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1. Changes with respect to the DoA

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2. Dissemination and uptake

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Outside the project: INNOPATHS, CMCC Research Paper

3. Short Summary of results (<250 words)

The current bottom-up architecture implies that for many years to come countries will face different carbon prices. The unprecedented commitment to address climate change with increasingly ambitious mitigation actions calls for a renewed assessment of climate policies and of measures to address carbon leakage. In this review we summarized the main conclusions of recent studies that considered past evidence (ex-post) as well as future scenarios pondering different policy settings (ex-ante). Taking into account the empirical and modelling evidence, we reviewed also the feasibility of several alternatives proposed to address carbon leakage and competitiveness concerns. Finally, and considering those alternatives, we highlight the directions that further research can take.

We conclude that a priority for future research is to analyze carbon leakage under the emerging heterogeneous climate policy landscape characterizing the current international policy context. In the context of wider and more ambitious climate action, innovation and spillovers play an important role for enabling competitiveness improvements in low carbon industries as well as increasing the chances of negative carbon leakage. Regarding the options to address carbon leakage, more evidence is needed in order to evaluate the potential effectiveness of consumption-based pricing. As noted in previous reviews, the use of multidimensional indicators in future analysis such as employment, import, export, output, innovation in EITE sectors, innovation in EITE and non-EITE, will be definitely welcome also for reconciling the ex-post and ex-ante analysis.

4. Evidence of accomplishment

Report, CMCC Research Paper

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1 Introduction

There are many alternatives to direct development towards a low carbon economy such as increasing energy efficiency, ramping up the development and use of renewable energy sources, or putting a price on carbon emissions. However, the main concerns of the literature analysing the implementation of climate policies have been the effectiveness of those policies, and the consequences on the competitiveness of industries within a climate coalition. Effectiveness concerns arise when a policy is implemented only by a subset of countries, and their mitigation effort could be offset by the rest of the world. This is related also to the carbon leakage phenomenon. Competitiveness concerns are intrinsically linked to climate policy effectiveness and carbon leakage. On the one hand, the policy would impose an additional burden on industries from the climate coalition that could constrain their performance when competing with industries located in the rest of the world. On the other hand, the policy could foster new technology developments that could render industries from the climate coalition more competitive in a future decarbonized economy.

Among all climate policy options, the carbon price is an instrument that could provide a clear economic signal both to reduce emissions and to foster the development of new technologies that could support the decarbonization of the economy. Policy design considers the implementation of carbon prices either through emission trading schemes or domestic carbon taxes. However, the existing literature highlights the fact that while a carbon price can reduce emissions within a coalition of countries; it may not help to reduce global carbon emissions. Following the ratification of the Paris agreement by more than 150 parties, the existence of carbon price differentials is a feature that will characterize the international climate policy landscape in the years to come. Therefore, an assessment of whether different carbon prices could lead to a shift in emissions rather than an actual reduction in global emissions is also required.

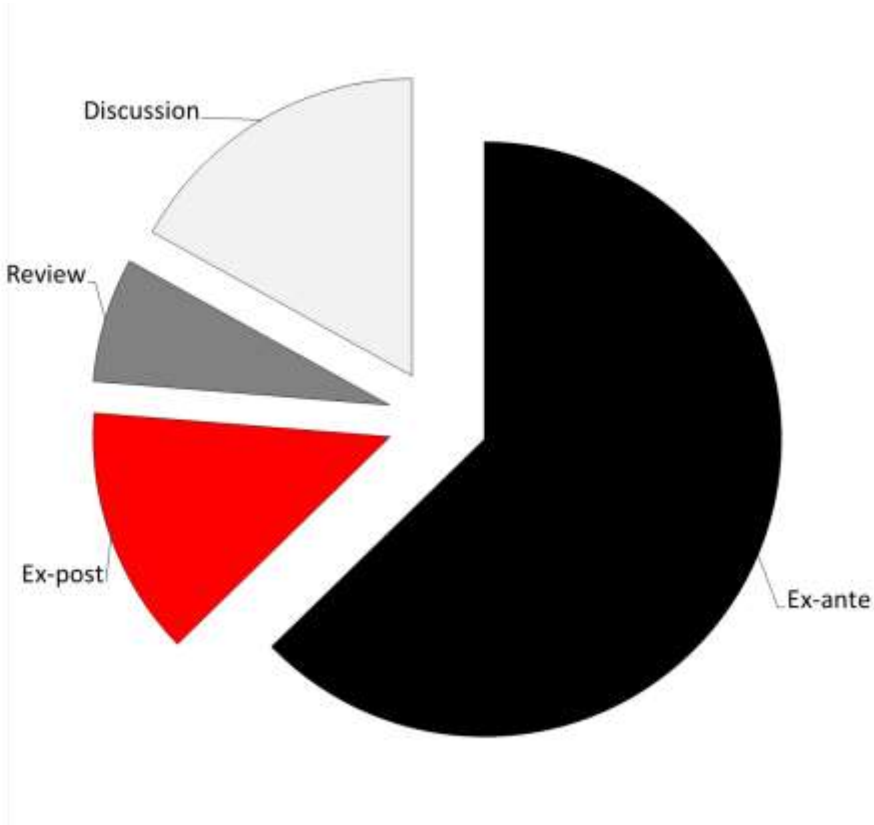
Indeed the potential impacts of climate policies on business, competitiveness and carbon leakage have influenced policy design and implementation since the Kyoto Protocol enforcement. Carbon leakage and/or competitiveness concerns are shaping the design of climate policy (e.g. EU ETS, Californian cap-and-trade system) and are arguments used by the most exposed industries when lobbying for free allocations. Addressing competitiveness and carbon leakage has motivated the European Union to allocate free allowances from Phase I to Phase III of the EU-ETS (Dechezleprêtre and Sato, 2014).

Despite the scarce academic evidence on carbon leakage, this concern has been a major obstacle in the implementation of climate policy (Grubb et al., 2013). Although the empirical analyses based on existing historical data do not find evidence supporting a significant causal relationship between carbon pricing and competitiveness indicators such as firm-level (or sectoral) productivity, or employment; still the evidence on relocation of polluting activities is mixed. Moreover, studies using modelling approaches to simulate more ambitious mitigation policies compared to empirical studies based on historical data reach opposite conclusions.

Recent reviews have been published over the last three years focusing either on the ex-ante literature (Branger and Quirion 2014, Carbone and Rivers 2017) or on ex-post contributions (Dechezleprêtre and Sato, 2014, Arlinghaus 2015). This deliverable brings together these different streams of literature with the aim of identifying research gaps and informing the policy analysis to be conducted in Work Package 3. Evaluating the findings from different approaches following the same systematic structure can shed light on key research gaps that need to be prioritized.

Figure 1 summarizes the most recent literature on competitiveness and carbon leakage, looking into options and solutions to address these issues. We have reviewed 59 papers, mostly ex-ante studies (37), while few ex-post (8) and discussion papers (10). We have also looked into 4 recent reviews, 2 on ex-ante studies (Branger and Quirion 2014, Carbone and Rivers 2017) and 2 on ex-post contributions (Dechezleprêtre and Sato, 2014, Arlinghaus 2015).

