**Carbon Pricing and Competitiveness: Are they at Odds?**

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Abstract

This paper reviews ex-post empirical assessments on the impact of carbon pricing on competitiveness in OECD and G20 countries, primarily in the European Union, in the electricity and industrial sectors. Most of these assessments find no statistically significant effects of carbon pricing or energy prices on different dimensions of competitiveness, including net imports, foreign direct investments, turnover, value added, employment, profits, productivity, and innovation. When statistically significant results have been found, the magnitude of such effects tends to be small - either positive or negative. Thus, concerns about negative short-term effects of carbon pricing on firms’ or sectors’ international competitiveness have not come to pass, at least to date. These findings are in part because carbon price levels have been low and because of exemptions to carbon taxes for industry, or generous levels of free allowances to firms covered by emissions trading schemes.

Key policy insights

* Most of the studies reviewed in this paper find no statistically significant effects of carbon pricing or energy price fluctuations on different dimensions of competitiveness (employment, profits, net imports).
* When statistically significant results have been found, the magnitude of such effects is small. This is not surprising, because long term trends in overall energy costs have a small effect compared to other trends. Moreover, carbon costs levied on industry have been low, either because of carbon tax breaks or free allowances to firms.
* Carbon pricing has a small and positive effect on productivity and innovation. In particular, all studies report statistically significant increases in patenting.
* On the contrary, studies that find small negative competitiveness effects tend to focus on net imports and outward foreign direct investment.
* Establishing a positive and stable carbon price (even if initially at a low level) will provide a clear signal of policy directions for participating firms. This may actually reduce risks to competitiveness in the longer-term if it incentivises firms to adopt advanced pollution abatement technologies in an increasingly carbon-constraint global economy.

Keywords: Environmental regulation; Carbon pricing; Competitiveness; Carbon Markets

JEL Classification: H23, Q54, Q56, Q58

# Introduction

Competitiveness refers to the capability of countries’ economic sectors or firms to maintain market shares, to stay in business and to be profitable(Berger, 2008[1])**.** The deep decarbonisation needed in order to reach the temperature goals of the Paris Agreement means that the relative competitiveness of sectors may need to change over time, with low-emission sectors gaining market share and higher-emission sectors losing market share or perhaps even ceasing to exist. The environmental impact of changes in relative competitiveness can be positive if these lead to lower-emission products gaining market share. Alternatively, changes in relative competitiveness can lead to negative side-effects on greenhouse gas (GHG) emission levels if the changes encourage a shift in the production of goods to areas with lower efficiency (i.e. using more polluting technologies). This negative impact is referred to as “carbon leakage”. Some emissions trading systems (ETS) are explicitly designed to avoid carbon leakage (Nachtigall, 2019[2]).[[1]](#footnote-1)

There are many aspects to competitiveness: temporal, sectoral, domestic and international. Depending on the specific market structure and context, some of the following may be more or less important factors that are internal to a given industry or firm: turnover, total assets, investment, employment, technology, productivity and profits, levels of exports, levels of foreign direct investment, and levels of innovation.

Competitiveness of a country, sector and/or firm will also be affected by many external factors. These include megatrends, such as increased vehicle electrification, as well as trends in the costs of producing a specific product, such as changes in commodity prices. Carbon pricing is another such external factor. While it is an efficient policy mechanism to reduce GHG emissions (OECD, 2018[3]), carbon pricing can increase production costs both directly, e.g. by imposing a carbon tax or by requiring a firm to purchase emissions allowances, and indirectly, e.g. by increasing the costs of inputs such as electricity. Carbon pricing thus has the potential to impact the relative competitiveness of a country, sector or firm. This paper uses “carbon pricing” to refer to GHG emissions trading schemes (ETS), carbon taxes, or taxes on fossil fuels.

This paper reviews the extent of carbon pricing in OECD and G20 countries, and explores its impact on different dimensions of competitiveness in the electricity and industrial sectors. We cover three types of policies which make emitting GHG more expensive at the margin: emissions trading schemes, carbon taxes and energy taxes. Existing studies are either ex ante (e.g. Carbone and Rivers’ (2017[17]), have reviewed the literature on the impact of a range of environmental policies on competitiveness, (e.g. Dechezleprêtre and Sato, 2017), or have reviewed the impact on competitiveness of the emissions trading scheme in the European Union (EU ETS), (e.g. Martin, Muûls and Wagner (2016) and Verde (2018), Joltreau and Sommerfeld (2019)). This paper focuses on the impact – as assessed ex post - of carbon prices (ETS and taxes, but without non-pricing policies), drawing on experience from a broader set of jurisdictions. Yet, the EU ETS clearly dominates the literature on carbon pricing, accounting for 27 studies or 65% of reviewed studies in this paper. This is because it is the largest and earliest experience and its design has made causal inference easier. However, to the best of our knowledge, we include all ex-post studies published during the last decade, on carbon taxes, energy taxes and non-EU emission trading systems. We also include the main studies that use energy price as a proxy for carbon pricing.

# The extent of carbon pricing in OECD and G20 countries

The extent of carbon pricing has increased over the last few years, and includes some coverage of trade-exposed sectors, see e.g. (OECD, 2018[3]; World Bank and Ecofys, 2018[4]). Figure 1 depicts selected ETS in operation in OECD and G20 countries. It highlights growth in the number of ETS, as well as the difference in their carbon prices at selected points in time, which vary significantly both in absolute and relative terms. For example, prices in the EU ETS were just over 10 USD/t CO2 in November 2012[[2]](#footnote-2), dropped to under 6 USD/t CO2 in 2013, and rose to more than 21 USD/t CO2 in November 2018. In terms of relative carbon prices, EU ETS prices were more than double those of the Guangdong ETS in November 2014, but were almost ten times those of the Guangdong ETS in November 2018.

Figure : Carbon prices of selected ETS at selected points in time (USD/t CO2-eq)



Source: Authors, based on ICAP price monitor

However, the effective costs of GHG emissions from trade-exposed sectors can be much lower than the overall carbon price shown in Figure 1 above. For example, free allowances are distributed to sectors at risk of a loss of competitiveness in the Californian ETS. In the EU ETS, sectors deemed at risk of competitiveness loss also receive free allowances. Since 2013, the level of free allowances in the EU ETS has been based on past production levels and product-specific carbon intensity benchmarks representing the 10% most carbon-efficient firms in each sector.[[3]](#footnote-3)

Indeed, Figure 2 shows that some non-electricity sectors in the EU ETS (e.g. cement, paper or cardboard) received more free allowances than their emissions until 2013. Since 2013, some sectors such as lime, aluminium, ceramics and glass have become net buyers of allowances. The method for calculating the level of free allowances should in theory lead to aggregate allocation below emissions for each sector. However, this is not observed for two reasons. Firstly, free allocation was based on previous production volumes, including the years before the economic crisis of 2008 (so the Historical Activity Level between 2005 and 2010 determined free allocation in the period 2012-2020).[[4]](#footnote-4) This updating of free allowances creates an incentive for higher production volumes (Böhringer and Lange 2005). Secondly, carbon intensities have decreased over time, due to technology improvements. In order to reflect the technological improvement, allocation benchmarks will be updated from 2021 onwards, reducing the number of allocated emissions per unit of output.

