the focus is on papers that set out to estimate a causal relation between carbon prices, emission reductions and competitiveness effects after introduction. Such *ex post* studies remain scarce due to data limitations and are plagued by methodological difficulties. However,

1 . Countries having introduced explicit carbon taxes include Finland (1990), Norway (1991), Sweden (1991), Denmark (1992), Slovenia (1997), United Kingdom (2001), Ireland (2009), Iceland (2010), Australia (2012) (scheduled to be abolished). In addition, the Canadian province of British Columbia (2008) has introduced a carbon tax. Other countries have undertaken an environmental tax reform (ETR), which refers to 'changes in the national tax system where the burden of taxes shifts from economic functions to activities that lead to environmental pressures' (EEA 2005). These countries are Austria (starting in 1989), the UK (starting in 1996), Italy (1998), Germany (1999) and France (1999) (IEEP 2013, OECD 2001).

2 . For further review on modelling studies on environmental tax reform and the EU ETS, please refer to among others: Withana et al. (2013), Ekins and Speck (2012), COMETR (Competitiveness effects of environmental tax reforms, 2004-2006) – published in Andersen et al. (2007), Oberndorfer (2006) and Bosquet (2000).

the available studies that tackle the econometric challenges most convincingly cannot find a causal relation between carbon pricing and competitiveness, as measured by a range of indicators. Section 2 provides a discussion of the channels through which these indicators affect competitiveness.

The papers reviewed generally do not find any economically meaningful effects of carbon prices at their current levels and design on competitiveness at firm, industry or national levels.[3] Empirical results confirm the environmental effectiveness of carbon prices. As a result, in the cases studied – which are fairly limited in number – a carbon price seems to be an effective environmental policy instrument with no substantial negative effects on competitiveness. The present analysis does, however, not allow any firm assertions concerning the impact of other carbon price levels on competitiveness.

In practice, carbon pricing systems often feature exemptions, reductions and rebates that are partly argued precisely on competitiveness grounds. The estimated competitiveness effects reviewed in this paper are thus often based on systems which feature exemptions and free allocation of emissions permits. This is with three the exceptions. First, Martin et al. (2014) investigate the effect of firms being subject to the full UK Climate Change Levy compared to firms being partially exempt, finding no competitiveness effects of the full carbon tax on firms. Second, Flues and Lutz (2015, *forthcoming*) compare German firms which had to pay a higher electricity tax to firms which were allowed to pay a reduced electricity tax rate, finding no robust impact of the reduced marginal tax rate on firm's turnover, investments, value-added, turnover abroad and employment. Thus, firms which had to pay the full electricity tax rate did not suffer from deterioration in competitiveness compared to firms which were partially exempt from the tax. Third, Anger and Oberndorfer (2008) compare firms which were practically exempt from payments under the EU ETS, by being over-allocated free emissions permits, to firms which were only partially exempt from payments, having to purchase additional permits at a cost. They find that whether German firms were over-allocated free emissions permits, or whether they were short of emissions permits and had to purchase additional permits at a cost, did not have a significant impact on firm revenues and employment. These case studies suggest that reduced rates and exemptions are not always necessary to maintain the competitiveness of firms affected by the policy.

A further insight of the review is that empirical pass-through rates often are large. This means that producers largely do not bear the full carbon cost, which may limit the direct competitiveness effects of carbon prices on firms from carbon prices. At the same time, high pass-through rates may increase the indirect effects of the carbon price on consumers. Pass-through rates found in the empirical literature for the power sector are between 60 and 117%, while pass-through in selected manufacturing sectors varies between no cost pass-through and exceeding 100%, depending on the sector investigated.

This paper proceeds as follows. Section 2 briefly considers different concepts of competitiveness and discusses the different channels through which competitiveness is affected by different variables. Section 3 considers the literature on carbon tax evaluations and section 4 is on the competitiveness effects of the EU ETS. Section 5 reviews literature inferring the impact of a carbon price from variations in energy prices. The last section concludes and discusses policy implications. Annex I lists the reviewed papers, their methods and results in table format, while Annex II is an overview on the research methods employed and their caveats.

3 . This finding is in line with OECD work on the effects of environmental policy tightening on multifactor productivity growth. Using a new cross-country dataset Albrizio et al. (2014) find that there is no lasting harm to productivity at aggregate, industry or firm level from the introduction of stricter environmental policies. On the contrary, a tightening of environmental policies is followed by a temporary increase in productivity growth, causing an overall improvement in production efficiency for a large share of the manufacturing industries.

2. Competitiveness, market structure and sector vulnerability

Competitiveness is a concept widely used in debates on environmental taxes and ETS, but it is not always defined precisely. This section briefly discusses some theoretical considerations concerning definitions of competitiveness at different levels, and highlights the effect of market structure and of competition in local or global output markets on the impact of environmental taxes; see Adams (1997), OECD (2001), Smith (2003) and Ekins and Speck (2012) for in-depth treatments. It also discusses the channels through which the indicators employed in the literature affect competitiveness.

Competitiveness at the firm level is primarily a matter of the firm being able to sell its goods or services in the domestic or international market and staying in business (Adams, 1997). An industrial sector consists of many firms, some of which will be more competitive than others. Industrial or sector competitiveness can be viewed as arising from lower costs than those facing international rivals or product differentiation by providing a higher value to the customer through service or quality (*ibid.*). Thus, sectoral competitiveness relates to whether a domestic sector as a whole can retain or expand its share of domestic and international markets.

The definition of firm- and sector-level, competitiveness cannot straightforwardly be translated to competitiveness on national level. For example, reduced competitiveness of one industry does not necessarily reduce the competitiveness of the economy as a whole. The competitiveness of a whole economy depends on a range of structural factors including the macroeconomic environment, commercial framework, openness to trade and investment, labour skills, ability to innovate and labour market regulation (Adams, 1997). If, for example, carbon prices enhance a country's ability to innovate (as proposed by the Porter hypothesis), high-quality environmental standards could well be viewed as a factor enhancing competitiveness. From a trade perspective, it would be ideal to measure a country's competitiveness by the reduction in net exports before any adjustments in the exchange rate have taken place. Practically, this is not feasible. Thus, whether environmental taxes harm a country's competitiveness can be assessed by whether they require a fall in a country's real exchange rate to maintain the internal trade balance at the level prior to policy introduction (Smith, 2003).

The logic behind the fear of loss of competitiveness caused by carbon prices is that *ceteris paribus* these prices generally entail a variable cost increase, making energy for production processes more expensive – directly, or indirectly via higher electricity prices (Ekins and Speck, 2012). If the carbon prices are implemented unilaterally, the additional production cost may impair the competitiveness of affected firms and sectors. However, dynamic effects of carbon prices may cause firms to discover and implement cost-effective energy efficiency measures to move them closer to the efficiency frontier. Furthermore, it may stimulate industrial innovation, which according to the Porter Hypothesis might even increase competitiveness. Such innovation and industrial development processes might take some time, suggesting that analysis of competitiveness effects from environmental taxes generally should distinguish between the long and the short term (ibid.).

Carbon and energy taxes, specifically, might be introduced as part of an environmental tax reform, such that the overall change is broadly revenue-neutral and the overall tax burden is unchanged (Ekins and Speck, 2012). In this case, the effect on competitiveness depends on which taxes are reduced to compensate for the increase in environmental taxes. If the taxes reduced are business taxes, this could offset competitiveness effect on business. At the same time, firms might be affected differently, for example, if the tax increase is on energy and the tax reduction is placed on employment, labour-intensive firms will be relatively better off, while energy-intensive firms might lose (ibid.). Also within a given sector, there will be differences across firms, with some being more strongly impacted by carbon taxes than others.

This paper follows the approach taken in the literature reviewed, assessing the effects of carbon prices on several variables, including employment, output or exports, at different levels of aggregation. The different channels through which these variables affect competitiveness and how they are treated in the literature reviewed in this paper merit brief consideration:

- *Profits, turnover (abroad), investment, value-added, output and plant exit:* In order to comply with regulations that price carbon, firms have to pay carbon taxes, use emission permits or undertake costly abatement. This not only lowers profits, but may also worsen the competitive position of regulated firms with respect to competitors from countries without carbon prices, and also with respect to less carbon-intensive firms within the same sector. Increases or decreases in investment may indicate how firms expect their competitive position to change, while value-added indicates whether a firm is able to create more or less valuable products or services than its competitors (Flues and Lutz, 2015). Losses of competitiveness at firm level could be manifested by decreased turnover or loss of market share, domestic or abroad (Adams, 1997). Ultimately, competitiveness losses could lead to a decrease in output, plant closure or relocation. Since it is empirically challenging to distinguish data set attrition from plant exit, the effects of carbon pricing on plant entry and exit are only addressed in one of the studies reviewed.

- *Employment:* Though the debate on carbon pricing is often framed as being a question of 'jobs versus the environment', it is not clear how changes in employment relate to competitiveness. An expansion of employment could be a sign of an expansion of production, but a large workforce may also indicate less productivity (Flues and Lutz, 2014). Furthermore, carbon pricing might also induce a restructuring of employment between more and less polluting sectors, where the net effect on employment is not clear (OECD, 2011). Nonetheless, being a variable of high political interest, employment is often considered in ex post evaluations of carbon prices.

- *Cost pass-through:* Competitiveness effects on the firm and sector level can be attenuated if firms manage to pass-through carbon costs, rather than having to absorb parts or all of the cost increase. This will have effects for industrial or residential consumers of these products, for example through electricity price increases. Empirically, the separate identification of the impact of higher carbon prices on electricity tariffs is, however, very challenging. Thus, all studies reviewed here focus on the direct competitiveness impact of carbon prices. The indirect effects of carbon prices for energy consumers from price increases are not investigated.

- *Investor expectations*: A small number of papers take a capital market perspective, measuring the distributional consequences of the EU ETS by looking at investor expectations of the regulatory impact on firm value (Veith, 2009; Bushnell, 2012). The intuition is that if the return on common stock of the most affected industries is positively correlated with rising prices for emissions rights, this implies that the market predicts that firms are not only able to pass on their share of the regulatory burden to customers, but even achieve windfall profits by overcompensating for the costs (Veith, 2009). This runs counter to the argument that carbon prices reduce the competitiveness of firms and industries, since such a finding provides evidence in favour of the hypothesis that firms are expected to profit from carbon prices.

