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**Research Report**

## Report on the dynamic efficiency of trade-related climate policy instruments

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# ENTRACTE

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## **Report on the dynamic efficiency of trade-related climate policy instruments**

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## Executive Summary

We analyse how anti-carbon leakage measures, i.e. Border Carbon Adjustments (BCA) would interact with domestic and foreign firms' R&D investment. This report presents the results of a multi-country multi-sector model with endogenous R&D investment, calibrated with data of major world economies. The model also features endogenous market structure in order to embed the effect of changes in market concentration on innovation incentives. Our analysis shows that endogenous R&D investments have significant effects on carbon leakage rates and also increase the effectiveness of BCA schemes. It also shows that understanding the competition-innovation nexus is crucial for a better design of unilateral climate policies.

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## 1. Introduction

There is a broad consensus that technological progress is a necessary condition, even if not sufficient, to achieve climate change mitigation targets. Public policy should foster the development and adoption of low-carbon technologies, by drawing upon a broad set of available policy instruments, i.e. R&D subsidies and tax credits for households and firms. Our work focuses on policy measures that do not target innovation incentives directly but that have potential effects on technological progress and the evolution of emission intensity and energy productivity. In particular, we analyse how anti-carbon leakage measures, i.e. Border Carbon Adjustments (BCA) would interact with domestic and foreign firms' R&D investment.

This issue has received little attention in the modelling literature and only recently some studies have addressed this point in a theoretical framework (Tsai et al. 2014). This report presents the results of a multi-country multi-sector model with endogenous R&D investment, calibrated with data of major world economies. The model also features endogenous market structure in order to embed the effect of changes in market concentration on innovation incentives.

The so called carbon leakage arises when countries engaged in international trade have asymmetric levels of environmental policy stringency. For the European Union, the participation in the Kyoto protocol and the following implementation of unilateral climate policies such as the 20/20/20 package have increased the risk of carbon leakage for domestic firms. Under the third phase of the European Emission Trading Scheme (EU-ETS), European authorities have therefore introduced specific measures to avoid the reallocation of production. The European Commission has identified vulnerable sectors involved in the EU-ETS in a special list (Commission decisions 2010/2/EU and 2014/746/EU), and has guaranteed the provision of free permits to firms in those sectors in order to prevent competitiveness losses in the short-term.

Policymakers are not only concerned of the economic costs associated with the unilateral policy, but also of the fact that carbon leakage makes the policy itself less effective. In this case non-abating countries would increase their level of emissions at the expenses of national firms. According to the EU list, firms that are more exposed to the risk of offshoring are in trade-exposed sectors with relatively high emission intensity as manufacturing and the mining and quarrying sector.

### **Innovation and regulation**

R&D activities and the adoption of low-carbon technologies are important instruments for those firms to cope with the burden of the carbon pricing. Increasing the efficiency of production processes and the adoption of abatement technology reduces the long-term costs for firms to comply with the emission restriction. Yet, within the group of sectors susceptible to leakage there is a quite high heterogeneity with respect to R&D intensity (R&D expenditure as a percentage of value added). Table 1 shows the R&D intensity for 2-digit sectors for a selection of countries. Besides country differences, research expenditures are concentrated in sectors like chemicals - that includes the pharmaceutical industry - and the production of capital goods like machinery and equipment. The assessment of anti-leakage measures with multi-sector general equilibrium models should therefore account for sectoral heterogeneity in innovation capacity.