The level of carbon taxes levied on industry is also low or zero in the majority of cases. This is because while some countries have put carbon taxes in place, there are many exemptions for industrial sources.[[5]](#footnote-5) The same holds true for excise taxes on fossil fuels which can be considered as implicit carbon taxes. Thus, overall in OECD and G20 countries, almost two-thirds of industrial GHG emissions are unpriced, and only 2% are priced at 30 EUR/t CO2 or higher (Figure 3). The largest part of the carbon price in the industry sector stems from energy taxes (OECD, 2019). In the electricity sector of the same set of countries, however, ETS contribute to the largest part of the carbon price (OECD, 2018[3]).

Figure : Allocation factors calculated as the ratio of free allocations over verified emissions for the main subsectors in the EU ETS



Source: CITL in EEA data viewer

# How does carbon pricing affect firms’ competitiveness?

Competitiveness effects from environmental regulation are mainly due to *differences* in regulation between sectors or countries rather than to the regulation itself. Dechezleprêtre and Sato (2017[5]) distinguish, first, second and third order effects resulting from differences in regulations. Asymmetric environmental policy induces differences in costs as a first order effect. Next, firms respond to the regulation by adapting volumes, product prices (e.g. via cost pass through) and productive investments (second-order effects). These firm responses in turn affect broader economic outcomes (profits, employment, market structures), technological outcomes (product innovation, process innovation, input-saving technologies) and international economic outcomes (trade flows, investment location), leading to third-order effects. It is important to note that many outcomes are interrelated. For example, input-saving innovation may decrease the cost of abatement, a change in profitability will affect investments, higher prices may affect the strategic positioning of the firm etc.

Figure : Proportion of OECD and G20 industrial and electricity CO2 emissions priced at different levels in 2015

The price includes emissions trading, carbon taxes and energy taxes.

Source: (OECD, 2018[3])

## First-order effects

Differences in costs caused by environmental regulation, e.g. via carbon pricing, represent a first-order effect on competitiveness. These first-order effects are potentially large, because energy costs for heavy industry (traditionally met by GHG-intensive energy sources) can represent a large proportion of total production costs. Such first-order effects include GHG abatement costs and direct carbon costs represented in Figure 4. Companies in an unregulated region will have a competitive advantage because they do not have these costs.

Figure 4: Abatement costs and the cost of buying or selling allowances for a firm

Figure 4A: Free allowances are lower than BAU emissions.

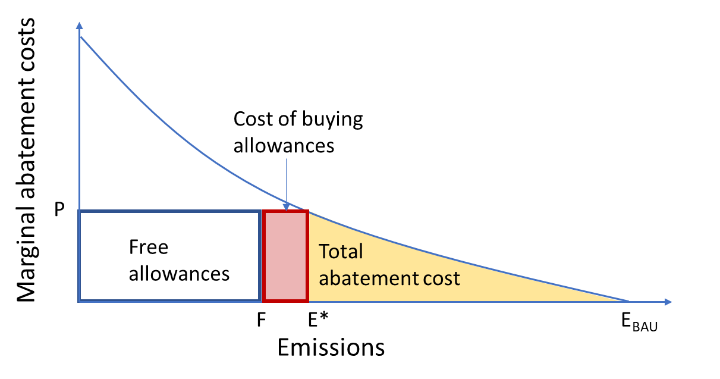
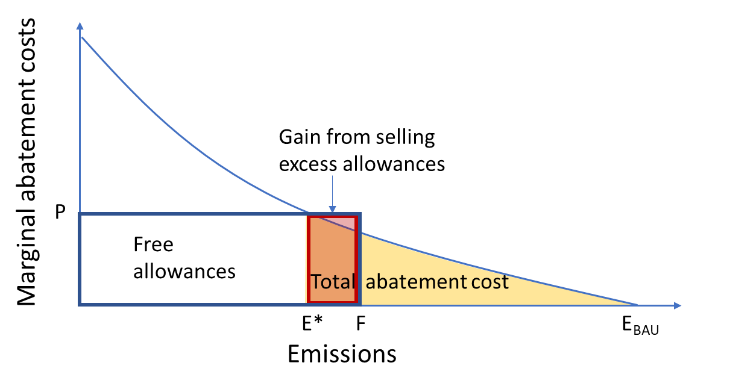


Figure 4B: Free allowances exceed emissions. 

Note: The marginal abatement cost function ranks abatement opportunities from most expensive (close to zero emissions) to least expensive (close to business-as-usual emissions, BAU). P is the market price for allowances, E\* represents the cost-minimising emission level for the firm, whereas F represents the level of free allowances. E\* depends on the aggregate emissions cap. The yellow zone represents the total abatement costs, the blue zone the market value of free allowances (P x F) and the red zone the cost of buying allowances (Fig. 4A) or gain from selling excess allowances (Fig 4B). If there are no free allowances, e.g. in the case of a carbon tax without exemptions or auctioned ETS, the cost of buying allowances, i.e. the red area, expands to include the blue area.

Source: Authors

There are a wide variety of possible GHG abatement opportunities and costs; these vary between and within sectors. For example, firms can invest in energy efficiency, switch to lower-carbon fuels, or substitute other inputs. The marginal abatement cost function represented in Figure 4 expresses the idea that when a company is close to business as usual emissions, reducing emissions tends to be cheap. But further emission reductions will come at a higher cost. Studies find that the EU ETS reduced emissions by around 10%, corresponding to 200 mt CO2 /year (Martin, Muûls and Wagner, 2016[8]). This indicates that the total abatement costs for at least certain firms were non-negligible.

Under a carbon price, firms have an incentive to avoid those emissions that can be abated at a cost below the carbon price. This is also the case when firms receive free allocation above their emissions, because every abated tonne of CO2 allows firms to sell an extra allowance. In other words, allocations create an opportunity cost which is the same for under- as well as over-allocated firms. Therefore, as a first approximation, free allocation does not affect the incentive for abatement (Coase, 1960[6]). Venmans (2016[7]) shows, however, that firms perceive an allocation below actual emissions as a stronger incentive to abate compared to an allocation above emissions.[[6]](#footnote-6)

Direct carbon costs occur if firms covered by emissions trading schemes receive fewer free allowances than their emissions and would therefore need to buy emissions allowances as shown in Figure 4. These costs can be large. As outlined above, all ETS whose coverage includes trade-exposed and carbon-intensive firms, apply a significant level of free allocation of allowances to such firms. This limits their direct carbon costs. Figure 2 highlights that the level of free allocation in the EU ETS exceeded 100% for some sectors in some years. In these cases, the EU ETS may have provided a direct *benefit* to participating firms, if the value of these excess allowances is larger than their total abatement costs.