- *Trade:* In a closed economy without trade, a carbon price signal provides incentives for efficiency improvements in production, innovation activity and demand substitution towards lower carbon goods. However, in an open economy, increasing carbon prices may lead multinational companies to relocate their carbon-intensive production activities to less-regulated countries and export back 'dirty' goods to carbon-constrained regions (Jaffe et al., 1995; Condon and Ignaciuk, 2013). Climate change policies may thus not only fail to achieve their environmental objective – pollution is shifted, rather than abated ('carbon leakage') – but may

also have adverse effects in terms of lost jobs, economic output and export revenue. Except for those studies which explicitly investigate trade relations, the studies reviewed in this paper do not control for the composition of trade with partner countries.

Literature practice is also followed concerning the time-frame of the analysis, for which in its great majority, data availability is the constraining factor. In general, those studies which establish causality of the effects of carbon prices on competitiveness with greater reliability focus on the short run effects of policy. Please consult Annex II for guidance on research design and causality, as well as some caveats concerning the interpretation of the findings presented in this paper. As indicated, the ability to pass-through rising production cost from carbon prices to output prices is an important indicator to assess whether carbon prices are harming or could potentially harm the competitiveness of firms. Market structures and the nature of competition (international or domestic) may give rise to very different incidence of carbon prices (OECD, 2001). However, even for the extreme cases of perfect competition and monopoly, a range of pass-through rates is possible, complicating ex ante predictions of pass-through (RBB Economics, 2014). For example, for firms operating in a perfectly competitive market and selling output domestically without import competition from countries without carbon costs, one should expect 100% or full cost pass-through to occur, since costs have nowhere to go but into output prices (Oberndorfer et al., 2010).[4] In contrast, if a sector competes internationally and has to meet world prices, suppliers may have to absorb parts (other parts might be offset by nominal exchange rate changes or reductions in other taxes) or the entire carbon price, which may lead to economic losses and may over time translate into plant closures.[5] At the other end of the spectrum, a firm selling a differentiated product or operating in an oligopolistic or monopolistic market may be highly affected by a carbon price, but can pass on additional costs to a certain extent easier via higher product prices, depending on the shape of the demand curve, and pass-through rates will still differ widely between cases.

RBB Economics (2014) considers a range of intermediate situations, such as those arising from vertical integration, firm-specific cost pass-through, different contractual situations between wholesale and retail firms, and different degrees of product differentiation. While an assessment of these situations complicates the picture even further, they might be practically more relevant than the extreme cases of perfect competition and monopoly. In general, theoretical insights provide limited intuitive guidance. For example, in theory, pass-through critically depends on the curvature of demand, i.e. pass-through is greater when the inverse demand curve becomes steeper as output decreases (convex-inverse demand), and smaller if the inverse demand curve becomes flatter with decreasing output (concave-inverse demand). However, there is little empirical work estimating the curvature of demand in practice. Moreover in the context of vertical integration, theory predicts that upstream firms can sell inputs to downstream firms at marginal cost, allowing for 100% cost pass-through. At the same time, empirical evidence does not establish a clear link between vertical integration and the extent of pass-through (ibid.). These examples suggest that estimates of cost pass-through should be obtained on a case-by-case basis. Section 4.3 discusses some empirical estimations of cost pass-through.

4 . This presupposes unilateral introduction of carbon prices. Cost pass-through dynamics will differ in the case of a multilateral introduction of a carbon price.

5 . Technological change allowing for the substitution of technologies away from carbon could help avoid this trajectory.

3. Impacts of carbon and energy taxes on indicators of competitiveness

This section reviews the empirical evidence on competitiveness effects of carbon and energy taxes. *Ex post* evaluations of carbon and energy taxes are scarce: only four papers which investigate the competitiveness effects of carbon taxes were identified. The contributions reviewed in this section do not find any effects of carbon and energy taxes on the various indicators of competitiveness of firms, except one which finds a small negative effect of energy taxes on employment. At the same time, comparing firms in the UK which had to pay the full Climate Change Levy (CCL) to firms which were exempt, Martin et al. (2011) find that the UK CCL did cause emissions abatement, while not affecting the competitive position of UK manufacturing. In sum, energy and carbon taxes do not seem to impact the competitive position of affected firms in the cases studied, while they do improve environmental outcomes.

Flues and Lutz (2015, forthcoming) study the competitiveness effects of the German electricity tax on companies, finding no robust causal effects of the tax on firm's turnover, investments, turnover abroad, value-added or employment of firms in the manufacturing sector between 1999 and 2004. The research builds on variations in the marginal tax rate: firms which use more electricity than a certain threshold face a lower marginal tax rate, in comparison to firms using less electricity. Using regression discontinuity analysis, the authors compare the competitiveness of firms having to pay the full electricity tax - those below the threshold – to firms which had to pay a reduced marginal electricity tax rate – those above the threshold. A central assumption of this research design is that the distribution of firms around the threshold is random, thus, that firms cannot precisely manipulate their electricity use, making it *ex ante* unknown to them whether they will end up paying the full electricity tax or not. While this assumption cannot be tested directly, it is convincingly argued and shown graphically that this assumption is reasonable. Overall, this research design is able to make the case that paying the full electricity tax did not have a significant causal effect on the competitiveness of the firms concerned.

Martin et al. (2014) evaluate the UK CCL[6] and find substantial environmental effects of the CCL but no effects on competitiveness of UK manufacturing between 2001 and 2004. Using a difference-in-differences regression design, including instrumental variables and fixed effects, they compare firms subject to the full CCL to plants who participated in Climate Change Agreements (CCA) and were thus granted an 80% discount on the CCL rate given that the targets agreed in the CCA are met. Martin et al. (2014) and Pearce (2004) argue that the CCA targets are not very different from a business-as-usual scenario and were thus not very difficult to meet. A credible baseline against which to evaluate the effects of the CCL hence is given by outcomes of plants facing lower tax rates by virtue of being in the CCA. Variables investigated include the impact of the CCL on energy intensity, measured as energy and electricity use, but also on employment, gross output and total factor productivity (TFP).

Results show that the CCL caused plants to substantially reduce plant-level energy intensity, measured as the share of energy expenditures in both gross outputs and variable costs, respectively, relative to CCA plants. This has been mainly achieved by a reduction in electricity use by 22.6%, which translates to a decrease in carbon emissions by between 8.4% and 22.4% of plants paying the full CCL rate compared to those paying a reduced rate. Disaggregating the effects of the CCL by year shows that while plants initially switched from electricity to gas, from 2002 onwards, they managed to reduce electricity consumption without significantly increasing the consumption of other fuels. While these significant estimates imply that the policy did have a substantial environmental effect on firms, estimates of the effects of paying the full CCL on gross outputs, employment and total factor productivity are insignificant.

6 . The CCL is a per unit tax payable at the time of supply to industrial and commercial (non-household) users of energy. The levy also excludes transport fuels. Effective tax rates vary substantially by fuel, ranging from GBP 31 per tonne of CO_2 for electricity, GBP 22 per tonne of CO_2 for petroleum, GBP 16 per tonne of CO_2 for coal and GBP 30 per tonne of CO_2 for natural gas (Pearce 2004, 2006).

The main identification challenge is selection bias, and in particular self-selection into the treatment group, since emission-intensive factories are more likely to enter CCA than less emission-intensive plants. This could mean that the treatment group under the CCL is structurally different from the control group. As a remedy, the authors exploit exogenous variation in eligibility rules for CCA participation as an instrumental variable for being subject to the full CCL. Exogenous variation in eligibility rules, which prevents that, for example, plants could self-select into the CCA scheme, stems from the fact that CCA eligibility rules were implemented only one year prior to CCL implementation, which makes it unlikely that firms switched technologies in the short run because of the CCA discount. Furthermore, when eligibility was first determined, criteria featured an exclusive focus on pollution intensity, which left many energy-intensive industries ineligible for CCA. Martin et al. (2014) also present a range of robustness checks on their results. Their research design appears well-suited for identifying the causal effect of the CCL on the variables investigated.

As discussed, firm-level analyses usually do not take into account effects of carbon prices on plant exit. However, using the database which serves as the sampling frame for data used for the energy intensity and energy efficiency analyses, Martin et al. (2014) construct a dummy variable for the year of exit to investigate how paying the full CCL affects plant closure or relocation. They do not find evidence that the CCL had an impact on plant exit decisions. This analysis focuses on exit decisions on plant unit level, whereas most variables employed in other parts of the paper are available at a slightly higher level of aggregation. Since employment is available at both aggregation levels, Martin et al. (2014) replicate the analysis using employment at the local unit level to verify that the results obtained at a higher level of aggregation are robust. The absence of any evidence suggesting that the CCL accelerated plant exit is an encouraging complement of the analysis.

Rivers and Schaufele (2014) investigate the impact of the carbon tax[7] in the Canadian province British Columbia (BC) on the competitiveness of the agricultural sector. Using a difference-in-differences design, the authors compare agricultural trade flows in all Canadian provinces between 1990 and 2011, before and after the introduction of the tax in 2008. The authors do not find a consistent and credible link between BC's carbon tax and agricultural trade. In nearly all cases, coefficients from the regressions are not statistically significant, which means that the carbon tax did not have an impact on the competitiveness of the agricultural sector. In the few cases where statistical significance is obtained, results suggest that agricultural exports increased and imports decreased in conjunction with the introduction of the carbon tax, which runs counter to the expectation that the competitiveness of the agricultural sector would be harmed by the carbon tax. Interacting commodity dummies with the carbon tax variable allows estimation of product-specific effects, which again does not yield significant results. The paper does not investigate the environmental effects of the policy.[8] Since Rivers and Schaufele (2014) use aggregate trade data for all Canadian provinces, it is a challenge to control for all factors except the carbon tax that could affect trade patterns on the provincial level, so their results should be taken as indicative.

In establishing the carbon tax, the provincial government has made a binding legislative commitment to return all carbon tax revenue to individuals and firms via corresponding tax cuts – mainly through cuts to income taxes (personal and corporate), as well as targeted tax relief for vulnerable

7 . The BC carbon tax was introduced in 2008 and applies to all greenhouse gases from burning fossil fuels with the effective tax rate on each fuel type determined based on carbon content. The rate was originally set at CAD 10 per tonne of CO_2 and increased by CAD 5 per tonne of CO_2 each year until 2012, when it reached CAD 30 per tonne of CO_2 (Harrison, 2013). Initially, the carbon tax was implemented without any exemptions.

8 . Comparing BC with other Canadian provinces, Elgie (2014) finds preliminary evidence that the carbon tax led to a decrease in fuel consumption.

households and communities. In practice, the tax reform has been revenue-negative: the province gave back more money in tax cuts than it collected in each of the first 5 years (Harrison, 2013).