| Sector (ISIC v. 3)   | EU <sup>1</sup> | Japan | Korea | United States | China |
|--|-----------------|-------|-------|---------------|-------|
| Mining and quarrying   | .74             | 2.32  | .20   | n.a.          | .62   |
| Manufacturing  | 1.48            | 3.57  | 1.94  | 3.39          | .97   |
| Food products, beverages and tobacco   | .23             | .85   | .50   | .41           | .32   |
| Textiles, textile products, leather and footwear   | .22             | 2.62  | .37   | .89           |       |
| Chemical, rubber, plastics and fuel products   | .45             | 3.51  | 1.01  | 4.01          | .85   |
| Basic metals and fabricated metal products   | .36             | .81   | .30   | .44           | 1.60  |
| Electrical and optical equipment   | 3.83            | 9.20  | 5.32  | 12.56         | 1.62  |
| Manufacturing n.e.c. and recycling   | .41             | 1.94  | .38   | .79           | .65   |
| Electricity, gas and water supply; sewerage, waste management and remediation activities | .13             | .24   | .46   | .06           | .18   |
| Construction   | n.a.            | .17   | .34   | .03           | n.a.  |
| Total Services   | .21             | .26   | .19   | .45           | n.a.  |

Table 1: R&amp;D Intensity of different sectors, ANBERD-OECD data for 2007 (\*)

A substantial amount of studies has investigated how technological progress reacts to environmental policy. Theoretical work has analysed under which conditions pollution-saving innovation might be triggered by carbon pricing, taxation and regulation, in both closed-economy (e.g. Bovenberg and Smulders 1995, Grimaud and Rouge 2005, Gans 2012) and open-economy (e.g. Di Maria and der Werf 2008) settings. The general result in this literature is that technological progress is able to reduce the cost of compliance with an emission reduction target but in any case it cannot replace environmental taxation and regulation. Moreover, some studies find environmental policy to have a negative impact on the overall rate of innovation because of the importance of the market size effect for research incentives (e.g. Smulders and de Nooij 2003, Goulder and Schneider 1999, Gans 2012). Redirecting innovation towards abatement technologies might crowd-out other technologies and lead to negative productivity effects. So far limited empirical evidence has been produced to support the findings of theoretical work. Some studies confirm the responsiveness of green-innovation to environmental regulation (i.e. Newell et al. 1999, Dechezlepretre and Calel 2012) but the microeconomic perspective of these studies gives little insights on general equilibrium outcomes, in particular the response of aggregate R&D spending.

## Regulation and competitiveness

This project focuses on the reaction of technological progress to environmental policy in an open-economy setting. Under the direct competition of foreign firms the unilateral introduction of carbon pricing leads, first of all, to an international reallocation of production. Countries with more lenient environmental standards are expected to benefit from the production of pollution-intensive goods that are traded internationally. The existence of *pollution havens* - countries where dirty productions would be reallocated to because of unilateral environmental policies - has limited empirical support (see Copeland and Taylor 2004 for a review) and other factors rather than pollution appear to be driving the terms-of-trade and production decisions. Several studies have used applied general equilibrium models to make a more comprehensive assessment of this issue. In fact, an important channel of carbon leakage is the international market of fossil fuels, i.e. oil (Fischer and Fox, 2012) . As the interventionist coalition reduces

<sup>1</sup> GDP-weighted average of countries for which data are available: Austria, Belgium, Czech Republic, Estonia, Finland, Germany, Greece, Hungary, Italy, Luxembourg, Netherlands, Norway, Slovak Republic, Slovenia, Spain and Sweden

the use of oil, the price in the international oil market experiences a downward pressure and the demand of oil from non-abating countries rise. The Energy Modeling Forum (EMF) model comparison study (Böhringer, Balistreri, and Rutherford 2012) provides a set of estimates of the overall leakage rate ranging between 5 and 19% with a mean value of 12%, affecting mostly energy intensive and trade exposed (EITE) industries.

Trade policy instruments such as BCA could at least partly immunize countries and regions that decide to implement unilaterally decarbonisation policies from the adverse effects on the policy effectiveness and competitiveness (Markusen 1975, Copeland 1996). Such a border measure could materialize as a tax on imported carbon-intensive goods or as a requirement for the exporting country to buy domestic emission permits to offset the carbon emissions related to the production of the imported good.