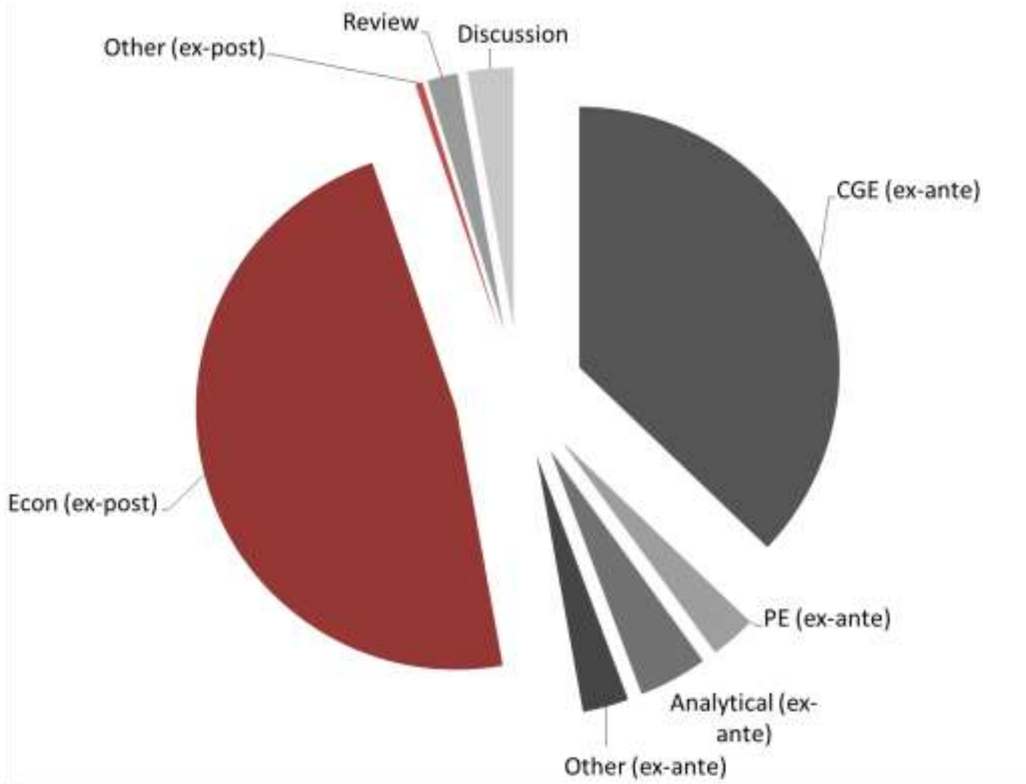
Figure 1. Studies analyzed in this deliverable. Total papers: 59. Ex-ante: 37. Ex-post: 8. Review: 4. Discussion: 10



Source: Authors' elaboration based on the literature reviewed in this deliverable

We do not examine each individual paper included in the four reviews (52 additional papers in ex-ante studies and 93 additional papers in ex-post studies), as the main findings have already been summarized in the review papers. We only count those contributions in order to characterize the overall distribution of the existing literature by type, as shown in Figure 2. From a total of 250 papers on the topic, 37% use Computable General Equilibrium models (CGE, 37%) or econometric methods (48%). The remaining 15% consists of other ex-ante approaches including Integrated Assessment Models (IAMs), Partial Equilibrium (PE) models, as well as analytical models, review/discussion studies for a 2% and 1 ex-post study which uses decomposition methods.

Figure 2. State-of-the-art on carbon leakage. Total papers: 210



Source: Authors' elaboration based on the literature reviewed in this deliverable

The remainder of the deliverable is organized as follows. Section 2 introduces concepts and definitions. Section 3 reviews the ex-post and ex-ante literature. Section 4 discusses policy options to address carbon leakage and competitiveness issues. Section 5 summarizes the main findings and concludes identifying some research priorities for the COP21-RIPPLES project as well as future research.

2 Key concepts and definitions

This section builds on previous review studies and defines some key concepts commonly used in the literature on climate policy. Four are the concepts defined in this section: 1) competitiveness, 2) carbon leakage, 3) the channels that propagate carbon leakage, and 4) the different approaches to measure emissions.

2.1 Competitiveness

Competitiveness concerns are more difficult to define as there is not an unequivocal definition of competitiveness and different indicators and definitions have been used in the literature. All four review papers examined begin with a discussion of the notion of competitiveness (Arlinghaus 2015, Dechezlepretre and Sato 2014, Carbone and Rivers 2017, Cosbey et al. In prep.), and of the indicators used to measure competitiveness outcomes, which is the focus of most papers analyzed in those reviews. Dechezlepretre and Sato (2014) define first the term competitiveness at the firm level: "… a business is competitive if it can produce better or cheaper products or services than its domestic and international competitors."; and at the sector level: "Competitiveness at the sector level refers to how attractive different countries are for a particular industry and it is often measured in terms of performance in international trade (net exports, investment flows)." All papers argue that competitiveness is a concept that is meaningful only at the firm or sectoral level. Sectoral competitiveness relates to whether a domestic sector as a whole can retain or expand its share of domestic and international markets. Changes in investment flows may reflect firms' expectations about future competitiveness. Value added indicates whether a firm is able to create more or less valuable products or services. Ultimately, competitiveness losses can lead to a decrease in output, with consequences on employment.

Carbone and Rivers (2017) in their review of CGE studies focus on competitiveness outcomes at sectoral level for energy intensive trade exposed (EITE) sectors. Example of variables that have been used in the modeling literature includes:

- Exports (proxy measure of competitiveness on the international market)
- Imports (proxy measure of competitiveness on the domestic market)
- Net exports (proxy measure of competitiveness on the domestic and international market)
- Relative terms-of-trade defined as the ratio of export value over import value of a specific sector over the ratio of aggregate export over aggregate imports

- Change in relative world trade share
- Market share of the domestic sector in the domestic market
- Cost of domestic output/world price

Some papers do not look at investment leakage but they frame the results in the context of the pollution haven hypothesis, which implies a reallocation of existing or planned production capacity. However competitiveness is only one of the possible channels that can propagate carbon leakage.

2.2 Carbon leakage

The IPCC defines carbon leakage as "the increase in CO2 emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries" (B. Metz, et al, 2007).[1] The literature distinguishes two main types of leakage: operational and investment leakage. Operational leakage refers to the loss in market share of profits resulting as a consequence of the substitution of domestic products with cheaper foreign ones. Investment leakage refers to the shift in investments driven by the differences in capital return induced by carbon pricing. Most studies focus on outcome indicators to measure leakage, e.g. change in emissions in a non-regulated region relative to the change in emissions in the regulated region, and therefore cannot distinguish between operational and investment leakage, although the majority seems to focus on the former. Eichner and Pethig (2015) introduce the concept of intertemporal leakage, e.g. impact of a regulation implemented in one period on the emissions in a subsequent period. Leakage can be defined not only across different national jurisdictions implementing environmental regulations but also across different sectors. Lanzi and Sue Wing (2013) distinguish between external leakage and internal leakage. External leakage is what the literature generally refers to as simply carbon leakage (see above mentioned definition from the IPCC). Internal leakage refers to the leakage across sectors within the same jurisdiction implementing the policy when not all sectors of the economy are regulated. In our opinion, intertemporal leakage is also related to investment leakage. While operational leakage can be consider more a short-run phenomenon, investment leakage is more related to the long-run.

[1] http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch11s11-7-2.html

2.3 Channels propagating carbon leakage

The literature has identified at least four channels that contribute to propagate carbon leakage (Droge et al. 2009, Cosbey et al. In prep.):

- Energy market channel
- Competitiveness channel
- Technology spillovers channel
- Income effect channel

Regions affected by a carbon pricing reduce their use of fossil fuels. Through the global energy market the reduced demand lowers the cost of fossil fuels on the global energy markets, inducing more consumption and thus emissions in non-regulated regions. Although the *energy market channel* has been found to be one of the largest channels of leakage (Fischer and Fox, 2012; Branger and Quirion, 2014), it is not the focus of the policy debate, which instead is more concern with competitiveness of energy-intensive, trade-exposed (EITE) sectors. The *competitiveness channel* is driven by the change in production costs. Carbon pricing increases production costs in the climate policy region inducing both consumers and producers to substitute domestically-produced goods with imported goods, leading to *operational leakage* (e.g. loss in market share and profits). Higher costs and lower demand can reduce market share, inducing firms in an ope n economy to migrate to regions with less stringent regulation (*pollution haven hypothesis* and *investment leakage*). Indeed operational leakage can be related more to a short-, medium-time horizon whereas the investment leakage to the long-term. Whereas the pollution haven hypothesis would tend to lead to positive leakage, the *Porter Hypothesis* (Porter and van der Linde, 1995) argues that higher production costs can provide an incentive to develop new technologies that will eventually save the most expensive input. More generally, environmental policy could help overcome other non-environmental externalities related to market failures (market power, asymmetric information, R&D spillovers), and organizational failures (Gosenth et al. 2015). Should this outcome prevail, the competitiveness effect of environmental regulations could actually be positive (leading to a negative carbon leakage). This dynamic effect associated with technological change and diffusion is commonly described as a *technology spillovers channel*. Carbon pricing induces innovation in carbon- and energy-saving technologies (Carraro et al. 2010) that spill across countries and over time leading to negative inter-temporal leakage. Within markets well-integrated, technology transfers can occur through climate policy linkages, such as the Clean Development Mechanism of the Kyoto Protocol or through trade flows, multinational enterprises, and skilled-labour mobility. Carbon pricing affects relative prices causing not only changes in the terms of trade (which is related to the competitiveness effect falling mostly on the supply side) but also *income effects*. Carbon pricing might reduce overall real income, which would induce both domestic and international consumers to buy less of all goods. The net result of these changes in global demand could be positive or negative leakage, but this channel is of secondary importance compared to the previous ones (Cosbey et al. In prep).