The agricultural sector is of special interest in the BC context, as the 2013 budget committed to return 80% of tax revenues to greenhouse vegetable and flower growers and to exempt fuels used in farm operations. While the two commitments together account for only 1% of combustion emissions and carbon tax revenues, nonetheless the form of concessions undermines the carbon price signal in both cases (Harrison 2013). The exemptions were introduced against the background that the agricultural sector has been classified as an "at-risk" industry due to perceived difficulties in adapting to the carbon tax by decreasing fuel use in the short run (Rivers and Schaufele, 2014). Comparing other highly-traded goods from BC to agricultural goods, Rivers and Schaufele (2014) find that the latter do stand out as neither particularly fossil fuel intensive, nor particularly trade intensive. Combining this result with the finding that the carbon tax has not caused any meaningful changes in the trade patterns of the BC agricultural sector compared to those in other provinces, exempting this sector from carbon tax payments for fuel and granting an exemption of the greenhouse flower and vegetable sector appears hard to justify.

In contrast to the previous papers, Commins et al. (2009) find evidence of negative impacts on employment. Examining the impact of energy taxes and the EU ETS on firms in Europe between 1996 and 2007, they find that those prices increase TFP by about 0.2% and returns to capital by about 0.25%, have a very small positive effect on investment (about 0.01%) and decrease employment by 0.1% on average for the sectors investigated. They also find that the impact of carbon prices on all dependent variables varies highly among industries, even among those with similar energy and technology use. For example, the effect of energy price changes on TFP growth is found to be of the largest magnitude in a positive direction in office machinery, metal mining and electrical machinery, while energy price increases are found to decrease TFP growth most in recycling, tobacco, leather and wearing apparel. According to the authors' interpretation, results on TFP growth in selected sectors could be explained by the Porter Hypothesis, stating that regulation spurs innovation, while increases in return on capital and investment are consistent with the substitution of capital for labour. The latter may also explain the finding that the level of energy prices may decrease investment. At the same time and as mentioned above, causal interpretation of the impact of carbon prices on productivity should always distinguish between effects over the short and long term.

The main identification challenge in Commins et al. (2009) is to pin down the causal effect of energy taxes on competitiveness, separating firms which were subject to the EU ETS from those which were not. The authors do include firms with small installations into the treatment group, although they are not subject to EU ETS regulation, so that they estimate sector effects including sector-level shocks (Martin et al., 2013). The results obtained may thus change if the data were further disaggregated to better reflect firm participation in the EU ETS.

4. Impacts of the EU ETS on indicators of competitiveness

This section discusses the literature on empirical *ex post* evaluations of the EU ETS. Since this literature has been reviewed in a recent paper by Martin et al. (2013), the paper selection and discussion will be based on their work and include some additional details. While all papers covering the competitiveness effects of ETS firms are included in the table in the Annex for comparison, the papers reviewing solely its environmental effects are not included.[9]

When interpreting the findings, it has to be taken into account that the price signal of the EU ETS is not entirely equivalent to a tax. Taxes are compulsory and unrequited revenue-raising fiscal policy instruments (OECD, 2004). In contrast, the purchase of an emissions certificate in the EU ETS context is associated with the right to pollute. Grandfathering in the EU ETS context implied that in the first phase of the scheme, from 2005 to 2007, almost all allowances were given to companies for free by means of a national allocation plan and only 5% of permits were auctioned. In the second phase, from 2008 to 2012, the auctioning requirement was raised to 10%. Thus, in contrast to carbon taxes, which are potentially revenue-raising, the EU ETS has until this point not been an instrument which raised significant revenue.

Another distinguishing factor between carbon taxes and ETS is the volatility of the price signal. This has both environmental and revenue-raising implications. While a tax gives an ongoing, fixed carbon price signal to the market, permits under the EU ETS are traded and prices are determined by the interaction between the supply and demand for permits. For the EU ETS, the price signal of emissions to firms has been very volatile, ranging from more than EUR 30 in 2006 and falling to near zero in 2007. From an environmental perspective, this means that the cost of carbon emissions is more difficult to predict under an emission trading system than under a carbon tax. This cost uncertainty may lead to different firm decisions in terms of abatement.[10] Although revenue stability under a tax also depends on dynamic policy impacts, e.g. behavioural changes which may over time lead to a decreasing tax base, revenues from a carbon tax tend to be more uniform over time than revenues from an ETS under an auctioning system.

Despite these differences, the findings of the papers evaluating the environmental and competitiveness effects of the EU ETS come to the same broad conclusion as the papers reviewing the effects of environmental taxes: while the EU ETS led to substantial emissions abatement, it did not affect the competitiveness of firms subject to the policy, as measured by employment, profits and output, the cost pass-through of emissions permits and its effects on trade. Studies dealing best with methodological challenges do not find competitiveness effects of the EU ETS, while finding that companies undertake substantial emissions abatement, up to 28% compared to business-as-usual. This means that the cap was binding and stringent enough to require significant emission reductions, while not causing disadvantages for the competitive position of EU ETS firms. The finding that the EU ETS does not negatively impact competitiveness is reinforced by the findings of cost pass-through especially in the electricity sector, suggesting that firms can actually reap windfall profits from CO_2 prices, since they can pass on the opportunity cost of emissions allowances to consumers without actually having to pay the carbon cost since emission permits mostly have been allocated for free. At the same time, more than full cost pass-through of permit costs to prices means that electricity consumers faced significantly higher prices, amounting to indirect policy impacts.

9 . For further detail concerning these papers, please refer to Martin et al. (2013).

10 . Firms' investment in abatement technology will likely always be positively correlated to the carbon price. Under a tax, this price will be stable and predictable, while under an ETS regime, the price signal will change over time, which may make it more difficult for firms to decide how much to invest in abatement technology.

4.1 CO_2 emissions effects

Concerning the effectiveness in terms of emissions abatement, the papers reviewed in Martin et al. (2013) using aggregate data find that emissions reductions during Phase I of the EU ETS were estimated close to 3% (210 million tonnes of CO_2) higher for firms participating in the EU ETS than for firms which did not participate (Ellermann and Buchner, 2007, 2008; Ellermann, Convery and de Perthuis, 2010; Anderson and DiMaria, 2011). Abatement is further shown to exhibit strong variation across countries and sectors. For example, abatement in Germany is estimated to be slightly higher at 5% for all EU ETS sectors for Phase I compared to non-ETS sectors. Considering different sectors, it is estimated that abatement was at 6.3% in the industrial sectors and at 4.1% in power generation (Ellermann et al., 2010; Anderson and DiMaria, 2011). Other authors estimate abatement at 5.1% for all EU ETS sectors during Phase I (Ellermann and Feilhauer, 2008). Egenhofer et al. (2011) estimate abatement for the first two years of Phase II at 3.35%, while others arrived at slightly lower estimates (Cooper, 2010; Kettner, Kletzan-Slamanigand Koeppl, 2011).

As seen earlier, it is easier to disentangle the effects of the EU ETS from confounding factors using firm-level micro data. For German manufacturing firms with more than 20 employees, Petrick and Wagner (2014) show that abatement in Phase I was relatively insignificant, but that ETS firms abated 26% to 28% more emissions between 2007 and 2010 than firms which were not subject to the ETS. Abrell, Ndoye and Zachmann (2011) exploit the structural break between Phase I and Phase II and estimate emissions reductions between 2007 and 2008 to be 3.6% higher than between 2005 and 2006. Further, McGuiness and Ellermann (2008) estimate abatement in the UK power sector through fuel switching in 2005 and 2006 to lie between 13 and 21 million tonnes of CO_2 (roughly between 8 and 12% of business-as-usual emissions of that sector) in each year.

All in all, the literature is in broad agreement that emissions abatement has taken place as a result of the carbon price associated with the EU ETS. Estimates of the rate of abatement vary by the kind of data used, by country and by sector; the full range is between 3% and 28%. Due to the altered institutional design of the EU ETS during Phase II, abatement was likely higher than during Phase I.

4.2 Effects on employment, output and profits[11]

Papers investigating the effects of the EU ETS on employment, output and profits do not find any evidence that the EU ETS had significant impacts on these variables. The only effects found are employment effects - likely driven by the non-metallic minerals sector – as well as increases in unit material cost and revenues in the power sector – explained by the cost pass-through of emissions prices by the power sector. This is consistent with evidence from the stock market, where firms are found to be able to financially profit from regulation. Examining firm-level micro data, Petrick and Wagner (2014) arrive at the remarkable finding that German manufacturing firms have reduced emissions due to the EU ETS, while the same firms have not suffered from any competitiveness effects arising from the EU ETS.

Anger and Oberndorfer (2008) convincingly study the impacts of the initial allocation of EU ETS allowances on revenue and employment in the German manufacturing sector, using matching and regression analysis, including instrumental variables. In this context, one problem may be that verified emissions do not stem from a pre- EU ETS period, making it difficult to distinguish the allocation factor from early abatement, i.e. from firms reacting to the ETS. However, evidence suggests that abatement in 2005 remained relatively low, so that the allocation factor should at least be a very good indicator for relative allocation (Ellerman and Buchner, 2006). Anger and Oberndorfer (2008) do not find evidence that firms subject to a more generous allocation of emissions permits had different revenues or employment, in

11 . Again, the paper selection is based on Martin et al. (2013).

2005. This study stands out by directly comparing firms which were over-allocated emissions permits to firms having to buy additional permits at a cost, which can be interpreted as comparing firms which are practically exempt from any payments to firms which are not exempt. Finding no difference between these groups provides some certainty that the absence of competitiveness effects is not the result of exemptions and rebates.[12]

Using propensity score matching, Abrell et al. (2011) do not find any impact of the EU ETS on firm added value or profit margin in manufacturing sectors (other non-metallic mineral products, electricity and heat, paper and paper products, basic metals and coke and refined petroleum products). A decrease in employment of 0.9% in EU ETS firms is found, which seems driven by the non-metallic minerals sector. While this is not a minor effect, one challenge of the paper is that Abrell et al. (2011) compare companies from all non-regulated sectors to companies from regulated sectors, since the matching procedure includes all sectors and not just sectors of interest for the study. As a result, sectoral trends could confound the policy effects of the EU ETS and the results of this paper should be interpreted with caution.