### **Innovation and competition**

Only few studies have introduced endogenous technological change in the analysis of carbon leakage and they mostly use a theoretical approach. Di Maria and der Werf (2008) show with an endogenous growth model with energy-saving and energy-using innovation that in the long-term the leakage effect is reduced by technological progress taking place in the suffering EITE sectors. In a more recent contribution, Tsai et al. (2014) find that it is possible, by accounting for endogenous innovation, to have a carbon leakage effect that is not increasing in the level of policy stringency. This case requires the technical possibility for R&D to develop technologies that can fully abate pollution. Such studies show that in the long-run technological change can mitigate the carbon leakage effect and the loss in competitiveness, but they rely on a stylized framework that has little to say about real world policies.

Innovation does not only depend on the relative terms-of-trade, but is also influenced by the degree of market competition within a country. There has been a growing interest on the relationship between competition and the investment in innovation, both product and process oriented. Empirical work, e.g. Blundell et al. 1999 and Aghion et al. 2005, has found evidence for innovation to be positively affected by more competition when markets are quite concentrated, but too much competition is detrimental for research incentives. Theoretical studies have explored this issue in endogenous growth models (Smulders and van der Klundert 1995 and Bento 2014) and other settings (Aghion et al. 2005). For policy analysis, the main issue is about where we are standing in the inverted-U shape curve.

The objective of this report is to better understand how anti-leakage policies introduced by the EU would interact with the innovation dynamics of both domestic and foreign firms. Having a special focus on BCA measures, in the first phase of the work our attention went on the implications of trade policy for the degree of market concentration. The model developed has the unique feature to embed endogenous market structure along with innovation. As explained above, there are theoretical and empirical reasons to include competition as a major driver of innovation. Introducing this argument in the analysis of BCA might give novel insights about the second-order effects of these policy instruments, in particular with respect to innovation.

The joint analysis of innovation and trade with respect to international environmental policy is by itself a quite new contribution, in particular with the use of numerical modelling. Taking into account the response of R&D activities of national and foreign firms might in fact have significant quantitative effects. The implementation of carbon pricing in the EU has significant competitiveness effects on EITE sectors under free trade. The tax increases costs for home firms and in turn home firms lose market share to the benefit of foreign competitors from countries without carbon pricing. The theory of induced technological change (i.e. Di Maria and der Werf 2008) would suggest that - under some conditions on production technologies - in the long run R&D investment would flow into the home EITE sector and therefore restore

competitiveness and reduce leakage. In this case innovation is driven by cost-cutting opportunities rather than by the market size effect of new technologies. The competition channel we introduce would as well affect the equilibrium outcome with respect to innovation.

## 2. Summary of Work Performed

### A non-technical description of the applied model

This study is based on a computable general equilibrium (CGE) model with multiple countries. We perform several policy simulations using the numerical model in order to better understand how firm R&D investment reacts to those measures, i.e. BCA, that are intended to address carbon leakage. The model differentiates between two sectors, EITE and a composite of other sectors that are not prone to carbon leakage, i.e. services, and we pay particular attention on the performance of EITE industries.

Our modelling framework is similar to the seminal trade model of Krugman (1980) with respect to the assumption of increasing returns to scale and symmetry (firms have identical production costs) and to the possibility for new firms to enter the market. We extend Krugman's model by introducing endogenous R&D investment and by changing the market structure from monopolistic competition to Cournot competition. The resulting model has endogenous mark-ups, depending on the firm's market share and the elasticity of substitution between varieties in the specific market. The existence of mark-up profits is generally considered a necessary condition for having positive investment in innovation. The possibility for mark-up profits to change with the degree of market power of the firm generates a direct channel connecting the incentive to engage in R&D with the level of market competition.

Each firm has the possibility to invest in process innovation and increase its efficiency of production, which also reduces the emission intensity of each unit of output. The stock of internal knowledge is firm-specific and it is a collection of ideas, produced through internal R&D activities. Each new piece of process-related technology is generated by investing in R&D activities. There are decreasing marginal returns on R&D spending, i.e. it gets harder to develop new technologies as the technological frontier advances.