Considering the broad definition of competitiveness as proposed by Dechezlepretre and Sato (2014), the competitiveness and the technology spillovers channels are indeed the ones most directly connected with potential changes in firms' or sectors' competitiveness. The energy market and income channels have more widespread consequences across the economy, and can lead to distributional implications for consumers as well. Here we focus on the competitiveness consequences and possible measures and policies to address those.

2.4 Emission accounting

Emissions are commonly divided in three scopes.[2] Scope 1 emissions are generated during the production of any commodity. Scope 2 emissions include the indirect emissions associated with energy use generated off-site and purchased. Scope 3 emissions regards all indirect emissions not covered by scope 2, which are embodied in inputs or related to downstream activities like transportation (Cosbey et al. In prep). These emissions would also include emissions embodied in trade. Scope 3 emissions are close to consumption-based emissions discussed below. The literature reviewed in section 3 has mostly focused on production-based emissions, mostly scope 1 and scope 2, with only one study accounting for scope 3 emissions. That study uses embodied emissions calculated using a global multi-regional input–output (MRIO) framework (Ghosh et al. 2012). The empirical literature on the Carbon Kuznets Curve has overwhelmingly relied on domestic production based emissions. Wagner (2010), Mir and Storm (2016) and Grubb et al. (2017)[3] show that using consumption-based emissions leads to a different conclusion regarding the decoupling between growth and emissions due to the dramatic increase in international trade and transportation.

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[2] www.ghgprotocol.org, as reported by Cosbey et al. In prep.
[3] https://www.ineteconomics.org/perspectives/blog/carbon-decoupling

Consumption and production based emission accounting differ in the definition of system boundaries. Production-based accounting is based on geographic boundaries. Consumption-based Carbon accounting (CBCA) requires a functional, cradle-to-grave or “footprint” approach, usually including processes in different geographical areas. The major difficulty is not much on the accounting of emissions but rather on the ability to connect processes (van de Lindt et al. 2017). The FP7 Carbon-CAP project[4] focuses on CBCA and demand side policies as an alternative to production based policies that could have lower implications in terms of competitiveness and carbon leakage. There are a number of global and regional databases suitable for calculating consumption-based emissions, but since CBCA requires consistent statistics across country borders[5] there is unlikely to be a universally accepted database for all countries in the near future (van de Lindt et al.2017). The Carbon-CAP project highlights these sources of uncertainties and uses four global multi-regional input–output (MRIO) databases (WIOD being one of them) to estimate consumption-based CO2 emissions. Moran and Wood (2014) show that even after attempting to control for sectoral GHG data there are substantial differences (5%-30%) in country based consumption related emissions between MRIO datasets. Hence using multi-model results/confidence intervals is necessary when drawing conclusions about consumption based emissions. The research focusing on consumption-based emissions highlights that, although countries and the EU have agreed on targets to reduce the GHG emissions produced in their territory, production-based policies need to be complemented with consumption-based policies, a topic that will be discussed in section 4.

[4] http://www.carboncap.eu/

[5] Certain nation’s imports must be consistent with other countries’ reporting of their exports. Currently, this is far from the case, with current trade data showing a significant gap between reported imports and exports even at the global level (van de Lindt et al.2017, D8.2).

3 Literature review

We review each study considering the type of analysis being ex-ante or ex-post and focusing on seven dimensions listed in **Table 1**, which summarizes the main characteristics regarding the climate policy, sectoral coverage, regional coverage, emission scope, type of leakage, leakage channels, and policies addressing leakage.

Table 1: Summary of main characteristics of Ex-ante and Ex-Post studies

	Type of study	
	Ex-post	Ex-ante
1. Climate policy	Climate policies included in historical data used for the analysis (implicit), mostly EU-ETS, but also energy prices and taxes	Broad range of policies (EU-ETS, carbon taxes, Kyoto Protocol, Copenhagen pledges)
2. Sectoral coverage	EITE (energy intensive, trade exposed sectors), manufacturing, macro-economy	All sectors, focus on EITE (energy intensive, trade exposed sectors)
3. Regional coverage	OECD, EU, US	Global with different regional aggregation (4 regional studies)
4. Emission scope	Scope 1 and 2. Most studies however do not focus on emissions as outcome indicator	Scope 1 and 2 (1 study on scope 3)
5. Type of leakage	Difference between consumption-based and production-based emissions; Operational leakage (via impacts on productivity, employment, innovation); Investment leakage (via pollution haven hypothesis)	Operational leakage (short-run) and investment leakage (long-run, via pollution haven hypothesis)
6. Leakage channels	Competitiveness, technology (via Porter hypothesis)	Energy market, competitiveness, income effect, technology (only in 4 papers)
7. Policies addressing leakage	Policies included in the historical data used for the analysis (implicit)	Broad range of policies (e.g. BTA, different allocation schemes, exemptions, global linking, offsets)

Source: Authors' elaboration based on the literature reviewed in this deliverable

3.1 Ex-post evidence from empirical studies

Two recent reviews have surveyed the recent ex-post literature (Dechezlepretre and Sato 2014 and Arlinghaus 2015). Here we summarize the main findings from that literature review as well as the new evidence that has been published over the last years, 2015 included. Indeed, both surveys review papers published until 2014 and only Arlinghaus (2015) includes a paper published in 2015. The sectoral coverage of most ex-post studies tend to focus on energy intensive industries with few studies looking at the differences in aggregate consumption and production based emissions. Studies tend to over-represent industrialized countries, where richer data on policy measures are available because of the history of environmental regulations. In terms of emission scope, most studies actually do not look at emissions as performance indicator, but rather focus on the implications on competitiveness indicators reviewed in section 2.1. The ex-post literature does not explicitly refer to operational or investment leakage but rather focus on hypotheses or leakage channels that can be related to operational and investment leakage. For example, the pollution haven hypothesis can be related to investment leakage. Impacts of climate policy on productivity, employment, and innovation can be expected to affect operational leakage in the short-run, whereas it is not known whether operational leakage will eventually lead also to investment leakage in the long-run. Empirical studies can only look into the policies that are part of the historical experience. Policies to address leakage are implicitly captured to the extent that the climate schemes considered (e.g. EU-ETS) have been designed to address competitiveness issues (e.g. free allocation to EITE sectors). Indeed, this might explain why ex-post studies do not find evidence on competitiveness effects. This result can also be attributed to the lack of very stringent policies in the historical experience so far. As noted in Dechezlepretre and Sato (2014), analysing the relative stringency of regulations have proven to be difficult for different reasons, from the lack of data to the complexity of identifying proper indicators and methods to measure either the regulation itself or the impacts on competitiveness. More specifically, the ex-post literature review (Dechezlepretre and Sato 2014) suggests that:

1) The costs of environmental regulations represent a small share of the production value for most activities, but they could increase entry and investment costs. However, the design and implementation of these regulations have also considered the possible negative effects on the industry which may have lessened those adverse impacts;

2) There seems to be short-run negative impacts on productivity, while in the longer run these seem to be smaller, or may be even positive;

3) Environmental regulations would induce insignificant effects on employment on regulated sectors that in the end suggest a substitution effect of movements of workers from polluting to clean sectors during a transition period. The costs of this transition depend of the imperfections of the labour market and the policies that could be implemented to help and safeguard workers;

4) There is mixed evidence about the relocation of polluting activities to lax or non-regulating countries. This is because of the challenges to test this issue due to implicit difficulties in measuring the effect on competitiveness and the lack of appropriate measures of relative stringency of regulations;

On the contrary, there is ample evidence for positive effects in terms of induced clean innovation from a set of studies testing the Porter Hypothesis. Moreover, these innovations could not only improve regulated companies to become more competitive, but also could benefit unregulated ones thanks to the new knowledge available fruit of innovation that may spill over to the rest of the economy. Gonseth et al. (2015) look into the role of human capital as a mean to reduce the competitiveness effects of climate policy, and they do find evidence that rising energy costs associated with carbon pricing can have a positive effect on competitiveness in terms of Total factor Productivity (TFP) in those industries with sufficiently high skilled labour. Another robust result emerging from the ex-post literature is the large empirical pass-through rates (Arlinghaus 2015), indicating that direct competitiveness effects are actually limited, and other agents (e.g. consumers) bear the costs of the policy.