Chan et al. (2013) study the effect of the EU ETS on unit material cost, employment and revenue of 5873 firms from 10 countries, in the power, cement, iron and steel sector, between 2001 and 2009, using a differences-in-differences approach. While they do not find any impacts of the EU ETS on any of the variables in the cement, iron and steel industries, they estimate that participation in the EU ETS increases unit material costs for power plants by 5% (by 8% in Phase II) and revenue increases in the power sector by a remarkably large 30% in Phase II. Their research design is questioned by Martin et al. (2013) on the grounds that it may not ensure that the treatment group is as similar as possible to the control group, which is key in order to identify the causal effect of the EU ETS. This is because Chan et al. (2013) simply compare participating firms to non-participating firms from the same industry. Selection bias into the treatment group based on, for example, company size makes it possible that the treatment group is systematically different from the control group. This makes the two groups difficult to compare.

In the most recent paper, Petrick and Wagner (2014) estimate the impact of the EU ETS on gross output, employment and exports of participating German manufacturing firms for the first (2005-2007) and the second (2008-2010) phase of the EU ETS. Potential methodological caveats (i.e. the construction of an adequate control group) are addressed by evaluating the common support assumption from a number or angles (i.e. by examining pre-ETS trends or directly controlling for pre-ETS trends). Since the assumption of no spill-overs cannot be tested either, the authors try to generate testable hypotheses of how violations of this assumption would manifest. Overall, Petrick and Wagner's (2014) research design is convincing and a range of robustness checks allow the authors to confirm that there was indeed no impact of the EU ETS on gross output, employment and exports.

A small number of papers take a capital market perspective by focusing on firm profitability and stock prices, as reflecting investors' expectations of firm's future discounted profits. Looking at 22 power companies between 2005 and 2007, Veith et al. (2009) show that returns on common stock of power generation are positively correlated with rising prices for emission rights, implying that investors predict that firms are not only able to pass-through their emissions costs to consumers, but will even be over-compensated for emissions-expenses by their customers. Their main findings remain unchanged when subject to several robustness checks. Similarly, Oberndorfer (2009) finds that price changes of European Emission Allowances are positively correlated with stock returns of the most important European electricity firms. Focusing on a broader set of industries with 548 firms listed on the EUROSTOXX index, Bushnell et al. (2013) find that CO_2 prices play a significant role in determining product prices and

12 . Using the same estimation method, Civitelli (forthcoming) evaluates EU ETS impacts on the competitiveness of Italian firms, again finding no statistically significant effects of the EU ETS on firm profitability, unit material cost and turnover between 2005 and 2012.

revenues. Benefits of higher CO_2 prices, as measured by larger declines in share-prices as a response to a devaluation of the CO_2 price, were concentrated amongst firms with the most exposure to markets within the EU and a relative high usage of electricity (basic metals, oil & gas extraction and utilities, sewage and refuse, land transportation and water utilities). Since these firms have most exposure to a CO_2 price, they are in a position to profit most from a revenue effect of the ETS. Since "dirtier" industries selling to EU markets seem to have performed the worst during the event, investors seem to have expected the profitability of these firms to be severely damaged as a result of lower CO_2 prices. This indicates that grandfathered CO_2 permits significantly increase firms' revenues and even profits. Thus, contrary to decreases in competitiveness, this paper's results suggest that the EU ETS has increased firm's competitiveness, as measured by the variables selected. A concern with this analysis could be that the price of allowances themselves will be driven by shocks to the product markets of regulated firms, i.e. that investors form their expectations based on different variables than on the price of CO_2 allowances. Bushnell et al. (2013) argue that the specific price shock analysed, is purely driven by the update of information about the aggregate number of allowances consumed. Therefore, it is argued, that the price shock analysed should be exogenous to the underlying product markets of firms.

4.3 Evidence on cost pass-through

The impact of the EU ETS might differ among sectors according to firm's possibility to pass-through carbon prices to consumers, as discussed in Section 2.2. A carbon price may have different impacts on sectors characterised by competition from national or international markets than on a sector where there is market power, in which firms may find it easier to pass on carbon prices to product prices. For example, while the manufacturing sector is typically relatively open to international trade and thus exposed to international competition, the power market is highly concentrated and less exposed to international competition since it is selling mostly to local markets (Demailly, 2008; Veith 2009).[13] Against this background, this section reviews the empirical literature investigating the pass-through of carbon prices to products in different sectors.

Sijm et al. (2006) analyse implications of the EU ETS for the power sector and present empirical estimates of CO_2 cost pass-through for Germany and the Netherlands. Despite power companies receiving almost all their CO_2 allowances for free, for a company using an emission allowance this represents an opportunity cost since the permit could otherwise be sold on the market. Therefore, a company is expected to add the cost of CO_2 emission allowance to its other variable cost when making short-term production or trading decisions. Depending on the carbon intensity of the marginal production unit and other market- or technology-specific factors, the pass through rates identified by Sijm et al. (2006) varied between 60% for off-peak and 117% for peak hours in Germany and between 64% and 81% in the Netherlands for peak- and off-peak hours between January and December 2005.

Using an instrumental variables approach, Fabra and Reguant (2013) measure the effects of an increase in emission costs in the Spanish wholesale electricity market, finding that the average pass-through in this market is above 80% while firms are found to increase pass-through in high-demand hours to 100%. Zachmann and von Hirschhausen (2008) provide evidence for asymmetric pricing in German wholesale electricity markets. Asymmetric pricing occurs when prices react more to allowance price increases than to decreases. Moreover, their evidence shows that asymmetric pricing is not a universal phenomenon in electricity futures markets but is specific to the pass-through of carbon allowance prices.

13 . The European Commission (Rademaekers, 2011; Renda et al., 2013) prepared two reports focusing on the costs of EU legislation on the steel and non-ferrous metal industries. Both industries have so far either not been much affected by the EU ETS due to over-allocation of emissions certificates and resulting windfall profits, or have felt some indirect EU ETS effects as a result of electricity price increases. The reports do not perform a causal analysis of the effects of the EU ETS on competitiveness. Empirical work reviewed in this section suggests that EU ETS costs can be passed-through to prices in manufacturing sectors.

Mokinski and Woelfing (2014) provide evidence that asymmetric pass-through of European emission allowance prices to wholesale electricity prices in Germany is the result of non-competitive pricing behaviour. Kirat and Ahamada (2011) investigate pass-through of allowance prices by German and French power producers during Phase I of the EU ETS, finding that allowance prices explain a substantial part of electricity price volatility in both countries before the year 2007. After the collapse of the carbon price 2007, electricity prices became disconnected from the carbon price. In an extension of the paper, covering Phase II of the EU ETS using data from 2008 to 2010, the impact of the carbon price on electricity tripled in France and was multiplied by 1.5 in Germany. This difference is explained by the possibility of banking permits, which increases the opportunity cost of using emissions permits for electricity production. In sum, estimated pass-through rates in the power sector of up to or even more than 100% provide evidence that power producers only bear parts or even no part of carbon costs imposed upon them, which likely limits competitiveness effects arising from carbon costs.

Price pass-through in the power sector might be possible due to electricity firms possessing market power and electricity markets being segregated by the structure of transmission networks, which limits competition from imports. Due to the absence of trade, prices are determined by the local cost of fuel inputs and by consumers' willingness to pay. The price formation of manufacturing firms whose products are traded is more complex, being determined, among other factors, by the interaction of transport and transaction costs, the different extents of market power and product differentiation, fluctuations in exchange rates, as well as the elasticity of substitution between products of different countries. It is thus more difficult to retrace price formation in the manufacturing sector than in the power generation sector (de Bruyn 2010). In order to work around the problem of cost collection for individual products, the available evidence on pass-through in the manufacturing sector is based on variation in fairly aggregated price series over time, or estimated pass-through for selected products of different sectors only (Martin et al., 2013).

These empirical studies find that even in manufacturing, pass-through rates of carbon prices can be substantial. De Bruyn et al. (2010) investigate whether energy-intensive industries such as iron, steel, chemicals and refining passed through carbon prices. Their analysis is based on the idea that if companies did pass through costs of ETS allowances, this would have made prices diverge between the EU and the United States. Cost pass-through is estimated to lie at up to or even above 100% for iron, steel and refineries. The evidence is less clear for chemicals. Alexeeva-Talebi (2011) estimate that since carbon costs account for only a small share in the total costs of petrol production (about 2%), European refineries can likely pass 100% of carbon costs to their consumers. This implies that European refineries at large have been strongly benefitting from the allocation of free allowances. Linking input to output prices, Oberndorfer et al. (2010) empirically analyse the carbon cost pass-through ability of selected products[14] within the UK refinery, glass, chemicals and ceramics sector using weekly price data. Their estimates suggest that up to 50% of energy price increases are passed through to retail consumers of diesel and up to 75% are passed through to retail consumers of gasoline over five weeks. In the chemicals sector, pass-through rates of more than 100% are found for low-density polyethylene film over one month and a pass-through rate 50% is found for ammonium nitrate over six months. Pass-through for glass products is lower, with no pass-through for container glass and 20% to 25% pass-through rates for hollow glass. In the ceramics sector, more than 100% energy cost pass-through rates for ceramic goods and 30-40% energy pass-through rates for ceramic bricks over six months are found. Empirical estimates of pass-through in the manufacturing sector thus exhibit substantial variation. Differences in the estimated pass-through rates can be explained by differences in country and product selection, for example De Bruyn et al. (2010) use petrol price data from the UK, France and Germany for investigation of carbon cost pass-through, while

14 . Products analysed are OPAL UK Diesel and gasoline for the oil industry, low density polyethylene film and ammonium nitrate for the chemical industry, UK hollow glass and container glass for glass production and ceramic goods and bricks, representing output of the UK ceramics industry.

Alexeeva-Taleebi (2011) uses data from 19 EU countries which were allocated emissions allowances in 2006.

All in all, substantial cost pass-through of EU ETS allowance prices is found in the empirical literature, both in electricity and manufacturing sectors. Especially in electricity markets, cost pass-through rates to wholesale prices are found to lie between 60% and larger than 100%. In manufacturing, the extent of cost pass-through is more varied. Pass-through rates found in the literature vary between 0% pass-through for UK glass production to 20% in ceramics, and more than 100% in iron, steel, chemicals and refineries. This implies that in all markets investigated, producers do not bear the full carbon costs and that in most markets investigated, producers can pass on a large share of the carbon cost to product prices and do thus not bear more than a minor share of carbon costs. If carbon emission allowances are allocated for free, cost pass-through of emissions prices which producers do not have to pay for, means that producers are able to reap windfall profits.