We acknowledge that the model offers a quite stylized representation of the market structure, as we do not allow for the heterogeneity typical of models based on Melitz (2003). Nevertheless we claim that the value added of introducing firm heterogeneity is limited. Our framework is able not only to account for intra-industry trade, but also to feature complex interactions between innovation and market structure. There are two main effects of the entry-exit process on innovation incentives. The first effect of having a higher number of active firms is fragmentation. A given level of industry demand has to be shared among more producers and their market shares tend to shrink. This implies a negative market size effect on innovation incentives, because the result of R&D activities can be applied on a smaller scale of production. The existence of a relationship between innovation and the scale of production is also supported by empirical evidence, e.g. Cohen and Klepper (1996). The second effect works in the opposite direction. A stronger level of competition in the market reduces profit mark-ups and the general price index in the industry. The induced price reduction raises larger demand for the sectoral goods and pushes up firms revenues and profits. This raises the incentive to invest in R&D. However, this positive effect is of second order and might not overcome the direct fragmentation effect (Vives 2008). However it is possible, for high levels of concentration in the market, to have on average net positive impact on profits from an increase in the number of firms because of pre-existing excessive mark-ups (Smulders and van der Klundert 1995). If the market power of incumbents is too high, they might also have a weaker incentive to exploit innovation in order

to gain market shares at the expenses of competitors (i.e. business stealing effect, see Peretto 1999). Even without heterogeneity, smaller firms have more to gain from the development of a competitive advantage through innovation.

### Calibration

The model is calibrated to the multi-regional input-output data of the World Input-Output Database (WIOD) that maps trade flows between sectors and regions. WIOD provides an annually consistent representation of the world economy and contains production, trade and emissions data for 35 sectors of 27 member states of the European Union plus 13 other major economies (Timmer et al. 2012). The originally 40 economies included in WIOD are aggregated to five regions. Some model regions are large countries, such as China or the United States; others are multi-country regions such as the European Union (EU).

The model is calibrated to replicate existing sectoral R&D intensities and pollution intensities, as well as the number of active firms in each sector. The elasticities of substitution in demand and production functions are calibrated following the existing literature, i.e. Balistreri and Rutherford (2012). The calibration of the R&D function is performed using data on sectoral R&D intensity from the OECD's ANalytical Business Enterprise Research and Development (ANBERD) database, using data for year 2007. This dataset contains information for industrial R&D expenditures and has a high degree of international comparability. Pollution intensities are calculated from WIOD and OECD data. Finally, the calibration of market concentration is not a straightforward task. As our model assumes that all firms export, calibration requires data on active and exporting firms in each country, by sector. Such data are available from the OECD, which provides information on the number of active multinational firms for Europe, US, Japan and Korea, but not China and other non-OECD countries. Yet, data for China are constructed using available information on the number of active firms by sector from the National Bureau of Statistics of China and applying the share of multinational companies over total from US data. This procedure might undermine the cross-country comparability of this piece of evidence but it preserves the original proportion of active firms between sectors in China.

### Policy Scenarios

In the first scenario it is assumed that the EU commits itself to unilaterally reduce its carbon emissions by 20 percent relative to baseline of 2009. Thereby we assume that the required emission reductions within the EU are granted by an Emission Trading System (ETS). This can be seen as a very stylized replication of EU 2020 climate policy that aims at reducing GHG emissions by 20 percent relative to the 1990 level by 2020. In other regions, no emission reduction regulations are in place.

In the second policy scenarios we supplement the unilateral domestic climate policy of the EU by a border carbon tax regime and assumes that the EU applies BCA on imports from countries that have non domestic carbon abatement policy in place and that the BCA of a certain imported good is computed based on the emission-intensity of technology used in the production of the imported good.