A number of recent empirical papers have started to investigate the divergence between consumption-based and production based emissions as indicator of the emissions that are embedded in international trade (Wagner, 2010, Davis and Caldeira, 2010). Indeed, the geographical definition of emissions hides the fact that some countries, such as the EU and more generally industrialized regions, have become net carbon importers, while some of the emissions linked to the production of goods consumed in Europe are produced elsewhere (Davis and Caldeira 2010, Mir and Storm, 2016). Based on this evidence, it has been suggested that consumption-based policies are necessary.

Dechezlepretre and Sato 2014 identify several gaps in the empirical literature. The empirical evidence on the pollution haven hypothesis is mixed and studies should look for evidence about the comparability of environmental efforts, as well as about the effectiveness of different measures addressing competitiveness effects. The literature has not explored the benefits of the regulations, especially in terms of health and technology benefits. Most studies focus on one individual indicator of competitiveness, whereas an assessment on multiple indicators (e.g. trade, employment, productivity) is missing. A key issue will be to gather improved data to measure policy stringency especially in developing countries and to determine credible methods to compare the policy stringency between different policy instruments.

3.2 Ex-ante model-based evidence

Two recent reviews have surveyed the recent ex-ante literature focusing on CGE approaches, Carbone and Rivers (2017) and Branger and Quirion (2014). Here we summarize the main findings from that literature as well as the new evidence that has been published over the last years, 2015 included. Most ex-ante studies, being based on empirically-calibrated CGE, represent all sectors of the economy with different aggregations generally meant to emphasize EITE sectors and have a global coverage, again with regional aggregations that vary across models. Partial Equilibrium models instead generally provide a more detail analysis of specific sectors, e.g. the cement industry (Allevi et al. 2016), or energy-intensive sectors (e.g. Bassi et al. 2009 examine iron, steel and ferroalloy products; primary and secondary aluminum; paper and paperboard mills; petrochemicals; alkalies and chlorine manufacturing), in specific countries or regions, e.g. Europe and the Mediterranean area (Allevi et al. 2016) and US (Bassi et al. 2009).

In terms of emission scope, most studies focus on scope 1 and 2. Ghosh et al. (2012) is the only study (among the papers reviewed in this deliverable and based on a fully-fledged CGE model) that consider also scope 3 emissions. Ghosh et al. (2012) compare the efficiency, distributional and emission leakage effects of border tax adjustments (BTAs) as part of unilateral climate policies that are based on carbon dioxide (CO_2)-only versus those based on all greenhouse gases (GHGs). Border tax adjustments are based on embodied carbon content of the product which is estimated by a detailed multi-regional input–output (MRIO) framework. The study shows that broadening the scope of BTA to all sectors and to non-CO_2 emissions can even lead to negative carbon leakage. In terms of type of leakage, the literature does not explicitly refer to either operational or investment leakage, if not with the exception of a few studies that explicitly focus on investment leakage (Kriegler et al. 2015, Weitzel et al 2012, Bosetti and De Cian, 2013). Investment leakage is also mentioned in the context of shifting R&D and market launch abroad by international companies: from this perspective, using revenues from carbon pricing mechanisms for supporting industrial innovation may be seen as preventing such "innovation investment leakage" (Antimiani et al. 2016). Most studies report results in terms of sectoral output, exports, imports, and employment (Carbon and Rivers 2017), and focus on leakage in terms of emissions.

The most investigated transmission mechanisms are the energy market effect and the competitiveness effect. Partial Equilibrium models do not feature the former channel (Branger and Quirion 2014). The literature has investigated a wide range of climate policies, from stylized carbon taxes, to more realistic policies such as the Kyoto Protocol, the EU-ETS and the Copenhagen pledges (Antimiani et al. 2016, Kriegler et al. 2015, Lanzi et al. 2012). Also a wide range of measures to address leakage have been analyzed, though the focus has been on Border Carbon Adjustments (BCA), different allocation schemes, output-based rebates, exemptions and linking carbon markets. Due to data limitations, CGE models do not fully capture heterogeneity of production processes in terms of energy- and emission-intensity. While this leads to underestimation of competitiveness impacts for particular activities, the level of data aggregation has limited impact on the assessment of macroeconomic impact and overall carbon leakage rates (Alexeeva-Talebi et al 2012, Caron 2012), although figures at the sectoral and firm level could differ when analysed at a more disaggregated level.

The stream of literature using ex-ante approaches unambiguously point at positive leakage in most cases. The strong agreement seems to be driven by common assumptions (Carbone and Rivers 2017). Branger and Quirion (2014) conduct a meta-analysis on 25 studies published until 2012, altogether providing 310 estimates of carbon leakage ratios according to different assumptions and models. The typical range of carbon leakage estimates are from 5% to 25% (mean 14%) without policy and from −5% to 15% (mean 6%) with BCAs. Carbone and Rivers (2017), which is more recent, confirm the range of leakage estimates between 10-30%, while Boringher et al (2017) also find a range of 5-30%. There are outliers with leakage rates above 100% under less conventional assumptions on international factor mobility or market power (Babiker, 2005). Branger and Quirion (2014) also suggest that partial equilibrium studies, which do not feature the energy market channel, tend to find lower leakage rates compared to CGEs.

As summarized in **Error! Reference source not found.**, most ex-ante analyses do not account for endogenous and induced technological change, and therefore miss the mechanism that could lead to negative leakage. This might be another reason behind the divergence between the results from ex-post and ex-ante studies, as ex-post studies strongly agree on the induced effect of climate policy. Gerlagh and Kuik (2014) study carbon leakage in the presence of endogenous technical change (ETC) and international technology spillovers. The paper addresses the issue first with an analytical model of carbon leakage introducing first endogenous technical change and then allowing for international spillovers. Carbon leakage is analysed through two versions of the model based on two channels: the energy channel based on international trade of energy commodities; and the pollution haven channel based on trade of energy-intensive manufactured commodities. In the numerical simulation, the rate of leakage amounts to 9.6% without ETC and spillovers, and falls to 2.6% when spillovers factored in the simulation. The sensitivity analysis shows that carbon leakage could become negative with moderate levels of international spillovers. Parrado and DeCian (2014) analyse technology spillovers embodied in international trade using a CGE model modified to take into account an endogenous relationship between machinery and equipment imports (the vehicle of embodied technology) and energy - and capital-biased technical change. The paper analyses the interaction of climate and trade policies in the presence of such spillovers and also study the effects on carbon leakage. The climate policy simulates an increasing carbon tax levied on CO2 emissions on developed countries only for the period 2002-2050. The carbon leakage rate is not provided, but positive. The analysis shows the impact of spillovers on effectiveness of trade policies at reducing leakage. The analysis also combines the carbon tax with border trade adjustments showing how spillovers: i) reduce the effectiveness of BTA, and ii) can make trade liberalization a more interesting policy to address leakage by stimulating the diffusion of clean technologies. Gonseth et al (2014) focuses on the role of human capital and shows that indeed human capital can reduce leakage by attenuating the negative impact of a carbon tax on firms' competitiveness.

The range of leakage estimates in the ex-ante literature can be attributed to a set of key assumptions summarized in **Error! Reference source not found.**. Carbone and Rivers (2017) note that main outliers deviate from conventional assumptions regarding market competition and international trade structure. Increasing returns to scale in EITE or assumption about homogeneity in the goods produced by EITE industries in different countries are assumptions that allow for larger relocation across countries.

Table 2: Key assumptions affecting leakage rates in ex-ante studies.