4.4 Effects on trade

Theoretically, by raising product prices, the EU ETS could have an impact on the export performance of ETS firms competing with firms which do not face explicit carbon prices. Costantini and Mazzanti (2012) aim to estimate the impact of the EU ETS on the export performance of 14 European countries (EU 15 with Belgium and Luxemburg merged). Sectors are disaggregated into high technology, medium-high, medium-low and low technology level.[15] The EU ETS variable is coded as a dummy variable, which is activated in 2005 when the EU ETS has entered into force. While the EU ETS is found to have a negative effect on all sectors, this result might be due to a high level of data aggregation and reflect sector trends. The results may change if data were further disaggregated to reflect participation in the EU ETS at the firm level. Costantini and Mazzanti also investigate the effect of levels of environmental and energy taxes on trade, which are both found to have a highly significant and positive effect on exports. Since environmental and energy taxes generally have broader application than the EU ETS, these results could be more robust than the EU ETS effects. Interpretation of the causal effects of environmental and energy taxes on exports have unfortunately also to remain cautious due to the absence of a control measure against which to evaluate these effects. For example, it could well be that countries which *ex ante* had higher energy and environmental taxes also happen to have higher levels of exports.

Reinaud (2008) regresses net imports of aluminium into the EU 27 on the year ahead price of ETS emission allowances (i.e. 2005 prices are the prices quoted for delivery in 2006 on the forward market), finding a negative relationship between the CO_2 price and net imports. This finding is counterintuitive as it was expected that a CO_2 price would increase imports. Since Reinaud (2008) bases her analysis on rather aggregate data, it is difficult to identify the causal effect of the EU ETS from other confounding trends and shocks which occur at the same time.

The literature on the trade effects of the EU ETS is very scarce and identifies no clear direct causal effects of the EU ETS on trade. The investigation of the effect of the EU ETS on trade is still dependent on the analysis of more aggregate data.

15 . High technology industries are among others air- and spacecraft, pharmaceuticals, office accounting and computing machinery, medium-high technology industries are electrical machinery and apparatus, motor vehicles, chemicals excluding pharmaceuticals, medium-low technology industries are building and repairing of ships, rubber and plastics products, coke, coke and refined petroleum products, low-technology industries are among others (other) manufacturing, wood, pulp and paper, food products and textiles.

5. Impacts of energy price fluctuations on indicators of competitiveness

Very few countries have so far introduced explicit carbon prices, and, as seen in the previous sections, *ex post* evaluations of these carbon prices, especially with respect to competitiveness, are even sparser. The literature surveyed in this section uses actual historical changes in *energy prices* to infer the effects of explicit carbon prices. This is justified on the grounds that both an explicit price on carbon, as well as simple energy price fluctuations, change the effective cost of energy for industry. One problem often encountered in the existing literature on pollution havens[16] is that pollution abatement costs change as a function of production levels. This creates a problem for the estimation of the causal effect of the influence of pollution abatement cost on production levels, since the variable of interest (production) and the explanatory variable (abatement cost) are determined simultaneously. The two papers cited in this section circumvent this issue by the use of exogenous variation in energy prices as a proxy for the stringency of environmental regulation. In response to a 1% increase in energy prices, Sato and Dechezleprêtre (2013) find imports increase by 0.1 to 0.2%, while Aldy and Pizer (2011) find a 1 to 1.5% increase in imports in response to a 10% increase in energy prices. While these results are among the largest found in this review, causal interpretation of the effect of energy price fluctuations on trade should be cautioned due to the absence of a method to infer how the trade pattern would have developed in the absence of the price fluctuations. It may thus be that the development of the trade pattern would have been similar in the absence of energy price shocks. This is in contrast to the experimental studies cited above, which make use of different techniques to construct counterfactual scenarios.

Next to methodological differences, the effects of an actual carbon price might differ from the effects of mere energy price fluctuations due to a higher visibility of the former, as well as different underlying expectations with respect to the persistence of a carbon price or energy price fluctuations.

Aldy and Pizer (2011) define the competitiveness effect as the difference in domestic supply owing to the absence of foreign regulation. Focussing on the sensitivity of producers and consumers to changes in energy prices, they measure the effects of price fluctuations on sectoral production and consumption. On the production side, estimates reveal that US producers' energy price sensitivity is positively correlated with energy-intensity of production. The median industry in terms of energy sensitivity has an estimated production elasticity of -0.16 with respect to energy prices. On the consumption side, the median industry experiences no decline in demand, while demand declines for more energy-intensive industries, implying that consumers shift consumption towards less energy-intensive goods. Comparing demand and supply patterns, the results show that demand decreases less than domestic supply, which suggests that the gap has to be filled with imports. More precisely, a 10% increase in energy costs is shown to lead to a 1% increase in net imports for most manufacturing industries and for those with energy intensity above 10% exceeding 1.5%. A potential problem with these results exists when imports are a substantial fraction of domestic supply, since net imports are measured as the difference between domestic supply and demand. The analysis of the effect of a carbon tax[17] based on these results does not

16 . The international discussions on the pollution haven effect is centred on the concern that as trade and investment barriers are removed across countries, domestic or multinational firms in polluting industries will move to and produce in countries with the weakest environmental policies. To measure the pollution haven effect, pollution abatement cost is often used as a proxy for direct measures of regulation (see Jaffe et al., 1995, Copeland and Taylor, 2004; Levinson and Taylor, 2008 and OECD, 2010 for more detail on the pollution haven effect).

17 . For the introduction of a carbon tax of USD 15 per tonne of CO_2, Aldy and Pizer find a competitiveness impact, measured as the difference between demand and supply which is replaced by imports, of around 1%. This effect is small in comparison to existing annual fluctuations in manufacturing demand, which during their sample averaged at 8.8% for the manufacturing sector. Energy-intensive industries are found to experience a decline in domestic demand between 3 and 4%, which is among others due to consumers

fall into our selection of topics, since it is not an *ex post* evaluation of an existing carbon tax, but is estimated based on changes in energy prices.

Sato and Dechezleprêtre (2013) focus on the consequences of energy price fluctuations on bilateral trade for 51 countries and 66 sectors between 1991 and 2011. They find that a change in the energy price ratio between countries has a statistically significant impact on the volume of trade between them. Regression results suggest that a 1% increase in the electricity price ratio between the importer and exporter increases exports from the country with a relatively lower energy price to the country with a relatively higher energy price by between 0.1 and 0.2%. This effect is found to vary across sectors and be more pronounced for energy-intensive sectors. However, while the change in the energy price ratio explains trade flows in a robust and statistically significant way, variation in energy prices only explain a small part of overall variation in trade patterns. One drawback of the analysis is the lack of disaggregated electricity price data at the sector-level, which does not allow for the inclusion of sector-level fixed effects. As a result, sector-level shocks may confound the estimated effects of electricity prices. In turn, this means that the estimated sector-level variations are not robust to changes in model specification.

The results of both papers seem to confirm the existence of a limited competitiveness impact in the form of a small increase in net imports as a response to higher domestic energy prices. For a 1% increase in energy prices, imports are found to increase by 0.1 to 0.2%, for a 10% increase in energy prices a 1-1.5% increase in imports is found. These magnitudes are relatively small compared to overall percentage changes in the value of shipments in the manufacturing sector, which averaged at 8.8% between 1974 and 1994 (Aldy and Pizer, 2011). These results are the largest effects found among those listed in the present review. Nonetheless, for most sectors, the magnitude of these effects does not appear large enough to have a strong influence on the design of carbon policy instruments. While differences between energy prices are conventionally driven by underlying differences in energy abundance, taxes, the extent of liberalisation of the market and other factors, carbon prices may in the future be an additional factor driving this divergence (Sato and Dechezleprêtre, 2013).

These results are in slight contrast to what has been found earlier in this analysis, namely that carbon prices do seem to have an environmental impact, without having substantial competitiveness impacts. It is worth noting some differences between the *ex post* literature of actual carbon prices and the analysis by Aldy and Pizer (2011) and Sato and Dechezleprêtre (2013). A conceptual difference to point out is that energy price fluctuations might be geographically much more global than taxes and ETS. Thus, trading partners might be as much impacted by these fluctuations than domestic industry, a factor which is difficult to take into account in the analysis. Furthermore, an explicit carbon price signal may produce a different type of price signal to firms than a mere swing in energy prices. As a result, the use of energy prices as a proxy for environmental stringency or even a carbon tax is subject to criticism by some authors (Haultfoeuille et al., 2011; Davis and Kilian, 2011; Li et al., 2012; Rivers and Schaufele, 2012), who discuss the salience of carbon taxes. Their analyses show tax-induced price changes are more salient, or yield a distinct demand response when compared to equivalent market-determined price movements. Explanations for this phenomenon are that taxes tend to be more visible to consumers than equivalent price changes, or that taxes are expected to be of a more durable nature than mere price changes, increasing behavioural responses. At the same time, these studies discuss demand responses at the retail level. Thus, observations may not be entirely comparable to behavioural responses at production level.

replacing consumption with less energy-intensive products. Sato and Dechezleprêtre (2013) estimate the trade impact of a carbon tax at a 1% increase in imports and a similar decrease in exports.

6. Concluding remarks

This review analyses the limited literature available on the competitiveness effects of carbon prices and shows that, while carbon pricing induces firms to substantially abate emissions, their negative effects on competitiveness are limited at worst. *Ex post* evaluations have generally not been able to identify economically substantive effects of carbon prices that can be causally attributable the measures investigated. While the concern over competitiveness effects is often a major argument against the introduction of carbon prices, these results mean that carbon prices, at their current levels and design, can be introduced without hurting competitiveness – they do not say that carbon prices would never hurt competitiveness.

While a large constraint for *ex post* evaluations is often data availability, further evidence on carbon taxes and trading schemes will become available over time – both for existing schemes, as well as for newly introduced policies, such as in a carbon tax in Chile and the Chinese ETS. Evaluation of these schemes should be taken into account when designing policies in the future. Moreover, while the studies reviewed here mostly focus on short-term effects, longer-term data may increase possibilities to evaluate the dynamic effects of carbon prices as well.

At first sight, the results from this literature review put a question mark on the manifold exemptions and rebates which have been introduced alongside carbon prices for many firms and industries, to prevent competitiveness effects from emerging. However, the estimated competitiveness effects reviewed in this paper are in their great majority based on systems which feature exemptions or rebates. To ensure that these results hold in their absence, future research could focus on comparing the effects of carbon prices on firms paying the full rate of the carbon price to firms which are exempt or pay a rebate, controlling for structural differences between these two groups. To date, only three papers (Flues and Lutz (2015, forthcoming; Martin et al., 2014; Anger and Oberndorfer, 2008) take this approach. The larger share of auctioning of emissions permits under the EU ETS scheduled for the coming years, will increase the evidence-base on the competitiveness effects of carbon pricing schemes with fewer exemptions and rebates.