### 3. Results and Conclusion

Of particular importance is the realized carbon leakage rate. As our analysis shows, the additional margin from R&D investments responses clearly affects leakage rates. Assuming firms are not able to respond with process innovation to the implementation of an ETS, we observe leakage rate of -42 percent. The left panel of Figure 1 shows the leakage rates for the two different policy scenarios without R&D responses. Border carbon adjustment is quite successful in reducing these leakage rates and brings down the carbon leakage rate to -10 percent.

Adding R&D investments to the firm's response menu has significant effects on trade responses to climate policy. Allowing for R&D responses by individual firms increases carbon leakage to over -100 percent. But also BCA becomes much more effective, even causes positive mitigation effects by firms not directly involved in the ETS. Note that the calibration of the R&D process needs more effort in order to replicate real firm behaviour. R&D data is often patchy and it is hard to reveal actual R&D processes. But nevertheless, our analysis shows that this matters for the effectiveness of unilateral climate policies.

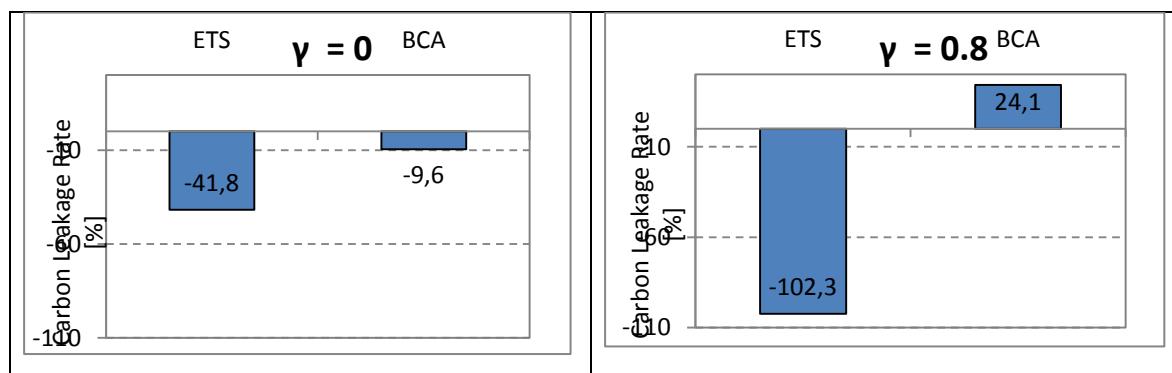


Figure 1: Carbon leakage rates under both climate policy scenarios. The left panel describes a situation that ignores the R&D response. The right panel includes the R&D response by firms.

Figure 2 depicts the percentage change in number of firms by origin. In European EITE sectors we see that unilateral policy measures lead to a significant reduction in the number of active European firms. New firms enter the market for EITE goods but are located abroad. Hence, the so called extensive margin is an important driver of carbon leakage in our analysis. If only the European firms are confronted with the costs of the policy they have higher average costs from the emission pricing but fewer profits to cover the necessary fix costs. This forces them to leave the market and gives room for entrants in non-regulated regions to take over their market shares, with the highest response in the ROW region.

If the unilateral implementation of an ETS in the EU is supplemented with a Border Carbon Adjustment on imports, we observe entry in all markets even in the EU. Under this scenario regions with higher pollution intensity, as China and ROW, have a disadvantage compared to cleaner productions located in the JK and USA regions. Higher entry rates in Japan and Korea indicate that the introduction of BCA in the EU makes them particularly competitive in this market.