Carbon prices in ETS can vary considerably over time, as shown in Figure 1. This price volatility has different effects and can create an incentive to invest or a disincentive to invest (Venmans, 2016).[[7]](#footnote-7) In general, moderate price volatility creates an incentive to invest, while extreme volatility is detrimental to investment.

Carbon taxes create a similar abatement incentive as an ETS without free allowances and a foreseeable cost. Energy taxes have the same effect as carbon taxes, although they often create a different implicit carbon price for different fuels.[[8]](#footnote-8)

As the carbon intensity of producing different outputs varies, so does their direct carbon cost (EUR/t output). Table 1 highlights the carbon intensity and direct carbon costs for a selection of outputs, assuming a fully auctioned price of 30 EUR/t CO2. Carbon intensities correspond to the current product benchmarks in the EU ETS, estimated to be the carbon intensity of the 10% most carbon efficient plants. They include direct CO2 or other GHG emissions (“scope 1”), not the indirect emissions from electricity production (“scope 2”).

**Table 1: Carbon intensities and direct carbon costs for selected products in the EU ETS (assuming a fully auctioned price of 30 EUR/t CO2eq)**

|  |  |  |
| --- | --- | --- |
| Product name | GHG intensity (tCO2eqper tonne of product) | Direct carbon cost (EUR per tonne of product) |
| Ammonia | 1.619 | 49 |
| Aluminium | 1.514 | 45 |
| Hot metal (liquid iron) | 1.328 | 40 |
| Lime | 0.954 | 29 |
| Grey cement clinker | 0.766 | 23 |
| Fine paper | 0.318 | 10 |
| Nitric acid | 0.302 | 9 |
| Coke | 0.286 | 9 |
| Uncoated carton board | 0.237 | 7 |
| Sintered ore | 0.171 | 5 |
| Roof tiles | 0.144 | 4 |
| Long fibre kraft pulp | 0.06 | 2 |
| Plaster | 0.048 | 1 |

Source: European Commission (2011[9]), Decision 2011/278/EU determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council

## Second-order effects

Second-order competitiveness effects include the pricing or output responses by firms who are affected by direct carbon pricing. For example, firms with little international competition can pass through abatement costs and the costs of purchasing any emission allowances to the final consumer. Cost-pass through can exceed 100% of real costs, because free allowances induce opportunity costs, which are part of marginal costs and can be included in sales prices. This led to large windfall profits in the electricity sector in the ETS, which received free allocations between 2005 and 2012 (Sijm et al., 2008[10]).

Such actions can impact the costs, and therefore competitiveness, of firms in downstream sectors. For example, cost pass-through by electricity generators increases costs for other industrial producers. Such cost rises will be particularly significant for large electricity consumers such as the aluminium sector.[[9]](#footnote-9) The EU ETS provides the possibility for member states to compensate electricity-intensive producers. The EU ETS State Aid Guidelines lay out criteria for Member States to compensate for the rise of indirect costs for electricity-intensive industries to prevent significant risk of carbon leakage while minimizing the competition distortion in the internal market (European Commission, 2012[11]). The Guidelines determine eligible sectors[[10]](#footnote-10) and maximum amounts for compensation of indirect carbon costs. The maximum amount of aid is decreasing over time and depends on the CO2 emissions factor (tCO2/MWh), the CO2 price in the EU ETS, the product-specific electricity consumption efficiency benchmark and the output of the eligible installation. As of 2018, the Commission had approved 12 compensation schemes in 11 Member States, including France, Germany, Spain and the United Kingdom (European Commission, 2018[12]). The aggregate compensation in 2017 amounted to EUR 694 million, benefiting primarily the chemical, non-ferrous metal, and iron and steel sectors.

On the other hand, firms in sectors with strong international competition (such as some heavy industries) will not fully pass through carbon costs, because an increase in sales prices will impact sales volumes.[[11]](#footnote-11) The direct and indirect pass-through costs are important for assessing the potential competitiveness impacts of sectors. Figure 5 highlights the variation between selected sub-sectors for value at stake and trade intensity. Sectors with a high value at stake, i.e. the ratio between carbon costs and value added, and/or a high trade intensity are vulnerable to competitiveness impacts due to carbon pricing. The EU applies free allocation to sectors that have a 1) value at stake above 30% or 2) trade openness[[12]](#footnote-12) above 30% or 3) value at stake above 5% and trade openness above 10%. There is however disagreement over the relevance of these criteria, because carbon-intensive firms with low trade openness are better able to pass through costs (Clò, 2010[13]). In fact, the challenge to accurately quantify sector’s ability to pass through carbon costs is one of the main barrier to allocate free allowances efficiently (Verde et al., 2019).

Figure : Value at stake vs trade intensity for selected sectors



Source: Authors

## Third-order effects

Third-order competitiveness effects include broader economic outcomes, technological outcomes, and international outcomes. These are typically more complex to assess as they can be affected by more than one second-order effect from more than one jurisdiction, which can interact in different and potentially unpredictable ways. For example, increasing energy costs can impact employment via two channels. On the one hand, increasing production costs may lead firms to raise product prices, resulting in lower product demand and thus lower levels of employment. On the other hand, abating emissions may increase the demand for labour relative to business as usual.

Technological outcomes, in particular those driven by innovation, are potentially important as they can increase the competitiveness of firms in the long run. Theoretical literature argues that there are many barriers to product innovation, including behavioural and organisational barriers, and that environmental regulation can help to overcome them (Ambec, Cohen and Elgie, 2013[14]). Porter and van der Linde (1995[15]) hypothesise (“Porter Hypothesis”) that “internationally competitive firms are not those with the cheapest inputs or the largest scale, but those with the capacity to improve and innovate continually”. The five potential channels through which environmental regulation can improve competitiveness have been identified by Porter and van der Linde (1995) as:

* Signalling to firms about likely resource inefficiencies;
* Focussing on information gathering and raising corporate awareness;
* Reducing uncertainty that green investments will be valuable;
* Creating pressure which promotes innovation and progress;
* Levelling the transitional playing field.

However, evidence to support this hypothesis is inconclusive. For example, Cohen and Tubb (2018[16]) did a meta-analysis on 103 studies with quantitative results. They found that 45% of these studies report results that are insignificant, 29% report positive results, and 26% report negative results. Dechezleprêtre and Sato (2017[5])’s review of the relevant literature also argues that there is no convincing empirical evidence for a significant increase of competitiveness caused by environmental regulation.