Channel	Assumption	Impact on Leakage Rate	Example
Competitiveness	Returns to scale (RS)	Increasing RS make sectoral output more sensitive to regulation stringency and increase Leakage Rate (LR)	Babiker (2005)
	Homogeneous goods	Homogeneity makes output more sensitive to regulation stringency and increase LR	Babiker (2005); Balistreri and Rutherford (2012)
	Armington elasticities; price elasticities of imports/exports	Lower elasticities make substitution more difficult and reduce LR. Higher price elasticities of imports/exports increase LR	Alexeeva-Talebi et al (2012) and Demailly and Quirion (2008)
	Capital mobility across sectors	Sector-specific capital increases external	Lanzi and Sue Wing (2013)

		leakage	
	Capital mobility across regions		Carbone and Rivers (2017)
	Heterogeneous firms		Balistreri and Rutherford (2012)
	Emission/sector coverage	Broader coverage reduces leakage	Gosh et al (2012)
	Sectoral aggregation	A finer sectoral disaggregation beyond widely used database aggregates (i.e. GTAP) can increase LR	Caron (2012)
Technology Spillovers	Spillovers, Endogenous technical change	Induced Technical Change, Endogenous Technical Change, spillovers reduce leakage	Gerlagh and Kuik (2014), Parrado and De Cian (2014)
Energy markets	Fuel supply elasticity	Constant elasticity of fuel supply reduces leakage	Boeters and Bollen (2012)
	PE vs GE	CGE estimate larger LR because PE do not include the energy market effect	Branger and Quirion (2014)
Income effect	Demand elasticity	Lower elasticity reduces leakage	Demailly et al (2006)

Source: Authors' elaboration based on the literature reviewed in this deliverable

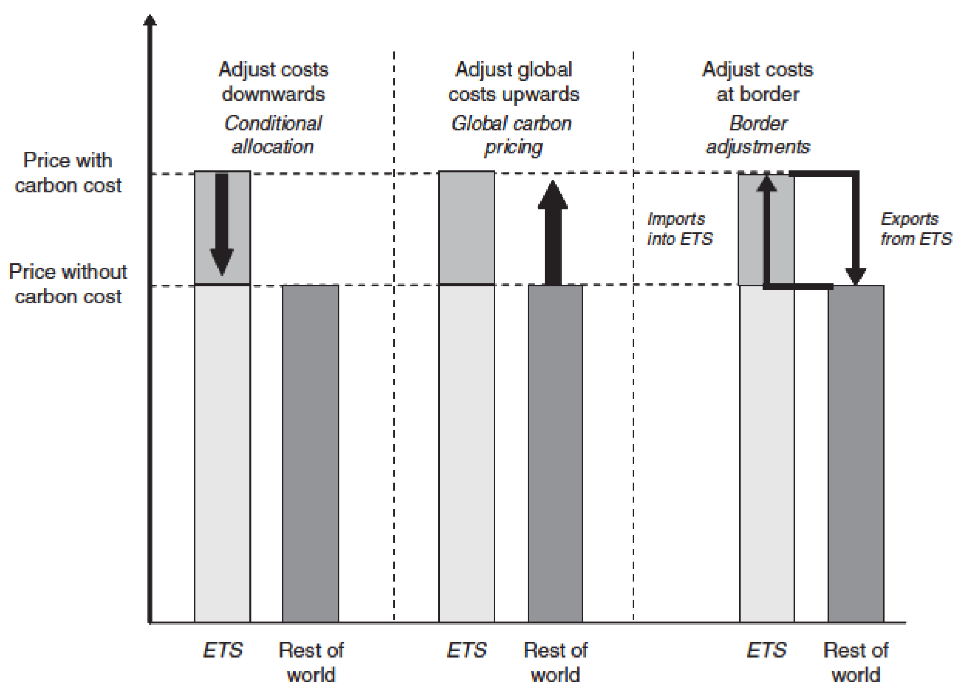
Carbone and Rivers (2017) identify a list of research priorities the ex-ante modeling community could address. Given the importance of industry and trade structure, more work should investigate alternative specifications. Given the political interest in job implications, CGE analyses could try to investigate the role of labour market imperfections. Given the ample evidence from the ex-post literature on the policy-induced innovation attempts to include this additional feature in ex-ante approaches is also advisable. Both Carbone and Rivers (2017) and Dechezleprêtre and Sato, (2014) point at the growing implementation of climate policies as an opportunity to gather more data that will allow the evaluation of the performance of those policies using ex-ante and ex-post approaches, and then compare the results with goal of improving the credibility of CGE assessment of competitiveness. Kehoe (2005) performed a similar evaluation in the context of international trade.

4 Feasibility of policy options to address carbon leakage risk

A range of options are available to policy makers to attempt to mitigate the potential for carbon leakage from EITE industries that are subject to a carbon price above that of competing jurisdictions. This section presents key examples of such options, and provides an overview assessment of different aspects of their 'feasibility', including their acceptability to EITE industries, the public and policy makers, their legal viability, and administrative feasibility. As the specifics of such an assessment will vary according to the specific design and circumstances in which an instrument is introduced, the number of permutations of which are vast, discussion is restricted to relatively general considerations, and for the introduction of a new instrument. Discussion of the theoretical and empirical effectiveness and cost-efficiency of these options are presented only where these elements influence issues of feasibility.

Options for tackling carbon leakage fall into three main categories: (a) options that seek to adjust carbon costs downwards for firms within the pricing regime, (b) those that seek to adjust carbon costs upward for firms outside the pricing regime, and (c) those that adjust carbon costs at the border of a given jurisdiction. **Figure 3**, below, summarises these three categories, with the EU ETS given as the domestic carbon-pricing example.

Figure 3. Option categories for tackling carbon leakage



Source: Grubb et al, (2013)

The following three sub-sections discuss the options and instruments that fall into these three categories. Only those that relate to mitigating the risk of carbon leakage from the pricing of direct (i.e. Scope 1) emissions are considered.

4.1 Adjusting carbon costs downwards for domestic firms

The options presented below seek to adjust carbon-related costs downwards for domestic firms in the presence of a carbon price, *a priori* maintaining a marginal abatement incentive equivalent to that if such measures are not introduced. As such, discounts or exemptions to carbon pricing instruments (taxes or tradable permit systems), or carbon price control mechanisms (e.g. price ceilings) are not considered. Instruments to remove the carbon cost burden upon export of a product are examined under Section 4.3.

4.1.1 Free Allocation of Tradable Permits

The free allocation of permits under an emissions trading system (ETS) seeks to shield the recipient from bearing the cost of purchasing allowances, which might otherwise have been allocated via auction. However, given that these permits hold a market value, the incentive to abate emissions up to the marginal cost equal to the value of the permit, remains (after which permits may be bought or sold, depending on the emissions of the firm and the volume of permits allocated).

Various free allocation methodologies may be employed, with varied consequences for feasibility. These include allocation of permits to an installation based on historic or expected future growth rates of emissions, fuel inputs or product output (in terms of market share), or emission intensity per product output ('benchmarking'). Each option may be used statically (i.e. using emissions, fuel inputs or product output experienced in the base period, or projected during the based period), or dynamically, where the basis for allocation is updated over time. In practice, a combination of these options and approaches may be employed (either in parallel or in sequence).

It is common practice to allocate all or significant proportion of permits to (perhaps a subset of) participants in an ETS, with the most common allocation method ('grandfathering') based on the emissions of an historic base year or period (as in the EU ETS Phases 1 & 2 – 2005-2012), due to its high political acceptability (Stavins, 1998). Grandfathering allocates scarcity rents to the recipient of the permits, rather than to the issuing authority as in the case of an auctioning system (Borghesi & Montini, 2015). The use of historic emissions as a baseline may lead to over allocation of permits, which may subsequently be sold (or banked for future use). As such, participants are more likely to accept the introduction of a system with permit grandfathering, than without. However, grandfathering permits may generate excessive profits, through two channels. The first is through the sale of permits that are allocated in excess of actual emissions. De Bruyn *et al* (2016) estimate that for the period 2008-2015, the industry sector in the EU ETS generated profits of €7.5 billion from the sale of over-allocated permits. The second channel is the pass-through of the opportunity costs (of not reducing output – and therefore emissions - and selling the permits) presented by freely allocated allowances to the consumer, generating windfall profits. De Bruyn *et al* (2016) estimate that for the period 2008-2015, 15 industrial sectors in the EU ETS across 20 Member States accrued over €29 billion in windfall profits in this manner. Such issues may reduce public acceptability of permit grandfathering, although as the EITE sectors commonly produce intermediate products, the general public has relatively little direct exposure (and consequently, awareness) of such phenomena (in contrast to windfall profits in the power sector, for example, which have also been substantial in the EU ETS).

Excessive profits resulting from over-allocation may be tempered to some degree by frequent updating of the baseline against which allowance allocations are calculated (either historic or projected emissions). However, this may create an incentive to maintain artificially high emissions, if it is assumed that future allocations will be based on contemporary or projected future levels of emissions. Additionally, the computation of new baselines may place additional administrative burden on the relevant authority.