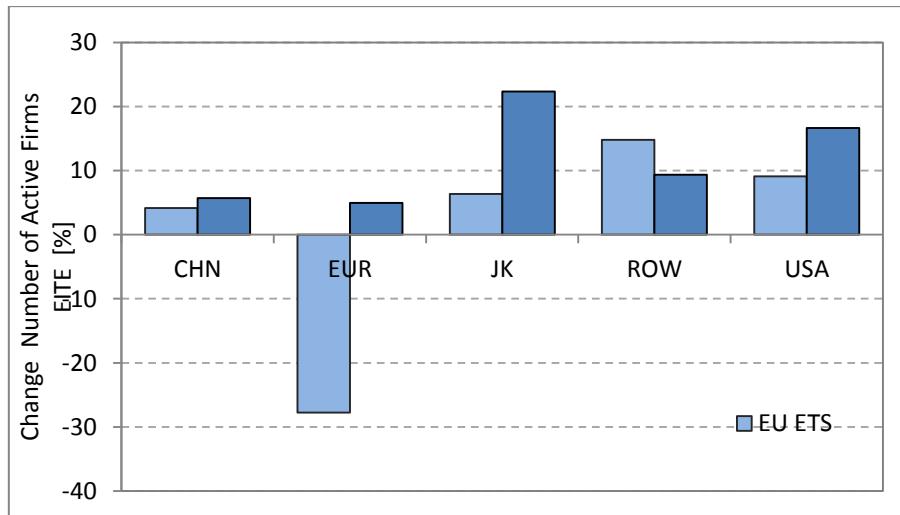


Figure 2: Percentage change in number of firms in EITE sectors relative to the baseline under the two climate policy scenarios and R&D investment responses by firms.

The model also provides some insights on optimal R&D investment for individual firms and sectors, in each region (see Figure 3). The extensive margin appears to have a much stronger role than within-firms R&D decisions in driving sectorial R&D investment outside EUR. But in EUR Firms R&D investment decrease under the both scenarios significantly, in particular under the ETS only scenario. Nevertheless, the majority of the aggregate R&D effect is caused by product innovation (i.e. the entry of new firms).

Our study with a relatively simple calibrated model at hand shows that innovation and competition closely interact with each other. This has significant effects on the effectiveness of unilateral climate policies and may give another justification of complementing unilateral climate policies with R&D subsidies. However, more research, in particular on the modelling of firm's innovation processes and on data to calibrate this process, is needed before final conclusions can be made.

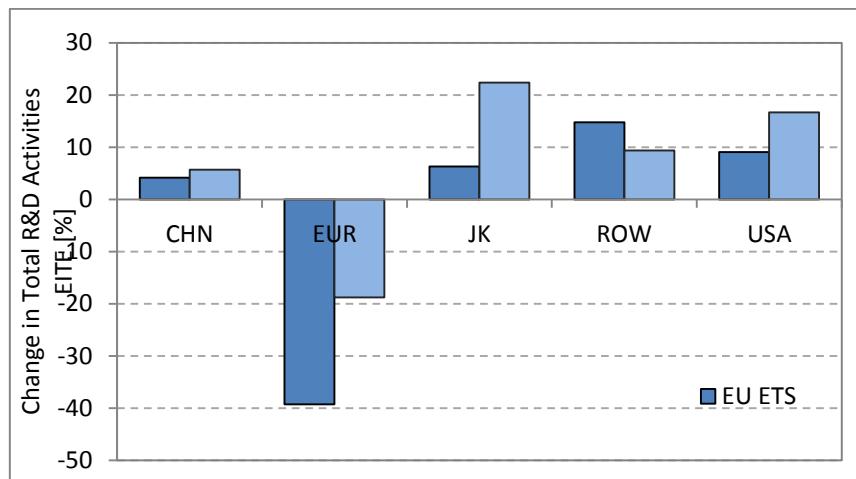


Figure 3: Percentage change in total R&D activities in EITE sectors under the two climate policy scenarios with R&D investment responses by firms.

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## 5. List of Abbreviations

BCA: Border Carbon Adjustment;

CHN: China;

EITE: Energy-Intensive and Trade Exposed;

ETS: Emission Trading Scheme;

EU: European Union;

JK: Japan and Korea;

OECD: Organisation for Economic Co-operation and Development;

ROW: Rest of the World;

US: United States of America;