# Empirical evidence of competitiveness impacts from carbon pricing

Most ex-post empirical studies find no statistically significant effects of carbon pricing or energy prices on different dimensions of competitiveness. This is in contrast to the result of many ex-ante simulations which predict the effect of unilateral carbon prices on competitiveness based on economic modelling (Carbone and Rivers, 2017[17]). Ex ante studies typically find negative impacts of diverging carbon prices, notably for energy-intensive trade-exposed (EITE) sectors. This section reviews the results of ex-post studies on key economic variables, i.e. the third-order effects mentioned above: trade; foreign direct investment; employment; turnover; value added; assets; investment; productivity; profits and innovation. As competitiveness is a multi-dimensional concept, it is most appropriate to assess competitiveness using multiple indicators. Most of the competitiveness dimensions are relatively straightforward to measure (e.g. turnover and value added; net imports as proxy for trade; number of jobs as proxy for employment). Yet, others are not as clear cut. For example, innovation could be measured by number of patents or by levels of research and development. Most studies measure innovation using the number of low-carbon patents, implicitly assuming equal weighting of all patents and not accounting for ‘disruptive’ patents, which trigger faster technological change than others

## International outcomes: Net imports and Foreign Direct Investments

Trade patterns measured through net imports are the most direct way to investigate international competitiveness effects and carbon leakage. Both relocation of firms abroad and the gain of market share of foreign firms at the expense of regulated domestic firms would lead to an observable change in the import/export ratio of carbon intensive goods.

Several studies have examined the effects of emissions trading on net imports, but have not found any. Most studies have focussed on the EU ETS. This includes a study analysing trade from and to 66 world regions, for 25 manufacturing sectors in 2004 (before the introduction of the EU ETS), 2007 and 2011 (Naegele and Zaklan, 2019[18]). Similarly, looking at carbon leakage within multinational firms, there is no evidence that the EU ETS caused a shift of emissions within firms from the EU to the rest of the world (Dechezleprêtre et al., 2014[19]), or that there has been an effect on net imports in the aluminium sector (Reinaud (2008[20]), Sartor (2012[21]), Healy, Schumacher and Eichhammer (2018[22])) or in the cement and iron and steel sectors (Branger, Quirion and Chevallier, 2014[23]).

Few studies find statistically significant effects from carbon pricing on net imports, and when they do, effects are relatively small in magnitude and can be either positive or negative. For the EU ETS, Petrick and Wagner (2014[24]) find overall increased net exports in regulated sectors in Germany by 9% to 18%, meaning that German firms improved their competitiveness due to the EU ETS. Conversely, Bouttabba and Lardic (2017[25]) find a modest decrease in net exports as a result of increasing carbon prices, more so in the steel than in the cement sector. For the RGGI in the Northeastern USA, Fell and Maniloff (2018[45]) find that the carbon market has led to changes in electricity trade patterns, estimating that Pennsylvania and Ohio - which are not part of RGGI, but have grid connections to RGGI states - increased their production by as much as 10%. Their results indicate that RGGI induced a reduction in coal-fired generation in RGGI states and an increase in natural gas electricity generation in RGGI-surrounding regions.

Several studies estimate trade effects from energy price fluctuations.[[13]](#footnote-13) Sato & Dechezleprêtre (2015) use a large dataset of 42 countries and 62 sectors and find almost no effect from energy prices on trade. A 10% increase in the difference between the energy prices of 2 countries decreases the short term exports by a mere 0.5%. For India, Kumar & Prabhakar (2020) find a larger, but still modest effect in the long run: an increase by 10% of the Indian energy price decreases Indian export by 1%. Similarly, for the US, Aldy and Pizer (2015[26]) investigate trade effects in the USA from sector-specific fuel price fluctuations between states, concluding that an increase by 10% in the energy price increases their net imports by a non-significant 0.6%. A hypothetical carbon price of USD 15/ton CO2 would lead to a mere 0.8% increase in imports in energy-intensive sectors.

Studies based on interviews with managers also find a very modest effect of energy prices on trade, be it for the EU ETS (Martin et al. 2016) or five other energy policies in Germany, Switzerland and Austria (Rammer et al. 2017). Table 2 summarises the studies on carbon pricing and trade effects, providing details regarding the region, covered period, sample size and method

**Table 2: Overview of empirical studies on imports and exports**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Authors** | **Year** | **Country** | **Policy** | **Sectors** | **Period** | **Method** | **Effect on trade** |
| Kumar & Prabhakar | 2020 | India | Energy Price | Manufacturing | 1998-2009 | Gravity trade model, GMM, IV (lagged energy prices) | 10% increase in energy price difference between India and trading partner reduces long term exports by 1% |
| Naegele & Zaklan | 2019 | EU | ETS | Manufacturing | 2004-2011 | Gravity trade model, input-output data | Insignificant effect on trade value and on embodied carbon |
| Dechezleprêtre et al. | 2019 | EU | ETS | Manufacturing | 2007-2014 | Regression of change of emissions within multinationals | No shift in emissions from EU to outside the EU within multinationals, even not for carbon intensive sectors. |
| Fell & Maniloff | 2018 | US | ETS (RGGI\*) | Electricity | 2003-2008 | Detailed electricity grid model | Reduction of production in coal-fired electricity in regulated states, increase in neighbouring states (leakage) |
| Healy, Schumacher & Eichhammer | 2018 | EU | ETS | Cement Aluminium | 2003-2016 | Descriptive approach, no causal inference | Cement imports have declined, exports have increased since 2005. Imports and export of aluminium relatively stable since 2005. |
| Boutabba & Lardic | 2017 | EU | ETS | Cement & Steel | 2005-2015 | Time series, rolling cointegration | Modest effect of EAU price on net imports, more in steel than in cement |
| Rammer et al. | 2017 | Germany, Switzerland, Austria | 5 energy policies (not ETS) | Manufacturing and services | 2013-2014 | Survey (N=4634), regression, matching | Energy policy has no relevant influence on firms’ international market position |
| Branger, Quirion & Chevallier | 2016 | EU | ETS | Cement & Steel | 1999-2012 | Time series (ARIMA) | Insignificant effect of EAU price on net imports |
| Aldy & Pizer | 2015 | US | Energy price | Manufacturing | 1972-2005 | Panel with sector and time fixed effects (and their interaction) | Higher fuel prices lead to more imports in energy intensive sectors (and less imports in low energy intensive sectors). 15$ carbon price would lead to 0.8% increase in imports in energy intensive sectors |
| Flues & Lutz | 2015 | Germany | Electricity Tax | Manufacturing | 1999-2004 | Regression discontinuity design | Insignificant |
| Sato & Dechezleprêtre | 2015 | 42 countries | Energy Price | Manufacturing and agriculture | 1996-2011 | Gravity trade model | 10% increase in the energy price difference between 2 countries reduces short term exports by 0.2% |
| Martin et al. | 2014 | Belgium, France, Germany, Hungary, Poland, UK | ETS | Manufacturing | 2009 | Interviews (N=761) | Expected outsourcing (relocation) by managers: cement and ceramics around 6%, Iron & Steel, Glass, Fuels around 8%. This is not an ex-post estimation, not counted as such in conclusion. |
| Petrick & Wagner | 2014 | Germany | ETS | Manufacturing | 2000-2010 | Difference in Difference and matching within 2 digit sector | Net exports +9% to +18%, depending on model specification |
| Costantini & Mazzanti | 2012 | EU | ETS | Manufacturing | 1996-2007 | Gravity trade model | Exports increase under an energy tax |
| Sartor | 2012 | EU | ETS | Aluminium | 1999-2011 | Time series, cointegration | Insignificant effect of EAU price on net imports |
| Reinaud | 2008 | EU | ETS | Aluminium | 1999-2007 | Time series | Insignificant effect of EAU price on net imports |