Output-based allocation (OBA), where a set volume of permits are freely allocated based on market share of a firm in a given sector, may reduce the potential for windfall profits. OBA penalises firms with high emission intensity and rewards those with low emission intensity, and thus incentivises increased output alongside emissions abatement. By no longer experiencing the incentive to reduce production (and experiencing an implicit production subsidy), opportunity costs from the freely allocated permit are largely removed. Ex-post adjustment to allowance allocation in a subsequent compliance period based on actual output share of the previous period reduces the risk of profit from over allocation. OBA is structurally equivalent to output-based rebating of emission tax revenues (Boringher et al. 2017), discussed below.

By reducing the risk of windfall profits, public acceptability may increase compared to permit grandfathering (although, this also means that the carbon price signal is not passed-through to the intermediate or final consumer). However, for the same reason (and the introduction of real carbon cost liability for some participants, if total allocated volume is less than actual emissions), along with relative uncertainty that stems from ex-post adjustment, industrial sector acceptance is likely to be reduced. Political acceptability will largely depend on the relative influence of the industrial sectors concerned, and the general public. However, thus far

OBA has been successfully introduced only by the Quebec ETS, and for just 25% of the allowances freely allocated to industrial sectors determined to be at risk of carbon leakage (allocated ex-post)[6]. From an administrative perspective, determining the market share of output for some sectors may be straightforward, for others it may be relatively cumbersome. For example, if market share in the clinker sector is defined in terms of tonnes of output, producers may have an incentive simply to increase the weight of clinker, rather than volume of output (Colombier & Neuhoff, 2007). Establishing an OBA system that maintains the appropriate incentives may therefore be administratively highly complex.

The 'benchmarking' approach to free allocation assesses the emissions intensity of the output of an entity against a sector-specific value. Entities that meet or exceed this threshold may receive all or a proportion of their allowances for free, whilst those that are more emission-intensive may receive none, or proportionally less. The incentives created, and consequences for windfall profits and over allocation, are similar to those for an OBA-only approach. However, elements of feasibility are altered.

Benchmarking may be more flexible than an OBA approach. Benchmark values may be negotiated and set as appropriate and acceptable to each sector, and may be altered over time. In order to create the greatest abatement incentive, the benchmark value should be set at that permitted when using best practice or the best available technologies (BAT). However, as the output of the majority of firms would likely rest under this value, acceptability for participants is likely to be low (and, consequently, may be the effectiveness of this option in mitigating the risk of carbon leakage). Additionally, in order to effectively determine what a benchmark based on BAT might be, access to industry data is likely to be essential. Such access may not be forthcoming in such a situation. Even if such data is made available, setting establishing benchmarks for each EITE sector (or sub-sector) and common definitions against which they may be set, along with appropriate measurement and verification systems, may be administratively highly burdensome (Jegou & Rubini, 2011).

Benchmarking of some description has been employed for industrial sectors in various ETS instruments around the world including, the Guangdong, Hubei and Shanghai Chinese pilot instruments, the Korean, Swiss and Californian ETS', and the EU ETS (ICAP, 2017). However, extra dispensation is often afforded for sectors or sub-sectors deemed at risk of carbon leakage. For the EU ETS, from 2013 onwards, benchmarks for industrial installations producing 52 different products have been set as the average GHG emissions of the 10% least

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[6] https://icapcarbonaction.com/en/

emission-intensive installations producing that product. Installations that meet these benchmarks receive 100% free allocation for their emissions, with others receiving less in proportion to their emissions. Installations in sectors considered to be at risk of carbon leakage, however, all receive 100% free allocation at the benchmark value. For Phase 3 (2013-2020), 150 sectors or subsectors are considered at risk of carbon leakage, accounting for 97% of industrial emissions covered by the EU ETS (DECC, 2015). A parallel approach exists for the Swiss ETS, whilst industries and subsectors considered at risk of leakage in the Korean ETS receive 100% free allocation for all emissions (ICAP, 2017).

From a legal perspective, under the World Trade Organisation (WTO) Agreement on Subsidies and Countervailing Measures (SCM), it is likely that 100% free allocation to all participants in an ETS is permissible. However, a situation where some sectors or participants receive free allocations where others do not may constitute a subsidy under the SCM, and thus be open to claims of unfair trade practices. However, no definitive conclusion has yet been reached, and the result would likely depend on the specific design of and free allocation approach taken by each instrument (Coppens, 2014; Jegou & Rubini, 2011).

4.1.2 Output-Based Rebates

As the name suggests, output-based rebates (OBR) seek to return the revenue generated by a carbon tax to participants in proportion to their output, such that sectors (or sub-sectors) experience no net cost on aggregate. OBR may be implemented by using output as a proportion of market share (and operate as equivalent to OBA of tradable permits), or linked to an emission intensity value (and operate as equivalent to benchmarking allocation of tradable permits).

The introduction of an environmental tax (for GHG emissions or otherwise) may increase public acceptability if the revenue generated is earmarked for a clear and specific purpose (Kallbekken & Saelen, 2011). Indeed, around two-thirds of carbon pricing revenue generated in 2016 is allocated for a specific purpose (e.g. further emission mitigation action, or the reduction of other taxes, as discussed under 'Environmental Tax Reform, below). Similarly, EITE sectors subject to a carbon tax are more likely to accept the instrument if revenues are returned through OBR (Bernard *et al*, 2007). Other elements of industrial, public, political acceptability, and administrative feasibility, are likely to be similar to OBA and benchmarking allowance allocation under a tradable permit system, for the two permutations of OBR described above, respectively. However, a difference lies in that under a carbon tax coupled with OBR, an actual transfer of funds from regulated entity to regulating authority occurs (rather than implicit value). In a world of competing priorities for government funds and the

potential need for flexibility in allocating such funds, there may be pressure to avoid the introduction of instruments that encode revenue earmarking (particularly for all revenue generated) into their operation.
However, at present, no carbon tax instrument returns revenue to EITE or other industrial sectors through OBR (Carl and Fedor, 2016). A common example of an environmental tax with OBR is the Swedish NOx tax, applied to NOx emissions from large stationary combustion plants producing at least 25 GWh of useful energy, annually. All revenue (except a small proportion for administration costs) is recycled to participants per unit of energy output. However, EITE industries are exempt from the tax. Such an exemption is seen as a key reason behind the ability for the Swedish government to introduce the instrument (OECD, 2013).
From a legal perspective, OBR unambiguously functions as a subsidy to production, and as such may be open to challenge under WTO law. If OBR are found to be actionable, even if they promote improved environmental outcomes, no explicit General Agreement on Tariffs and Trade (GATT) Article XX exists in the SCM agreement (Fischer and Fox, 2012). As such, a carbon tax with OBR for EITE industries may fail the test of international trade law.

4.1.3 Investment Support

Revenues from carbon pricing instruments may be used to provide investment support (or subsidies) that seek to reduce the cost of new, low-carbon or more efficient equipment to help reduce the carbon cost burden (particularly for capital-intensive sectors), and in turn reduce (principally) investment leakage (Carbon Trust, 2010).
Investment support is likely engender less enthusiastic support from EITE industries as a mechanism to counter the additional cost of emissions than output-based rebates, and particularly free allocation of tradable permits. As suggested above, investment subsidies are likely to only (perhaps partially) counter the additional cost of a carbon price in the short-term for firms for which capital equipment has reached the end of its useful or economic life, and requires replacing. For other firms, the (near) full cost of the pricing instrument will be borne (at least in the short-term). As such, although investment leakage in the long-term may be buffered, the risk of operational leakage in the short-term remains.
In order for investment support to be permissible under WTO or other subsidy-related law (e.g. State Aid rules in the EU), it must not constitute a distortionary subsidy. For this to be the case, the target and level of support provided should be closely linked to the rate of innovation and carbon intensity of supported technologies. This helps to ensure the objective of the support is clear (and does not indirectly constitute a protectionist measure), and the rate of support is not excessive (Carbon Trust, 2010; Holzer, 2014). Although this would

design against excessive cost to governments (which may or may not be fully compensated by income from the carbon pricing instrument), it may be administratively highly burdensome. In addition, as with a benchmarking approach to free tradable permit allocation, access to industry data may be required to effectively track such metrics, which again may not be forthcoming. These issues in turn render the political acceptability of introducing investment support as the only instrument to tackle the potential for carbon leakage, relatively low.