ANNEX I: OVERVIEW OF PAPERS, METHODS AND RESULTS

1. Impacts of carbon and energy taxes on indicators of competitiveness

Paper	Causal Effect of Interest	Sectoral coverage	Competitiveness Effects	Methodology	Findings	
					Environment	Competitiveness
Commins, Lyons, Schiffbauer & Tol (2009)	Impact of Energy taxes and the EU ETS on European firms (1996 – 2007)	Manufacturing[18]	TFP, employment, investment, return on capital	Panel regression using fixed effects.	Not investigated.	Marginal tax change leads to a small improvement in TFP growth, lower employment, an average increase in profitability and no change in investment levels. Results vary strongly across industries.
Martin, dePreux & Wagner (2014)	Impact of the UK Climate Change Levy (CCL) on manufacturing plants (2001 – 2004)	Manufacturing	Real gross output, employment and TFP	Diff-in-diff design comparing outcomes between plants subject to full CCL and those with an 80% discount both over time and between plants receiving different treatment. Exploit exogenous variation in eligibility rules for discounts an instrumental variable to remedy self-selection into the treatment group.	Being subject to the full CCL decreased energy intensity and electricity use resulting in lower CO_2 emissions	No significant results for the effect of the full CCL on energy expenditure, employment and TFP.
Rivers & Schaufele (2014)	Impact of carbon tax on international competitiveness of the agricultural sector in British Columbia (1990 – 2011)	Agriculture	Gross exports	Estimate whether introduction of the carbon tax has been associated with a measurable change in trade patterns (diff-in-diff design).	Not investigated.	Hardly any significant effects on gross exports or sector-specific effects. In the few cases where significant effects are found, results suggests that agricultural exports increased or imports decreases in conjunction with the carbon tax.
Flues, F., Lutz, B. (2015, forthcoming)	Impact of the German electricity tax on firms in the manufacturing sector (1999-2004)	Manufacturing	Turnover, investments, value-added, turnover abroad, employment	Investigate the competitiveness outcomes of firms paying a reduced marginal tax rate, compared to firms paying the full tax rate, using a regression-discontinuity design.	Not investigated.	No robust negative or positive competitiveness effect of the electricity tax reduction on manufacturing firms could be identified.

[18] More specifically, sectors investigated by Commins et al. (2009) are: office machinery, metal mining, electrical machinery, media, radio equipment, electricity & gas, motor vehicles, pulp & paper, medical instruments, other transport equipment, food processing, gas extraction, other manufacturing, refinery, basic metals, metal products, plastics, chemicals, wood products, other machinery, cement, quarrying, textiles, apparel, leather, tobacco, recycling

2. Impacts of the EU ETS on indicators of competitiveness

Paper	Causal Effect of Interest	Sectoral coverage	Competitiveness Effects	Methodology	Findings	
					Environment	Competitiveness
Anger & Oberndorfer (2008)	Impact of allocation factor[19] of EU ETS on competitiveness in Germany (2005)	Mining, electricity, energy, business, pulp & paper, coke & petroleum and other manufacturing	Revenue and employment change in 2005.	Matching + Regression analysis using instrumental variables (2SLS).	Not investigated.	No significant impact of relative allocation of EU emissions allowances on firm revenue development and employment.
Abrell, Ndoye Faye & Zachmann (2011)	Impact of EU ETS on firm competitiveness (2005-2008)	Non-metallic mineral products, electricity & heat, paper & paper products, basic metals, coke & refined petroleum products	Added value, profit margin, employment	Propensity score matching, exploiting the structural break between the first and the second phase of emissions (diff-in-diff approach).	EU ETS led to emissions reductions in its 2nd phase. Non-metallic metals and basic metals contributed most to this reduction while electricity and heat sectors did not at all.	EU ETS is found not to have an impact on firm added value, profit margin or employment.
Bushnell, Chong & Mansur (2013)	Impact of a sharp drop in CO_2 prices on the share price of affected firms(April 2006)	Firms traded on Dow Jones STOXX 600 index	Expected profitability	Event study	Not investigated.	Share prices of dirtiest industries experience the largest abnormal declines. Within the power sector, firms with highest emissions experience declines which are less severe than did cleaner firms.
Chan, Li, & Zhang (2013)	Impact of EU ETS and initial allocation of allowances on competitiveness (2001-2009)	Power, cement, iron and steel	Material costs, employment and revenue	Matching + diff-in-diff.	Not investigated.	No effects found for cement, iron and steel sectors. EU ETS has no effect on power plant employment, but increases unit material costs for power plants. Phase II participation in the EU ETS is found to have a positive effect on power plant turnover.
Petrick & Wagner (2014)	Impact of EU ETS on German manufacturing plants (1995 – 2010)	Manufacturing	Employment, gross output and exports.	Semi-parametric nearest neighbour matching + diff-in-diff.	ETS firms abate 26-28% more CO_2 emissions (2007 – 2010) relative to non-ETS firms. This is achieved improving energy efficiency, decreasing consumption of natural gas and petroleum products.	No evidence that emissions trading lowered employment, turnover or exports of treated firms.

[19] The allocation factor represents the allocation of EU emissions allowances relative to actual emissions. It is calculated as the quotient of allowances allocated to verified emissions.

Yu (2011)	Impact of EU ETS on Swedish firms (2004-2006)	Manufacturing (pulp, paper, paper product, chemicals and chemical products, other non-metallic products) and Electricity	Profitability	Diff-in-diff comparing firms that own regulated heating installations subject to EU ETS with non-participating firms.	Not investigated.	No significant impact of the EU ETS on profitability of Swedish firms in 2005, negative impacts on profitability in 2006.
Jaraité and Di Maria (2012)	Impact of the EU ETS on power generation sectors (1996-2007)	Power generation	Productivity growth	Panel regression with fixed effects.	CO_2 Price improves environmental efficiency. Over-allocation of emissions permits reduces improvements.	No significant effects of EU ETS on productivity growth.
Veith, Werner & Zimmermann, (2009)	Impact of EU ETS allowance price changes on stock prices (25 April 2007 – 31 August 2007)	Power generation (22 publicly traded power firms of EU 25)	Expected profitability	Apply asset pricing theory to capture the effect of the EU ETS on profitability using regression analysis.	Not investigated.	An increase in emission allowance price is correlated to an increase in the firm's share prices. Investors expect higher earnings in case of positive returns on carbon markets.
Zachmann & von Hirschausen (2008)	Impact of EU ETS on German electricity prices (2005 - 2006).	Power generation	Cost pass-through	Error Correction Model & Autoregressive Distributed Lag Model	Not investigated.	Asymmetric pass-through of EU emission allowance prices exist (i.e. rising prices have a stronger impact on wholesale electricity prices than falling prices).
Fabra & Reguant (2013)	Pass-through of emissions costs to electricity prices (January 2005 to February 2006).	Spanish wholesale electricity markets (micro-level firm data)	Cost pass-through	Regression analysis using an instrumental variables approach and fixed effects	Not investigated.	Emissions costs are fully passed through to electricity prices. Average pass-through is found to be at 80%. Pass-through is at 100% in peak times.
Kirat & Ahamada (2011)	Impact of EU ETS on electricity prices in France and Germany (July 2005 – June 2007).	Power generation	Cost pass-through	Regression analysis (feasible least squares).	Not investigated.	Impact of carbon price is found to depend on the country's energy mix. The highest correlation between electricity prices in Germany and France coincided with the highest carbon prices, while the collapse of the carbon price led to divergence of carbon prices.
Ahamada & Kirat (2012)	Impact of the EU ETS on wholesale electricity prices in France and (2008-2012)	Power generation	Cost pass-through	Regression Analysis	Not investigated.	The impact of the carbon price on electricity prices tripled in France and was multiplied by 1.5 in Germany in Phase II with respect to Phase I.

De Bruyn Markowska, de Jong & Bles (2010)	Impact of EU ETS on prices of manufacturing products (2005-2009)	Key products from refineries, iron and steel, chemicals	Cost pass-through	Vector Error Correction Model estimating the long- and short run dynamics of price differences between EU and US prices	Not investigated	For €1 cost increase in emissions allowances, €2.2 price increase will be passed into prices of hot rolled and cold rolled coils (full cost pass-through for iron and steel). Refineries have likely been able to pass through the full costs of their freely allocated allowances in prices. Full cost pass-through is also found for chemicals.
Alexeeva-Talebi (2010)	Impact of EU ETS on petrol retail prices in 14 EU member states (2005-2007)	Refineries	Cost pass-through	Vector Error Correction Model estimating the long- and short run dynamics of petrol prices. Variance decomposition allows uncovering heterogeneity of price dynamics between countries.	Not investigated	In 10 out of 15 countries, the refineries are found to pass-through 50% or more of crude oil price increases to consumers within two weeks. Variance decomposition indicates that carbon costs play a large role in explaining the variance of differences petrol prices in Austria, Germany, France and Spain (between 10% and 20% of variance).
Oberndorfer, Alexeeva-Talebi & Loschel (2010)	Impact of EU ETS allowance prices on prices of UK manufacturing products (weekly data: 2005-2007, monthly data, 2001-2007)	Selected products within refineries, glass, chemicals and ceramics	Cost pass-through	Autoregressive distributed lag model	Not investigated	Pass-through rates of 50% and 75% for diesel and gasoline over a 5 week span. For chemicals, pass-through rates > 100% are found for low density polyethylene film. Over 6 months, 20% to 25% pass-through is found for hollow glass, no pass-through is found for container glass, >100% pass-through for ceramic goods, 30-40% pass-through for ceramic bricks.
Costantini & Mazzanti (2012)	Impact of environmental and energy taxation and the EU ETS on exports of 14 European countries (1996-2007)	Sectors are classified into high-medium-high, medium-low and low-technology industries	Exports	2-stage estimation allows modelling the selection process of countries engaging in trade with each other to account for the large number of 0's (countries which do not trade), while estimating trade only for countries which actually engage in trade in the second stage.	Not investigated	Environmental and energy taxes are found to increase exports in high-technology sectors. Energy taxes are also increase exports in medium-low tech sectors. The EU ETS in found to have significant negative effects on all sectors.
Reinaud (2008)	Impact of EU ETS on net trade flows (1999-2007)	Aluminium	Net imports	Regression analysis	Not investigated	Negative correlation between CO_2 price and net imports and no evidence of a structural break in imports after the introduction of the EU ETS.