Note: \*RGGI = Regional Greenhouse Gas Initiative.

Foreign Direct Investment (FDI) measures the flow of capital across national borders and reflects the expectations of firms about the profitability of foreign versus domestic investments. On the one hand, an increase in outward FDI can be a proxy for the extent to which carbon pricing leads to “offshoring”. Offshoring may be driven by firms’ perception that carbon prices will hamper future profits and will make the country less attractive as a manufacturing base. On the other hand, if carbon pricing leads to a positive competitiveness effect (e.g. through innovation, higher productivity or resource efficiency), firms may prioritise domestic investments at the expense of FDI.

The evidence for the impact of the EU ETS on FDI is so far mixed and based on a small number of European countries. Borghesi, Franco & Marin (2018[27]) investigate Italian firms and find the ETS increased both the number of subsidiaries opened outside the EU and increased the turnover in these subsidiaries. Both effects are more pronounced for competition-exposed sectors. In contrast, Koch and Basse (2016[28]) focus on German firms and do not find an effect on FDI both in general and for sectors deemed at risk of carbon leakage.

Carbon prices can increase outward FDI, but the effects are small and tend to be heterogeneous across sectors. Both Dlugosch and Koźluk (2017[29]) and Garsous, Koźluk and Dlugosch (2020[30]) use energy prices as proxy for carbon pricing for assessing the impact on FDI in the OECD. Dlugosch and Koźluk (2017[29]) find that increases in domestic energy prices lead to a decline in domestic investment across all manufacturing sectors and to an increase in outward FDI from firms operating in high-energy sectors. The findings of Garsous, Kozluk and Dlugosch (2020) suggest that a 10% increase in domestic energy prices of listed companies leads to an increase of 5 percentage points in the ratio between foreign and total assets (from a mean of 14%), indicating an increase in outward FDI. Table 3 reports further details regarding the region, covered period, sample size and method of the studies on FDI.

**Table 3: Overview of empirical studies on Foreign Direct Investment**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Authors** | **Year** | **Country** | **Policy** | **Sectors** | **Period** | **Method** | **Effects on FDI** |
| Garsous, Kozluk,& Dlugosch | 2020 | 24 OECD countries | Energy price | Manufacturing | 1995-2008 | Panel with company, sector and year fixed effects. 2SLS (N=3364) | A 10% increase in energy prices in the country where a company is listed, leads to a 5% increase in its international assets as a proportion of its total assets. |
| Dlugosch & Kozluk | 2017 | 30 OECD countries | Energy price | Manufacturing | 1995-2011 | Panel with company and year fixed effects. | An increase in energy prices is associated with lower domestic investment. However, total investment is unaffected for medium energy intensive companies and increases for energy intensive companies. |
| Borghesi, Franco & Marin | 2018 | Italy | ETS | Manufacturing | 2002-2010 | Difference in Difference at firm level, matching | ETS had significant effect on FDI for all sectors during 2008-2010, effect is more pronounced in leakage-exposed sectors. |
| Koch & Basse | 2016 | Germany | ETS | Manufacturing | 1999-2013 | Difference in Difference at firm level, matching | Insignificant effect on FDI overall, "non-process" regulated sectors (machinery, electrical equipment and automotive sectors), increase FDI by 50% |

## Economic outcomes: Turnover, value added, total assets, investment, employment, productivity and profit

The results from empirical studies on the impact of carbon pricing on selected economic variables are mixed, with most studies finding no statistically significant effects. Table 4 lists several recent studies that robustly apply state-of-the-art econometric techniques. The datasets used for most studies allow the authors to investigate the effect of carbon pricing on many economic variables simultaneously. Most studies do not find a statistically significant effect from carbon pricing on variables such as turnover, value added, total assets, investment, and employment, meaning that the current design of pricing schemes has had no detrimental impact on proxies for competitiveness.

Carbon pricing has recently been assessed as having a positive effect on the turnover of regulated firms. Turnover (value of sales) and value added (value of sales minus costs of intermediary inputs) is a proxy for the market share of firms subject to international competition. Finding a positive impact of carbon pricing on turnover can be the result of cost pass through of carbon (opportunity) costs as well as a result of efficiency gains. This will be discussed further below. Evidence from China suggests that the 6 pilot ETSs reduced GHG emissions without coming at the expense of reducing economic growth (Dong et al., 2019).

Carbon pricing tends to increase total assets and investments. Finding a positive effect of carbon pricing on investment and total assets is in line with firms investing in abatement technology (see second-order effect above). Many abatement options require investments in more modern fixed assets, e.g. better insulated kilns, variable speed drive motors, and installations for heat recovery. On the other hand, expectations about lower production levels and profitability may hamper investment. Only one out of the six studies in our sample finds a negative effect; three report a positive effect, one finds effects to be mixed; and one could not find a statistically significant effect.

Carbon pricing can impact employment via three channels (Hille and Möbius 2020). First, increasing production costs may force firms to increase product prices, resulting in lower product demand and thus lower levels of employment. Second, abating emissions can be obtained by substituting fossil fuels for labour, increasing employment. Third, substituting fossil fuels for emission abatement technologies increases the demand for labour in upstream sectors (Hille and Möbius 2020). Empirically, most studies find an insignificant effect of the EU ETS on employment. When effects of the EU ETS on employment have been noted, they tend to be small ranging from a decrease 2% (Marin, Marino and Pellegrin (2018[31]) for phase I of the EU ETS) to an increase of 1.5% (Commins et al. (2011[32]) for phase I). Other studies have investigated the effect of energy prices on employment. Earlier studies in the US found that higher electricity prices led to lower employment, essentially in energy-intensive sectors (Deschênes 2001, Kahn and Mansur 2013). But more recent studies concluded the opposite, that higher energy costs lead to higher employment. This was due to spill overs effects in sectors with low energy consumption (Yamazaki 2017) and due to substitution effects in production (Hille and Möbius 2020).