4.1.4 Environmental Tax Reform

Environmental tax reform (ETR) involves a shift in the target of taxation from ‘goods’ such as labour or capital (e.g. income taxes, social security contributions or corporation taxes) to ‘bads’ such as the generation of pollution (e.g. carbon pricing). By doing so, a ‘double divided’ of environmental improvement (e.g. reduced pollution) and stimulation of other positive economic activity (e.g. employment) may be achieved.

Using revenue to reduce, for example, labour costs for employers, may help to counter the additional cost burden levied through a carbon price (either a tax or ETS) (Kosonen & Nicodeme, 2009). However, the extent to which additional costs are neutralised depends on the relative inputs required (and emissions created) by the firm. Using this example, the most energy- (or emission-) intensive and least labour-intensive firms would be subject to a higher net cost than firms with the opposite characteristics. For EITE industries, it is likely that a net cost (and thus the risk of carbon leakage) would indeed remain. The value of the net cost (or benefit) would also vary over time, as such inputs and other cost elements vary (particularly for an ETS, with variable prices). Although an ETR may be administratively simple to introduce through a single adjustment in tax rates, it is infeasible to dynamically alter rates to maintain revenue neutrality (and thus minimise net costs to varied participants and the administrating authority). As such, ETR as a carbon leakage protection mechanism is likely to be politically difficult.

Indeed, although several examples of ETR around the world are available (including those coupled with carbon pricing instruments), no examples of ETR being used as a carbon leakage protection mechanism are forthcoming. Instead, analysis often centres on the risk of carbon leakage induced by ETR (see, for example, Andersen *et al*, 2007). There are no particular legal barriers to the introduction of ETR.

4.2 Adjusting carbon costs upwards for non-domestic firms

In theory, the first-best option to remove the risk of carbon leakage by EITE sectors is the introduction of a global carbon price or market, with EITE sectors in all countries participating (Lanzi *et al*, 2013). However, this simply removes the issue of differentiated carbon prices experienced by EITE sectors in different jurisdictions, rather than providing an option to tackle the potential for carbon leakage in their presence. As such, this option is not discussed.

4.2.1 Sectoral Agreements

Broadly defined, sectoral agreements aim to broaden global participation in climate change mitigation activities in a given sector (or sectors) through a range of options, including the sharing and transfer of best available technologies and practices, benchmarking across regions and countries, collaborating in research and development, binding mitigation targets, or coordinated policy mechanisms (Reinaud, 2008; 2009). From the perspective of addressing carbon leakage, the preferred option would be a sectoral agreement that places binding targets for sectoral abatement for each country that accounts for a significant global market share of the output of the EITE sector of concern. This would require these countries and sectors to introduce instruments that would explicitly or implicitly introduce a carbon-related cost, thus reducing the differential between countries with a pre-existing carbon-pricing instrument, and those without. However, it is highly unlikely that emerging economies would voluntarily seek to participate in a mechanism that would necessarily reduce their competitive advantage, without incentives to do so. Such incentives would likely involve some form of financial and/or technology transfers (through, perhaps, a sector-specific Clean Development Mechanism, CDM). However, such an approach may exacerbate the risk of carbon leakage, by improving competiveness of the firms in the recipient nation (Reinaud, 2009). In addition, financial transfers may constitute an actionable subsidy under WTO Law. An alternative approach may be to direct financial incentives to the government of the recipient nation, conditional upon the sector in question achieving the agreed targets. However, the political feasibility of such an approach in both donor and recipient nations is questionable (Colombier & Neuhoff, 2007). In summary, any sectoral agreement that came into effect is unlikely to equalise carbon costs faced by sector firms in different counties, at any level greater than zero (Grubb *et al*, 2013). In addition, the burden of administering such a system may also be prohibitive. All countries would require firm-level emissions inventories, which may in turn require substantial capacity building in emerging economies for data collection, monitoring, verification and enforcement, before any agreement may come into effect (Baron *et al*, 2007).

4.3 Aligning Carbon Costs at the Border

4.3.1 Border Carbon Adjustments

Border Carbon Adjustments (BCAs) seek to equalise carbon costs by imposing a carbon price on emissions embodied in imports from non-regulated jurisdictions, at a value equal to the regulated jurisdiction (either through a direct levy if the instrument is a carbon tax, or requiring the purchasing of allowances under an ETS), and rebating the carbon costs for the emissions embodied in exports from the regulated jurisdiction to non-regulated jurisdictions. The carbon price is then limited to products consumed within the regulated jurisdiction, regardless of where these products originate. Although relatively simple in concept, various political, legal and administrative complications arise (Grubb *et al*, 2013).

Substantial administrative challenges present themselves concerning the value and implementation of import and export adjustments, and in determining the scope of participating products and firms. For import adjustments, regardless of whether the domestic carbon pricing instrument is a tax or an ETS, and largely regardless of the specific design (for example, whether importing firms must purchase tradable permits, or receive freely allocated permits either for all embodied emissions or at a benchmarked level), the embodied emissions in the imported product must be measured, reported and verifiable, to determine the level of tax due, or the number of permits to be freely allocated or purchased. As with a sectoral agreements, the administrative challenge of establishing such a system would likely be substantial for emerging economies. An option to reduce such a challenge may be to set a 'default' import adjustment tax or tradable permit requirement, set at an average emission intensity level. Importers may then have a 'right to refute', whereby they may submit evidence to prove their products are produced at an emission intensity lower than the benchmark, and are granted exemptions from the import adjustment (however, this may incentivise the most efficient firms in the external jurisdiction to prioritise exports to the carbon-constrained jurisdiction, with less efficient plants servicing local demand, potentially increasing transport-related emissions) (Grubb *et al*, 2013). For export adjustments, if the rebate level were to be set at a nationwide average carbon cost per unit of product exported, this would constitute an export subsidy for more efficient firms, and a net cost for less efficient firms. Setting this average value becomes particularly difficult under an ETS, with permit prices varying over time, and with firms likely holding permits purchased or freely allocated at different times (and thus prices). To remove such distortions, the rebate must be specific to the actual carbon cost involved in producing the specific unit of product exported. Such monitoring and reporting requirements by governments and firms would be complex, and highly administratively burdensome (Reinaud, 2008).

Another key administrative challenge is determining which products from a given EITE sector, and which countries with such EITE sectors, should be covered by the BCA. Regarding products, if the BCA covers only raw material produced by EITE sectors (e.g. cement, paper or steel), and not products that incorporate these materials (e.g. vehicles), gaming strategies may be triggered, where materials are first transformed or incorporated into products which are not covered by the BCA, before export (potentially damaging the competitiveness of downstream industry). However, incorporating a wider range of raw materials and downstream products is likely to be administratively infeasible. (Reinaud, 2008; 2009). In parallel, the countries in which 'comparable efforts' at emission reductions from EITE sectors, and thus comparable carbon costs, are and are not present, and thus should be included or excluded from the BCA, must be determined. Any methodology to objectively determine this is likely to be highly complex, subject to poor data availability and quality (as countries are unlikely to provide accurate data, if it exists, that would likely lead to their industries being subject to such an instrument), and be highly contested.

Such administrative challenges are intertwined with legal and political concerns. For import adjustments, WTO principles of non-discrimination must apply, as expressed through Articles III and I of the GATT (de Cendra, 2006). Article III (the 'national treatment' principle) states that measures should not discriminate against foreign producers of 'like' products, whilst Article I (the 'most favoured nation' principle) states that privileges applied to any WTO party must be applied to all. As such, importers cannot bear a carbon price on any terms different than domestic firms, and such terms must be applicable to all nations, if they are applicable to any. For an ETS, a benchmarking approach would like satisfy these requirements (Carbon Trust, 2010). However, in the case of an 'average' benchmark coupled with a 'right to refute', the risk of affording some domestic firms effective export subsidies would risk challenge under the SCM. Although placing a small, notional import tax on imports from countries without 'comparable effort' (which is demonstrably smaller than the cost borne by domestic producers) is likely to be legally permissible and (relatively) administratively simple, its ability to prevent the risk of carbon leakage is also much reduced. Although a BCA may be exempted from these rules under Article XX of the GATT, it must first be shown that the instrument is necessary for 'the protection of a global resource', i.e. that is sought primarily to induce stronger action on climate change, rather than to protect against the risk of carbon leakage (Carbon Trust, 2010).