3. Impacts of energy price fluctuations on indicators of competitiveness

Paper	Causal Effect of Interest	Competitiveness Effects	Methodology	Findings
Aldy & Pizer (2011)	Analyse the effect of energy price variations between 1974 and 1994. Estimate and predict the effect of a USD15 per ton CO_2 price on that basis.	Difference between the effects of a CO_2 price on US manufacturing with US only regulation vs. a global CO_2 pricing regime. Measure effects on Energy Intensity, domestic supply, demand-supply, competitiveness effect as a share of the overall supply effect.	Exploit idiosyncratic, within-industry variation in energy prices and estimate a two-equation system of regressions.	A 10% increase in energy prices results in a 1 to 1.5% increase in net imports for manufacturing industries, with some ranging below 1% and some, particularly those industries with energy intensity above 10%, exceeding 1.5%.
Sato & Dechezleprêtre (2013)	Impact of historic asymmetries in industrial energy prices and bilateral trade patterns between 1991 and 2011	Bilateral trade	OLS with standard errors clustered at country-pair-sector level to control for unobserved heterogeneity. To investigate sector heterogeneity, the authors interact sector dummies with the energy price variable.	A 1% increase in the electricity price gap in associated with a 0.1 to 0.2% increase in imports. This effect is strongest for heavy manufacturing and smallest for primary sectors.

ANNEX II: METHODOLOGIES AND ASSOCIATED CAVEATS[20]

Ex post evaluation of taxes and ETS requires identification of the true causal effect of the impact of the given policies on firms, controlling for other influences or simultaneous developments. To achieve this, a baseline is needed against which changes can be evaluated. Of course it is not known how firms would have acted in the absence of a carbon price where one was introduced, whether the firms are subject to the policy or not.

At a given point in time, a firm will either be exposed to the programme or not. The only thing that can be estimated is the average impact of a programme on a group of firms ('treatment group') by comparing them to a similar group that was not exposed to the programme ('control group'). In reality, firms subject to a carbon price will most likely differ from those who are not. Any difference in outcomes between the treatment and the control groups then could be attributable to the programme or to pre-existing differences. The challenge is to separate these two potential sources of differences in outcomes, i.e. to correct for 'selection bias'.

One setting in which selection bias can be removed is when individuals or groups of individuals are randomly assigned to the treatment and control groups, but the selection of which firms are subject to carbon pricing is not random by policy design. For example, participation in the EU ETS is mandatory for firms exceeding certain capacity thresholds, so that EU ETS firms are larger than non-ETS firms. Other methods to address selection bias create control groups that are valid under a set of identifying assumptions. These identifying assumptions cannot always be tested directly and the validity of any particular study thus depends on how convincing they are.

One method to address selection bias is to account for *observable* firm characteristics, such as output, number of employees or location (zip code). This is sufficient if, conditional on these observable characteristics, the treatment can be considered to be randomly assigned. Methods to control for observables are non-parametric matching, propensity score matching and different types of regression analysis.[21] There are many ways in which the assumptions underlying this simple setup may fail. For simple regression analysis or matching to work, there can be no unobservable ('omitted') characteristics that differentiate the control group from the treatment group. If, after accounting for observables, there are other differences between treatment and control groups, matching and simple regression analysis will not yield consistent[22] results and the resulting effects of the policy will be biased.[23]

---

20 . This section draws on Angrist and Pischke (2009), and Duflo, Glennerster and Kremer (2006).

21 . Non-parametric matching means that the treatment effect is calculated as the weighted average of differences between the outcomes of the treatment and comparison groups formed by the various possible values of observable variables. With propensity score matching, matching can be implemented based on the probability of being assigned to the treatment group conditional on these observables. Regression analysis controls for all observable characteristics upon which selection into the treatment group has been performed.

22 . An estimator is consistent when the probability that it is in error tends to zero as the sample becomes larger. An estimator is inconsistent if its distribution does not become more concentrated around the true parameter value when the sample size increases.

One method to control for *unobservable* differences between treatment and control groups is difference-in-differences estimation, which compares differences in outcomes after and before the intervention of groups affected by the intervention, to the same difference for unaffected groups. Applied to the evaluation of the effect of a carbon tax on emissions, for example, one would observe the difference in emissions between firms who were subject to a carbon tax and those who were not, before and after its introduction. On the assumption that pre-tax trends in the emissions path would have continued for both groups, the excess reduction in emissions by the treatment group can be causally attributed to the policy (the 'treatment effect'). Whether or not difference-in-difference designs are convincing depends on whether the assumption of parallel evolution of the outcomes in the absence of treatment is convincing ('common trends assumption'). This assumption is testable only prior to the policy – if confirmed, it can be inferred that it also holds in later periods. In addition, in order to compare trends among groups it is necessary to have several data points over time.

Performing difference-in-difference analysis in a regression setting involves including fixed effects for the treatment and control group. Panel regression with Fixed Effects (FE) generalises difference-in-difference estimates when there is more than one time period or more than one treatment group. If the panel units contain an omitted variable that is fixed over time, the fixed components of the error can be subtracted, which leaves only the time-variant portion of the error in the model. While fixed effects can control for factors which are unobserved but constant over time, it is more difficult to control for shocks that asymmetrically affect treatment and control groups. In that case, the change that the asymmetric shock brought about will tend to be perceived as part of the treatment effect, since fixed effects estimation is only able to account for unobserved constant factors. When trying to estimate the effect of the introduction of a carbon price, it might be the case that one sector or one firm has unobserved characteristics which affect the outcome of the policy. When estimated, these unobserved factors will usually influence the outcome and researchers will be tempted to mistakenly interpret this influence as part of the policy. If these effects are specific to the sector or the firm, they are usually constant over time. Using sector or firm-level fixed effects, these factors can be controlled for.

Countries may have other environmental policies, such as renewable energy standards, or feed-in tariffs, which could influence policy outcomes in a range of ways and could distort policy evaluations. When the impact of taxes on specific variables is being assessed in a quasi-experimental setup, and if assumptions have been reasonably tested or convincingly argued, these confounders should be controlled for, and the effect estimated should be the clear effect of the policy on the dependent variable. Other environmental policies may indeed pose a problem in the case of the evaluation of bilateral trade relations, where absolute product prices will play a role for the strength of the competitiveness impact of carbon prices. Here, national policies can be controlled for via fixed effects, but this becomes more challenging the longer the time period and the larger the number of countries under scrutiny. This should be kept in mind when considering the results of research presented in this paper. Other policies will by definition influence the evaluation of the effects of energy price fluctuations on trade.

Establishing causality with reasonable confidence is easier with micro-data than with aggregated data. With aggregate data, impact estimation could be attempted by comparing outcomes between treated and untreated sectors. Identification of the causal impact of a policy then is challenging, since there are a number of factors that will distinguish treated from untreated sectors. In addition, macro-level shocks, such as changes in energy price or a financial crisis, which decrease emissions, might accidentally be counted as treatment impacts if they are not adequately controlled for. Firm-level micro data makes it easier to credibly identify the causal effect of a policy, since treatment status can be measured more accurately. For

23. Bias refers to how far the average point estimate lies from the true population parameter. A point estimator is unbiased if, on average, it hits the true parameter value.

example, using firm-level data, there is more variability to exploit in order to distinguish between treated (ETS) and untreated (non-ETS) firms within one sector.

Of course, challenges remain: EU ETS participation is mandatory for all combustion installations with a thermal input of 20 kW or more. Industrial plants are regulated if they specialise in certain activities and exceed specific capacity thresholds. It is thus by definition impossible to match EU ETS participating firms to non-ETS firms, since EU ETS firms will always be larger than non-ETS firms. In contrast, precise estimation of the effect of the EU ETS requires that treated firms under the EU ETS are not systematically different from non-ETS firms which are matched to them ('common support') after controlling for observables. Since this assumption cannot be directly tested, it has to be argued whether it likely holds or not. When different treatment groups of firms are separated from each other via an externally imposed threshold (e.g. a certain amount of energy use), this discontinuity can be exploited by analysing firms just below or beyond the threshold. The underlying reasoning is that – other than being separated by the threshold - these firms will have very similar characteristics. In this case it is essential that firms cannot manipulate their belonging to the treatment or control group, so that assignment is still random.

Lastly, unbiased estimation requires that the effect of the EU ETS for firms subject to the policy do not spill-over to firms that do not participate and are part of the control group (the 'stable unit treatment value assumption'). A carbon price likely affects the whole economy, since, for example, higher electricity prices will translate into higher input prices for the manufacturing sector. As an indirect result of the EU ETS, the manufacturing sector might thus undertake some abatement, which would qualify as a spill-over. Even at a micro-level, if firms used to construct the control group are affected by these spill-overs, the effect of the EU ETS on emissions will also include these spill-overs. As a result, the estimate of the effect of the EU ETS will be biased. Although differential effects between groups can still be identified in the presence of spill-overs, the treatment effect will likely appear to be smaller as a result.

REFERENCES

Abrell, J., A. Ndoye Faye and G. Zachmann (2011), "Assessing the impact of the EU ETS using firm level data", *Bruegel Working Paper* 2011/08, Bruegel, Brussels.

Adams, J. (1997), "Environmental Policy and Competitiveness in a Globalised Economy: Conceptual Issues and a Review of the Empirical Evidence", in OECD (1997), "*Globalisation and Environment – Preliminary Perspectives"*, *OECD Proceedings*, OECD, Paris.

Alexeeva-Talebi, V. (2010), "Cost Pass-Through of the EU Emissions Allowances: Examining the European Petroleum Markets", *ZEW Discussion Paper No. 10-086*, ZEW, Mannheim.

Ahamada, I. and D. Kirat (2012), "The impact of Phase II of the EU ETS on the electricity generation sector", *Documents du travail du Centre d'Economie de la Sorbonne*, Paris.

Albrizio, S., T. Koźluk and V. Zipperer (2014), "Empirical Evidence on the Effects of Environmental Policy Stringency on Productivity Growth", *OECD Economics Department Working Papers*, No. 1179, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/5jxrjnb36b40-en.

Andersen, M.S., et al. (eds.) (2007): Competitiveness Effects of Environmental Tax Reforms (COMETR). *Final report to the European Commission, DG Research and DG TAXUD. National Environmental Research institute, University of Aarhus, 111 pp*. www.dmu.dk/Pub/COMETR_Final_Report.pdf .

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

Angrist, J. D. and J.-S. Pischke (2009), "Mostly harmless econometrics: an empiricist's companion." *Princeton University Press, 2009.*

Aldy, W.A. and J.E.Pizer (2011), "The Competitiveness Impacts of Climate Change Mitigation Policies." *NBER Working Paper 17705*, National Bureau of Economic Research, Massachusetts.