Carbon pricing has been found by most studies to increase productivity (Table 4). Environmental regulation increases innovation (see below) which will improve productivity, i.e. the efficiency of turning inputs (labour, capital and natural resources) into output. The effect on total factor productivity are found to be either small ((Calligaris, Arcangelo and Pavan, 2018[33]), (Commins et al., 2011[32])) or statistically insignificant (Löschel, Lutz and Managi, 2018[34]). Effects may be heterogenous, however. Some studies find that environmental costs boost productivity only for firms with high human capital (Gonseth et al. 2015) or firms that are already highly productive (Albrizio 2014) and reduces productivity otherwise. Many studies find large increases in labour productivity measured as value added per unit of labour of up to 26% (Klemetsen, Rosendahl and Jakobsen, 2016[35]). This reflects the results reported above as the effect on employment tends to be very small while turnover increased (Marin, Marino and Pellegrin 2018).

The ability of sectors to pass through costs differs considerably between economic sectors. Sectors with low international competition can pass through their carbon costs on sales prices and firms can be expected to preserve both their profit margin and incentive for future investment. In contrast, sectors subject to strong international competition cannot fully pass through carbon costs because an increase in sales prices will have a strong effect on sales. Cost pass-through rates have been found to be around 30% in the cement sector (de Bruyn et al. (2015[36])), between 55 and 85% in the iron and steel sector (de Bruyn et al. (2015[36])) and above 80% in the petrochemical sector (Alexeeva-Talebi, 2011[37]). Generally, a higher market concentration seems to be associated with a higher ability to pass through costs (de Bruyn et al. (2015[36])).

Carbon pricing has not been found to negatively impact profits, but differences between sectors exist. While abatement costs as well as direct and indirect carbon costs decrease profits and hamper future investments, free allocation may at the same time have increased profits of regulated firms.[[14]](#footnote-14) Most ex-post studies do not find any effects of the EU ETS on profits overall ((Dechezleprêtre, Nachtigall and Venmans, 2018[38]), (Abrell, Ndoye Faye and Zachmann, 2011[39])). However, Makridou et al. (2019) find increased profits for energy efficient firms whereas Abrell, Ndoye Faye and Zachmann (2011[39]) find an increase in profits for the electricity and heat sector and a decrease for non-metallic mineral products, pointing to the fact that the electricity sector may have been in a better position to pass through the carbon costs to end-users.[[15]](#footnote-15) In Indonesia, small manufacturing business in locations with higher energy prices show a significant but small decrease in profitability (Rentschler & Kornejew 2017). The effect is small because companies switch to other fuels, are more energy efficient and pass on energy costs to end-users.

## Technological outcomes: Innovation

Carbon pricing drives innovation in clean technologies to a large extent, in some cases even without crowding out innovation for other technologies. Innovation is typically measured by the number of low-carbon patents.[[16]](#footnote-16) It is the key channel to strengthen the competitiveness of firms in the long-run. The empirical evidence on the impact of carbon pricing or energy prices is most robust on this factor: all studies so far report statistically significant increases in patenting in response to carbon pricing (Calel and Dechezleprêtre (2016[40]) for the EU ETS, Cui, Zhang and Zheng (2018[41]) for the Chinese ETS) or energy prices ( (Ley, Stucki and Woerter, 2016[42]) and (Aghion et al., 2016[43]) for OECD countries). Notably, Calel and Dechezleprêtre (2016[40]) find that EU ETS regulated firms increased green patents by 10% compared to their non-regulated European peers, while not crowding out patenting for other technologies. Ley, Stucki and Woerter (2016[42]) find that a 10% increase in energy prices in OECD countries increases the number of green innovations by 3.4% and the ratio of green innovation to non-green innovations by 4.8%.