If any WTO member feels any of the above principles are being violated, or they are otherwise against the introduction of a BCA that would impact their EITE industries or otherwise be under burden, they may invoke lengthy WTO dispute procedures in order to delay its introduction. Although prior discussion and agreement over the terms of the BCA may avoid such disputes, it is likely this would only occur if significant concessions were given. Indeed, BCAs have been proposed in the USA (in the American Clean Energy and Security Act of 2009 and the American Power Act of 2010, neither of which passed into legislation) (Holzer, 2014), and introduced (after a fashion) in the EU, by bringing domestic and international aviation into the scope of the EU ETS (by requiring airlines to hold allowances for their emissions for any flight to or from any EU airport, even if their origin or destination lies outside the EU, this constitutes a BCA). However, this was almost immediately suspended for international flights after a broad coalition of countries (including Russia, India, the USA and China) heavily opposed the measure (Foure *et al*, 2013). Innovative design options, such as the redistribution of at least part of the revenues generated from a BCA to source countries, may help to ease such tensions in future proposals (Fischer and Fox, 2012). However, it is clear that there is tension between elements of administrative, legal and political feasibility of a BCA, which may prohibit its practical application in the near future.

4.3.2 Consumption-Based Pricing

A carbon price levied on the consumption of goods produced by EITE sectors in concept eliminates the risk of carbon leakage associated with unilateral production-based carbon price, as the consumption-based price applies to products regardless of their origin (Eichner & Pethig, 2015) (however, analysis in the literature questions this effect in practice – see Jakob *et al* 2013). As such, it is functionally equivalent to a production-based carbon price with a BCA (Böhringer *et al*, 2017), and as such broadly experiences much of the administrative and (external) political issues experienced by a BCA. However, as the charge applies on the same terms for all products regardless of source, there can be little contest that Articles I and III of the GATT are satisfied, and that the SCM is not violated, as long as revenues generated are not directly recycled back to domestic firms (Neuhoff *et al*, 2016).

Although political issues between jurisdictions may remain similar to a BCA, the political feasibility of a consumption-based tax within a jurisdiction may become more difficult. Other carbon leakage protection measures (e.g. free allocation, OBR) may reduce or even prevent a carbon price signal from reaching the consumer (or even incentivise increased output), there is little incentive to reduce demand or for product substitution. With a consumption tax, although firms may no longer be concerned with the risk of carbon leakage, the price signal is applied to the consumer, supressing demand and encouraging substitution. Such an effect (along with the removal of the possibility for windfall profits) may render this option difficult to accept for both EITE sectors and the consumers, who both bear a direct cost, and thus politically difficult to implement.

Various authors consider the greatest potential for consumption taxes to be their ability to improve the functioning of existing carbon pricing instruments with other options for the mitigation of carbon leakage. For example, Neuhoff *et al*, (2016) and Böhringer *et al* (2015) examine the use of consumption taxes with an upstream carbon-pricing instrument with OBR. Both studies conclude that a consumption tax would indeed improve the functioning and outcomes of a pre-existing carbon price. As noted above, such a combination would be equivalent to a production-based tax with a BCA, with an easier legal route to implementation than a BCA, effective downstream carbon price signalling, and offsetting of the incentive for increased production generated by an OBR system.

Table 3 summarises in general terms the political feasibility (typically driven by acceptability by the EITE industries themselves, and the general public, if relevant), administrative feasibility, and legal compatibility. However, such a summary is necessarily generalised, with each specific element to a large degree dependent on the design of the specific measure and carbon pricing mechanism, and the context in which they are introduced.

Table 3: Feasibility of carbon leakage protection measures

	Political feasibility	Administrative feasibility	Legal feasibility
Free allocation of permits	High	High	High
Output-based rebates	Medium	Medium	Medium
Investment support	Low	Medium	Medium
Environmental tax reform	Low	High	High
Sectoral agreements	Low	Low	High
Border carbon Adjustments	Low	Medium	Medium
Consumption-based pricing	Medium	Medium	High

Source: Authors' elaboration based on the literature reviewed in this deliverable

5 Conclusion

The new climate agreement reached in Paris in December 2015 represents an unprecedented commitment to address climate change with increasingly ambitious mitigation actions. In this new international context where many countries have pledged to contribute in favour of mitigation efforts, the concerns about the effectiveness of climate policies and the competitiveness of industries within countries implementing such policies need to be assessed and addressed in a different way from the past where only a handful of countries were committed to fight climate change. The current bottom-up architecture implies that for many years to come countries will face different carbon prices, with international consequences that could induce countries to consider additional policy measures to address carbon leakage and competitiveness. In light of previous experiences and their corresponding assessments reviewed in this deliverable, the wide participation to the Paris Agreement may constitute a fertile terrain where issues like carbon leakage will no longer been seen as a threat against lowering global warming but could constitute an opportunity to create synergies and increase competitiveness in low carbon industries which can eventually be reaped by the rest of the economy.

In this review we summarized the main conclusions of recent studies that considered past evidence (ex-post) as well as future scenarios pondering different policy settings (ex-ante). Taking into account the empirical and modelling evidence, we reviewed also the feasibility of several alternatives proposed to address carbon leakage and competitiveness concerns.

Our literature review confirms the tendency for ex-ante studies to find higher leakage rates compared to ex-post studies. Several explanations have been put forward also by previous reviews (Dechezleprêtre and Sato, 2014; and Carbone and Rivers 2017). It could be due to the lack of stringency of most of the climate policies that have been implemented so far (Dechezleprêtre and Sato, 2014) compared to the more ambitious policies that can be simulated by ex-ante studies. Another explanation could be that ex-ante studies generally assume that climate policy has strong relocation effects on energy-intensive production. However, that assumption is challenged by empirical evidence suggesting it is not the case (Barker et al. 2007) because countries adjust policies in order to avoid these effects. In other words, real-world climate policies implemented so far have included compensation mechanisms in their design (Dechezleprêtre and Sato, 2014). Both Dechezleprêtre and Sato (2014) and Carbone and Rivers (2017) point out the need to develop more sophisticated methods to compare ex-ante and ex-post studies. Because climate policy is a relatively recent phenomenon, data limitation has held back this form of comparison. However, future research could exploit the growing data availability after the implementation of recent climate policies, also in developing countries, to pursue this approach.

Carbone and Rivers (2017) note that this would constitute an important step for increasing the credibility of CGE-based assessments.

By comparing the findings that emerge from the ex-post and ex-ante literature, the following conclusions can be made. The degree of concern about carbon leakage and climate policy effectiveness, which are closely related to competitiveness of firms and/or industries, depends on the size of the coalition implementing a climate policy. Whereas initially there were few countries committed to emissions abatement, now the number of countries adhering to limit global warming has clearly increased after 2015. This opens a window of opportunity for increasing competitiveness in low carbon industries as long as the following conditions are met. To start off with, the role of technological change is of crucial importance in lowering the costs of the transition and could become the initial lever to foster competitiveness in low carbon industries. This must be accompanied by the diffusion and transfer of new technologies which could end-up driving a positive effect on global abatement through negative leakage. Among the alternatives to address carbon leakage that could be considered politically, administratively and legally feasible are the free allocation of permits, output based rebates, and consumption-based pricing.

A priority for future research is to analyze carbon leakage under the emerging heterogeneous climate policy landscape characterizing the current international policy context. In the context of wider and more ambitious climate action, innovation and spillovers play an important role for enabling competitiveness improvements in low carbon industries as well as increasing the chances of negative carbon leakage. These benefits could be the fruit of international collaboration and therefore it is also important to analyse and explore innovative design options that could put incentives at hand for all countries/sectors within and beyond a climate policy coalition. In this way, hypothesis such as the pollution haven could also be tackled since the probability of encouraging investment leakage would also be reduced. Regarding the options to address carbon leakage, the literature has focused on Border Carbon Adjustments, despite the difficulties related to implementation, free allocation and output/based rebates. More evidence is needed in order to evaluate the potential effectiveness of consumption-based pricing. Finally, the use of multidimensional indicators in future analysis such as employment, import, export, output, innovation in EITE sectors, innovation in EITE and non-EITE, will be definitely welcome also for reconciling the ex-post and ex-ante analysis.

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