Civitelli, F. (2015), "Firm competitiveness and the EU Emission Trading System: The case of Italy." Bocconi University, Milan, *forthcoming*.

Commins, N., et al. (2009), "Climate Policy and Corporate Behaviour", *ESRI Working Paper, No. 329.*

Bosquet, B. (2000),"Environmental tax reform: does it work? A survey of the empirical evidence.", *Ecological Economics* 34 (2000) 19-32.

Bushnell, J. B., H. Chong and Mansur (2013), "Profiting from Regulation: Evidence from the EU Evidence form the European Carbon Market", *American Economic Journal: Economic Policy*, 5(4): 78-106.

Chan, H. S., Li, S., Zhang, F. (2013), "Firm Competitiveness and the European Union Emissions Trading Scheme", *Energy Policy* 63 (December 2013), 1056 – 1064.

Condon, M. and A. Ignaciuk (2013), "Border Carbon Adjustment and International Trade: A Literature Review", *OECD Trade and Environment Working Papers*, 2013/06, OECD Publishing. DOI: http://dx.doi.org/10.1787/5k3xn25b386c-en.

Cooper, R. (2010), "Europe's emissions trading system", *Harvard Project on International Climate Agreements Discussion Paper*, 10-40, Harvard University, Boston.

Davis, L.W. and L. Kilian (2011), "Estimating the effect of a gasoline tax on carbon emissions", *Journal of Applied Econometrics* (26), pp. 1187 – 1214.

De Bruyn, S., et al. (2010), "*Does the energy intensive industry obtain windfall profits through the EU ETS? An econometric analysis for products from the refineries, iron and steel and chemical sectors*", CE Delft, Delft.

Demailly, D. and P. Quirion (2008), "European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry", *Energy Economics*, Issue 4, July 2008, pp. 2009-2027.

Duflo, E., R. Glennerster and M. Kremer (2006), "Using Randomization in Development Economics Research: A Toolkit", *NBER Technical Working Paper No. 333*, National Bureau of Economic Research, Massachusetts.

Durrmeyer I., P. Février and X. D'Haultfoeuille (2011), « Le coût du bonus/malus écologique : que pouvait-on prédire ? », *Revue Économique, 62 (3)*, pp. 491-500.

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

Ekins P., and S. Speck (2012), "Impact on competitiveness: what do we know from modelling?", in Milne. J.E. and M. S. Andersen (eds.) (2012) *Handbook of Research on Environmental Taxation*, Edward Elgar Publishing Limited, Cheltenham/Massachusetts.

Ellermann, A. D. and B.K. Buchner (2008), "Over-allocation or abatement? A preliminary anaylsis of the EU ETS based on the 2005-2006 emissions data", *Environmental and Resource Economics*, 41(2), 267-287.

Ellermann, A. D. and B.K. Buchner (2007), "The European Emissions Trading Scheme: Origins, Allocation and early results", *Review of Environmental Economics and Policy*, 1 (1), 66-87.

Ellermann, A.D., F.J. Convery and C. dePerthuis (2010), "Pricing Carbon: The European Union Emissions Trading Scheme." *Cambridge University Press*, Cambridge.

Ellermann, A.D. and S.M. Feilhauer (2008), "A top-down and bottom-up look at emissions abatement in Germany in response to the EU ETS." *Working Paper*, MIT Center for Energy and Environmental Policy Research, Massachusetts.

Fabra, N. and M. Reguant (2013), "Pass-through of emissions costs in electricity markets", *NBER Working Paper 19613*, National Bureau of Economic Research, Massachusetts.

Fitz Gerald, J. and S.Scott, (2007), "The market: structure and sector vulnerability", in Andersen, M.S. et al. (2007) *Competitiveness Effects of Environmental Tax Reforms (COMETR)*, Publishable Final Report to the European Commission, DG Research and DG TAXUD, Brussels.

Flues, F. and B. Lutz (2015, forthcoming): "Competitiveness Effects of the German Electricity Tax", *OECD Environment Working Paper*, OECD Publishing, Paris.

Harrison, K. (2013): "The Political Economy of British Columbia's Carbon Tax". *OECD Environment Working Papers*, No. 63, OECD Publishing, Paris. http://dx.doi.org/10.1787/5k3z04gkkhkg-en.

Jaffe, A., et al. (1995), "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What does the Evidence tell us?" *Journal of Economic Literature* Vol. 33 (March 1995), pp. 132-163.

Jaraité, J. and C. Di Maria (2012), "Efficiency, productivity and environmental policy: A case study of power generation in the EU", *Energy Economics 34 (2012) 1557-1568*.

Kettner, C., D. Kletzan-Slamanig and A. Koeppl (2011), "The impact of the European Union Emissions Trading Scheme on the Electricity Generation Sector", *Energy Economics*, 33(5), 995-1003.

Kirat, D. and I. Ahamada (2011), "The impact of the European Union emission trading scheme on the electricity-generation sector", *Energy Economics* 22 (2011) 995-1003.

Levinson, A. and M. S. Taylor (2008), "Unmasking the pollution haven effect", *International Economic Review* Vol. 49, No. 1, February 2008

Martin, R., L. dePreux and U. Wagner (2014), "The impacts of a carbon tax on manufacturing: Evidence from microdata", *Journal of Public Economics* 117 (2014), 1-14.

Martin, R., M. Muûls and U. Wagner (2013), "Impact of the EU ETS on Regulated Firms: What is the Evidence after Eight Years?" Draft prepared for a symposium issue of the *Review of Environmental Economics and Policy*.

McGuiness, M. and A.D. Ellermann (2008), "CO_2 abatement in the power sector: Evidence from the EU ETS trial period", *MIT Centre for Energy and Environmental Economics Working Paper No. 810*, Massachusetts.

Mokinski, F. and N. Woelfing (2014), "The effect of regulatory scrutiny: Asymmetric cost pass-through in power wholesale and its end", *Journal of Regulatory Economics* 45: 175 – 193.

Oberndorfer, U. (2012), "EU Emission Allowances and the stock marker: Evidence from the electricity industry", *Ecological Economics* 68, pp. 1116 – 1126.

Oberndorfer, U., V. Alexeeva-Talebi and A. Loeschel (2010), "Understanding the competitiveness implications of future phases of EU ETS on the industrial sectors", *ZEW Discussion Papers No. 10-044*, ZEW, Mannheim.

Oberndorfer, U., K. Rennings and B. Sahin (2006), "The impacts of the European Emissions Trading Scheme on Competitiveness and Employment in Europe – a Literature Review", *ZEW*, Mannheim.

OECD (2011), *Towards Green Growth*, OECD Green Growth Studies, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264111318-en.

OECD (2010), *Globalisation, Transport and the Environment*, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264072916-en.

OECD (2004), "*Glossary of statistical terms – Environmentally related taxes*", https://stats.oecd.org/glossary/detail.asp?ID=6270.

OECD (2001), *Environmentally Related Taxes in OECD Countries: Issues and Strategies*, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264193659-en.

Pearce, D.W. (2006), "The political economy of an energy tax: The United Kingdom's Climate Change Levy", *Energy Economics 28 (2008) 149 – 158.*

Pearce, D.W. (2004), "The United Kingdom Climate Change Levy: A Study in Political Economy", *OECD Papers*, Vol. 5/5. http://dx.doi.org/10.1787/oecd_papers-v5-art19-en.

Petrick, S. and U. Wagner (2014), "The Impact of Carbon Trading on Industry: Evidence from German Manufacturing Firms", *Kiel Working Paper No. 1912*, Kiel Institute for the World Economy, Kiel.

Porter, M.E., van der Linde, C. (1995), „Toward a New Conception of the Environment- Competitiveness Relationship", Journal of Economic Perspectives 9, pp. 97 – 118.

Rademaekers, K. et al. (2011), "Competitiveness of the EU Non-ferrous Metals Industries. *Final Report prepared for the European Commission*, Directorate-General Enterprise and Industry. http://ec.europa.eu/enterprise/sectors/metals-minerals/files/fn97624_nfm_final_report_5_april_en.pdf.

RBB Economics (2014), "Cost pass-through: theory, measurement, and potential policy implications – A report prepared for the Office of Fair Trading", RBB Economics, London. www.gov.uk/government/uploads/system/uploads/attachment_data/file/320912/Cost_Pass-Through_Report.pdf.

Renda, A. et al. (2013), "Assessment of Cumulative Cost Impact for the Steel Industry", *Final report prepared for the European Commission*, Centre for European Policy Studies, Brussels http://ec.europa.eu/enterprise/sectors/metals-minerals/steel/index_en.htm.

Rivers, N. and B. Schaufele (2014), "The Effect of Carbon Taxes on Agricultural Trade". *Canadian Journal of Agricultural Economics 00 (2014)*, 1-23.

Rivers, N. and B. Schaufele (2012), "Carbon Tax Salience and Gasoline Demand", *Working Paper No. 1211E*, Department of Economics, University of Ottawa.

Sato, M. and A. Dechezleprêtre (2014), "The impacts of environmental regulations on competitiveness", *Policy Brief*, Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science.

Sato, M. and A. Dechezleprêtre (2013), "Asymmetric industrial energy prices and international trade", *Working Paper*, Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science.

Sijm, J., Y. Chen and F. Hobbs (2009), "The impact of power market structure on the pass-through of CO_2 emissions trading costs to electricity prices – A theoretical approach", *Paper presented at the 17th Annual Conference of the European Association of Environmental and Resource Economics* (EAERE, Amsterdam, June 24-27, 2009).

Sijm, J., K. Neuhoff and Chen (2006), "CO_2 cost pass-through and windfall profits in the power sector", *Climate Policy, 6:1, 49-72.*

Veith, S., J.R. Werner and J. Zimmermann (2009), "Capital market response to emission rights returns: Evidence from the European power sector", *Energy Economics*, 31 (2009) 605-613.

Withana, S., et al. (2013): *Evaluation of environmental tax reforms: International experiences.* A report by the Institute for European Environmental Policy (IEEP) for the State Secretariat for Economic Affairs (SECO) and the Federal Finance Administration (FFA) of Switzerland. Final Report, Brussels.

Yu, H. (2011), "The EU ETS and firm profits: An ex-post analysis for Swedish energy firms", *Working Paper 2011:2*, Department of Economics, Uppsala University.

Zachmann, G. and C. von Hirschausen (2008), "First evidence of asymmetric cost pass-through of EU emissions allowances: Examining wholesale electricity prices in Germany", *Economics Letters*, 99 (2009) 465-469.