Table 4. Studies reporting effects from carbon pricing on turnover, value added, assets, investment, productivity and profit.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Authors** | **Year** | **Country** | **Policy** | **Sectors** | **Period** | | **Sample Size** | **Explained variable (left hand side)** | | | | |
| **Turnover & Value Added** | **Total Assets & Investment** | **Employment** | **Productivity** | **Profit** |
| Hille & Möbius | 2020 | OECD | Energy price | All sectors | | 1996-2009 | 33 sectors in 27 countries |  |  | All sectors: increase. Manufacturing: insignificant. |  |  |
| Makridou et al. | 2019 | EU | ETS | Manufacturing | | 2006-2014 | 3952 ETS firms, no non-ETS |  |  |  |  | For energy efficient firms |
| Dong et al. | 2019 | China | ETS | Manufacturing | | 2006-2015 | 30 provinces (6 with ETS) | Effect on GDP |  |  |  |  |
| Marin, Marino, Pellegrin | 2018 | EU | ETS | Manufacturing | | 2002-2012 | 792 ETS firms, 2500 non ETS | Turnover +7%, only phase II (2008-2012) | Gross fixed capital formation/assets +1,5% | -2% phase I (2005-2007) only | Labour productivity (VA/L) +5% | Markup +1,5% in phase I and +3% in phase II |
| Löschel, Lutz, Managi | 2018 | Germany | ETS | Manufacturing | | 2003-2012 | 520 ETS firms, > 10000 non-ETS |  |  |  | Total factor productivity Insignificant overall, + 1% in paper industry |  |
| Dechezleprêtre et al. | 2018 | EU | ETS | Manufacturing | | 2003-2013 | 1,787 ETS firms; 1,280 non-ETS | Turnover +16,7% | Total Assets +8,1% | Insignificant |  | Insignificant |
| Calligaris et al. | 2018 | Italy | ETS | Manufacturing | | 2005-2013 | 662 ETS firms, >3000 non ETS |  | Insignificant | Insignificant | Total factor productivity (TFP) increases |  |
| Rentschler & Kornejew | 2017 | Indonesia | Energy price | Manufacturing | | 2013 | 41,402 small firms (<19 employees) |  |  |  |  | 10% increase in energy price increase cost/revenue by 0.5% for electricity and 3.7% for diesel |
| Yamazaki | 2017 | Canada | Tax | All sectors | | 2001-2013 | 68 industries in 6 provinces |  |  | Overall: +0,7%, decrease in 6 energy-intensive industries. |  |  |
| Dlugosch & Kozluk | 2017 | 30 OECD countries | Energy price | Manufacturing | | 1995-2011 | 3500 listed firms |  | Investment insignificant overall, increase for energy-efficient firms. |  |  |  |
| Lutz | 2016 | Germany | ETS | Manufacturing | | 1999-2012 | 400 regulated, 15000 in total |  |  |  | Total factor productivity +1 % to +2% |  |
| Klemetsen et al. | 2016 | Norway | ETS | Manufacturing | | 2001-2013 | 150 ETS firms, 515 non-ETS | Value added +24% |  |  | Labour productivity +26% |  |
| Jaraite & Di Maria | 2016 | Lithuania | ETS | Manufacturing | | 2003-2010 | 330 ETS firms, 271 non-ETS |  | Total Assets increase, but decrease in phase I |  |  | Insignificant |
| Lundgren | 2015 | Sweden | ETS | Pulp and Paper | | 1998-2008 | 100 firms |  |  |  | Total factor productivity |  |
| Gonseth et al. | 2015 | BEL, CZR, DEN, FIN, FRA, ITA | Diesel price and tax | Manufacturing | | 1990-2003 | 11 sectors in 6 countries |  |  |  | TFP decreases in low wage sectors and increases in high wage sectors |  |
| Aldy & Pizer | 2015 | US | Energy price | Manufacturing | | 1972-2005 | 450 subsectors | A 10% increase in fuel prices reduces output by 0.8% |  |  |  |  |
| Wagner et al. | 2014 | France | ETS | Manufacturing | | 2000-2010 | 287 ETS firms, 287 non-ETS | Value added insignificant | Large impact during phase II (2008-2010) | Insignificant at firm level, but negative on installation level |  |  |
| Petrick & Wagner | 2014 | Germany | ETS | Manufacturing | | 2000-2010 | 400 ETS firms, 280 non-ETS | Turnover +5% to +7% |  | Insignificant |  |  |
| Martin, dePreux, Wagner | 2014 | United Kingdom | Tax | Manufacturing | | 1999-2004 | 4000 plants |  |  | Insignificant | Total factor productivity insignificant |  |
| Yu | 2013 | Sweden | ETS | Energy sector | | 2004-2006 | 113 regulated, 1000 in total |  |  |  |  | Insignificant in 2005, -1% in 2006 |
| Chan, Li & Zhang | 2013 | EU | ETS | Cement, iron, electricity | | 2001-2009 | 5873 ETS and non-ETS firms | Electricity (+30%), cement and iron & steel insignificant |  | Insignificant |  |  |
| Kahn & Mansur | 2013 | US | Electricity price | Manufacturing | | 1998-2009 | 21 sectors in +-540 counties |  |  | all sectors: non-significant. Energy-intensive sectors: negative. |  |  |
| Commins et al. | 2011 | EU | ETS & Tax | Manufacturing | | 1996-2007 | 160,000 firms |  | Investment : negative for tax, -1,6% for ETS | Temporary increase for tax; +1,5% for ETS | Total factor productivity: negative (tax); -3,2% (ETS) | Return On Capital: negative for tax; -4,7% for ETS |
| Abrell et al. | 2011 | EU | ETS | Manufacturing | | 2003-2008 | 2101 ETS firms, 2101 non-ETS | Value added insignificant |  | Insignificant phase I; -0,9% in phase II (2008) |  | Overall insignificant, Elec. (+),non-metallic minerals (-) |
| Deschênes | 2011 | US | Electricity price | All sectors | | 1976-2007 | 11 sectors in 52 states |  |  | 10% increase in electricity price reduces employment by 1%. |  |  |
| Anger Oberndorfer | 2008 | Germany | ETS | Manufacturing | | 2003-2005 | 419 ETS firms only | Turnover insignificant |  | Insignificant |  |  |

Note: The colour schemes indicates whether carbon pricing had a positive (green), negative (red), statistically insignificant (yellow) or mixed (blue) effect on the outcome variables of regulated versus non-regulated states, sectors, firms, or installations.

*Source*: Authors

# Conclusions

Limited effects of carbon pricing on short-term competitiveness have been found to date. When effects have been found, they are small (either positive or negative). This demonstrates that concerns about negative short-term effects of carbon pricing on firms’ or sectors’ international competitiveness have not come to pass, at least to date. However, these findings are in part because carbon prices levied on industry have been low, either because of exemptions to carbon taxes, or because of generous levels of free allowances to firms covered by emissions trading schemes. There is therefore no experience to date on how the competitiveness of energy-intensive industries could be affected in the absence of free allocation of allowances or at substantially higher carbon price levels, although ex-ante studies indicate that levels of carbon leakage could be significant.

Table : Overview of ex post studies on the effect of a carbon tax, ETS or energy price variation on different dimensions of competitiveness in industrial sectors\*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Loss (Negative) | Insignificant | Gain (Positive) | Mixed |
| Net exports | 5 | 7 | 2 | 0 |
| Foreign Direct Investment\*\* | 3 | 1 | 0 | 0 |
| Turnover and value added | 1 | 4 | 3 | 2 |
| Total assets and investment | 1 | 1 | 3 | 2 |
| Employment | 2 | 6 | 2 | 4 |
| Productivity | 1 | 1 | 4 | 2 |
| Profit | 2 | 2 | 2 | 2 |
| Innovation | 0 | 0 | 4 | 0 |

Note: \*Number of studies which report negative, positive, insignificant or mixed results for all industrial sectors on aggregate (according to a 10% significance level). \*\*A loss in competitiveness corresponds to a positive effect on outward FDI and/or negative effect on inward FDI.

Source: Authors

Free allocation of allowances (or carbon tax exemptions) is likely to continue to be needed in some sectors while significant differences in carbon pricing exist between jurisdictions. However, there is no agreement on which sectors should benefit, or on what level of free allowances is appropriate. The level of optimal free allocation will vary depending on the stringency of carbon constraints, the carbon price, as well as the level of trade exposure for specific products. Allocating free allowances based on a benchmark performance standard in terms of GHG per unit output instead of allocation based on past emission levels would reduce perverse incentives for keeping emission levels high.

Setting up carbon pricing schemes (even if the initial price is low) and smoothing out the significant price variability noted to date in ETS will provide a clearer policy signal to participating firms. It may be more politically acceptable to establish a carbon pricing system with a low initial carbon price, and then raise it over time – as has occurred in the trading systems in place e.g. in the EU, South Korea, New Zealand and Shenzhen. Further, postponing the introduction of carbon pricing may entail competitiveness risks if it means that firms delay the adoption of abatement technologies. A price stability mechanism (potentially including a price floor and/or ceiling) could thus provide a stable incentive to invest in GHG abatement, increasing firms’ long-term competitiveness in an increasingly carbon-constrained economy. A price stability mechanism can also increase the stringency of the system if, as in the EU ETS, it is used to reduce the number of allowances in circulation.

Carbon pricing has a positive effect on innovation, but effects on long-run competitiveness remain inconclusive. Innovation is key to driving the low-carbon transition in many sectors. Carbon pricing has been found to drive private money into innovation of low-carbon technologies, which equip firms for international competition in the long-run – when carbon price levels increase. However, this competitive advantage in the long-run has not (yet) materialised into economic outcomes.

Future research could follow two avenues once more empirical studies are available: First, carving out the competitiveness effects depending on the instruments used. While economic theory predicts that the effect of different pricing instruments (e.g. carbon tax or fuel tax) would be the same, actual responses of firms might differ depending on how the instrument is labelled. Second, analysing the competitiveness impacts of different ETSs designs, including different price stability mechanisms, such as a price floor (as in California) and the market stability reserve (as in the EU ETS).

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1. Carbon leakage is defined as the increase of emissions abroad as a causal effect of climate policy in a given jurisdiction. Competitiveness impacts are only one channel of carbon leakage (Zhang and Zhang, 2017). Carbon pricing will reduce emissions and energy demand in the regulated jurisdictions, leading to lower world market prices for fossil fuels, which increases emissions in unregulated regions. Inversely, carbon pricing will make low-carbon technologies cheaper, lowering emissions in unregulated regions. See Partnership of Market Readiness (2015) for an overview of leakage estimates. [↑](#footnote-ref-1)
2. Equals EUR 7,58 based on the exchange rate on 31 December 2012. [↑](#footnote-ref-2)
3. While there are some differences in the design of ETSs, we cannot draw clear conclusions on the effect of these differences on competitiveness. [↑](#footnote-ref-3)
4. The Historical Activity Level is calculated as the median (middle value) of the yearly production volume between 2005 and 2008 or the median of the production volume between 2009 and 2010. Free allocation after 2020 will be determined by the mean volume of production in 2014-2018. [↑](#footnote-ref-4)
5. There are far fewer studies on the competitiveness impacts of carbon taxes compared to emissions trading schemes, because industry is often exempt from high carbon tax rates. Also, identification strategies are more difficult, since a carbon tax generally covers all firms within a sector and has much less price variation over time. [↑](#footnote-ref-5)
6. The main reason is a perceptional bias. “An implication of the endowment effect is that people treat opportunity costs differently than ‘out of pocket’ costs. Foregone gains are less painful than perceived losses. Endowment effects are predicted for property rights acquired by historic accident or fortuitous circumstances, such as government licences, landing rights, or transferable pollution permits” (Kahneman, Knetsch and Thaler, 1990[44]). Next, cash costs also have a different risk profile compared to opportunity costs. Cash costs are more likely to lead to bankruptcy than opportunity costs (Venmans, 2016). [↑](#footnote-ref-6)
7. Price uncertainty has four effects on investment:

   * The carbon price volatility is procyclical. The carbon price tends to decrease in economic downturns, which is risk-hedging. This reduces the risk-adjusted carbon costs compared to a less volatile price with the same mean.
   * Firms anticipate future carbon price scenarios, each with a specific probability, when they take an investment decision today. In scenarios with increasing carbon prices in the future, early innovators in low-emission technologies gain market share, while slow innovators make losses. This creates an incentive to invest, especially in innovation.
   * Firms also anticipate future scenarios in which the carbon price is extremely high, making them want to relocate (causing stranded assets). This is a barrier for investments with a long time horizon.
   * Finally, firms anticipate future scenarios with very low carbon prices, in which certain abatement investments would be unprofitable. This a barrier for these abatement investments.

   [↑](#footnote-ref-7)
8. An energy tax of € per unit of fuel with a CO2 intensity of tCO2 per unit of fuel corresponds to an implicit carbon tax of € per tonne of CO2. Energy taxes can be made proportional to their carbon content and result in a unique implicit carbon price across fuels. Yet, most energy taxes are based on the energy content.. [↑](#footnote-ref-8)
9. Even if aluminium producers produce their own electricity, they will have to buy auctioned emission allowances for their electricity production. [↑](#footnote-ref-9)
10. Eligible sectors are specified in Annex II of the Guidelines and include, inter alia, aluminium production, lead, zinc and tin production, manufacture of paper and paperboard. [↑](#footnote-ref-10)
11. Firms with high international competition may still chose to increase prices and lower their market share. Even without international competition, cost pass through also depends on market structure (monopoly power). Cost pass through is therefore an imperfect measure of international competitiveness. [↑](#footnote-ref-11)
12. Defined as , including only the extra-European trade. [↑](#footnote-ref-12)
13. In fact, most of this time-series variation for energy prices can be attributed to changes in energy taxes (Sato et al., 2019), rendering energy prices a good proxy for changes in energy taxes. Yet, in cross-country studies energy prices do not perfectly capture the extent to which taxes affect competitiveness. While there are common factors that affect energy prices globally, such as oil and gas prices, energy price variation can also result from limited integration of energy markets due to transport costs or infrastructure bottlenecks. In addition, energy price fluctuations are found to have a lower effect on behaviour than energy taxes, because taxes are more salient and expected to have lasting effects (Rivers & Schaufele, 2015; Scott, 2012). Hence, results from studies using energy prices can be interpreted as a lower bound of the effect of carbon pricing. [↑](#footnote-ref-13)
14. There are two ways in which free allocation may increase profits. The first is because free allowances create an opportunity cost and may therefore be passed through in sales prices, as was observed in electricity markets (Sijm et al., 2008[10]). Second, if free allocation exceeds emissions, the income of selling allowances may exceed abatement costs (see Figure 4B). [↑](#footnote-ref-14)
15. There are several studies looking at how stock market prices of regulated firms react to carbon price variations (Verde, 2018). This gives an insight in investor’s expectations about the effect of carbon prices on future profits. In general, the relationship between stock market returns and carbon prices depends on sectors and phases, though relationships are more often positive than negative (Venmans (2015[46]), Pereira da Silva et al. (2016[47]) and Moreno and Pereira de Silva (2016[48])). For electricity producers, studies find a positive relationship between carbon price variation and stock market returns during the first phase, indicating that investors expected firms to gain from the EU ETS (Oberndorfer, 2008[49]), (Veith, Werner and Zimmermann, 2009[50]), (Mo, Zhu and Fan, 2012[51])). For the second phase, some studies find a positive relationship (Pereira da Silva, Moreno and Carvalho, 2016[47]) whereas others find a negative relationship (Tian et al., 2016[52]). In the third phase, the relationship between carbon prices and stock returns was not statistically insignificant (Moreno and Pereira da Silva, 2016[48]). [↑](#footnote-ref-15)
16. The number of patents is an imperfect proxy for innovation, since some patents are more impactful than others and certain types of innovation such as learning by doing occur without patents. Expenses in research and development is another proxy, but many companies do not report R&D as an asset because it leads to earlier tax payments. [↑](#footnote-ref-16)