Climate Policy and the Problem of Competitiveness: Border Tax Adjustments or Integrated Emission Trading?

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Abstract

In the absence of an international agreement on climate policy, unilateral carbon abatement creates two problems: It tends to have a detrimental effect on domestic competitiveness, and it leads to an increase in carbon emissions abroad (leakage). This paper analyses two policies that have recently been proposed to mitigate these problems: Border tax adjustments (BTA) and integrated emission trading (IET). The former policy levies a quantity-based, the latter an emission based duty on imports from non-abating countries. In a stylised two-country model we demonstrate that the policies address both problems. However, BTA protects domestic competitiveness more effectively, while IET achieves a greater reduction in foreign emissions. A computational general equilibrium analysis of the unilateral abatement policy adopted by the European Union confirms our theoretical insights for the sectors covered by the offsetting measures. However, the implications for the competitiveness of non-covered sectors are negative. These two effects constitute the central trade-off in the implementation of both policies.

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1 Introduction

At the Spring Summit in March 2007, the European Council agreed upon an ambitious plan for the post-Kyoto era. It envisages reducing greenhouse gas emissions in the EU by at least 20% compared to 1990 levels by 2020, and by 30% if other industrialised countries undertake similar efforts (EU, 2007). For the time being, however, international disagreement over future climate policy persists. With the adoption of the Bali Action Plan in December 2007, the thirteenth United Nations Climate Change Conference outlined schedule and structure for follow-up negotiations towards a post-2012 framework. But given deep divergences among industrialised and developing countries on new binding reduction commitments, an international agreement upon ambitious abatement targets for all parties remains rather uncertain in the medium term.

Evidently, unilateral environmental policies cause concern about competitiveness implications, particularly for those sectors that are energy-intensive and export-oriented. Companies from EU member states facing high prices for emission certificates may find it difficult to compete against foreign companies unconstrained by such environmental regulation. Hence, unilateral actions envisaged by the European Union may lead to the relocation of European installations to countries with less strict emission regulation. This phenomenon - known as "carbon leakage" - could undermine European efforts to combat climate change and damage international competitiveness of European energy-intensive industries. Trade policy measures as a remedy are on the top of the European political agenda and have found support by many EU stakeholders. As a prominent example, a resolution of the European Parliament has recently called on the Commission to consider border tax adjustments (BTA) for third countries which are not bound by the Kyoto Protocol (European Parliament, 2007). An alternative remedy - the integration of importers into the European Emissions Trading Scheme (EU ETS) - is being considered by the European Commission. In a speech in London on January 21st 2008, the President of the European Commission, Jose Manuel Barroso, said: "[...] I think we should also be ready to [...] require importers to obtain allowances alongside European competitors, as long as such a system is compatible with WTO requirements...".

Referring to this political debate, this paper compares these two alternative policy regimes that are to mitigate competitiveness and carbon leakage problems in unilateral climate policy: border tax adjustments (BTA) and integrated emission trading (IET). We thus extend the existing literature by adding the concept of IET. Border tax adjustments consist first of tariffs on imported goods mimicking an (environmental) tax on domestic goods and second of rebates for the domestic tax on exported goods. In contrast, under an integrated emission trading regime, foreign producers purchase emission certificates for their imports according to the emissions produced. Correspondingly, domestic producers do not participate in the emission trading scheme. In other words, the former regime levies a quantity-based, the latter an emission based duty on imports from non-abating countries and compensates domestic exporters accordingly. Given the GATT treaty on free trade and the absence of official carbon registers in some countries both BTA and IET raise legal and practical questions concerning their implementation. While these questions are not the focus of this article, we will discuss them in the conclusions.

Early contributions on border tax adjustments show that they guarantee trade neutrality in a world with differentiated taxation under the origin and the destination principle

(Bhagwati and Srinivasan 1973, Meade 1974, Grossman 1980). Barthold (1994) and Poterba and Rotemberg (1995) introduce BTA into the field of environmental economics. Babiker and Rutherford (2005) quantify allocative effects of BTA for abating and non-abating countries in the context of climate policy under the Kyoto protocol. Ismer and Neuhoff (2004), Demailly and Quirion (2006) and Peterson and Schleich (2007) analyse BTA as a complementary policy measure of the European Emission Trading System (EU ETS). Based on a partial equilibrium model, Ismer and Neuhoff (2004) demonstrate that BTA can mitigate the productive and allocative inefficiencies of an emission trading scheme. One main caveat in their formal setup is, however, that the energy efficiency decision of firms is not modelled explicitly. Using a computational general equilibrium model, Peterson and Schleich (2007) emphasise the importance of alternative benchmarks for the BTA level and corresponding economic implications. Demailly and Quirion (2006), who focus on the cement sector and use a numerical partial equilibrium framework, find that BTA can be an efficient remedy for the leakage problem. Mathiesen and Maestad (2004) show a similar result for the Norvegian steel industry under the Kyoto protocol. This paper contributes to the existing literature by introducing the concept of IET and comparing the economic and environmental implications of both instruments.

We apply a theoretical and a computational framework. In a stylised two-country model capturing basic features of emissions and international trade we show that both policies address both the competitiveness and the leakage problem. The main result in the theoretical part is that the BTA regime is more effective in mitigating the negative competitiveness effects of unilateral climate policy on the domestic sector, while the IET scheme achieves a greater reduction in foreign emissions in the respective sectors.

These results are confirmed for energy-intensive sectors (which participate in the emission trading scheme and thus in a BTA or IET policy) by a multi-region multi-sectoral computable general equilibrium (CGE) analysis, in which we adopt a unilateral abatement policy that reduces effective emissions in the European Union by 20% until 2020. The multi-sectoral numerical approach provides further insights into economic and environmental implications of the offsetting measures, as it takes into consideration the fact that only energy-intensive sectors are covered by an emission trading scheme. Countries introducing BTA and IET for energy-intensive sectors end up with higher emission allowance prices compared to the unilateral abatement policy without any complementary measures. This is due to the emissions abatement shifting from covered energy-intensive industries with relatively low abatement costs to non-energy-intensive sectors with relatively high abatement costs. This shifting is particularly pronounced under the BTA regime with a strong negative impact on the production level of the non-energy intensive sectors. It can lead to a reversion of the aggregate effect of BTA on the production level. Finally, the implication of BTA and IET for global emission levels are quite similar.

This paper is organised as follows: Section 2 presents the setup of the two-country model and analyses the equilibrium outcomes for three stylised policy options, i.e. unilateral abatement policy, BTA and IET. Section 3 provides a description of the computable equilibrium model, introduces policy scenarios and presents main numerical results. Section 4 concludes.

2 Theoretical Analysis: A Two-Country-Model

In this section, we introduce a simple two-country model to study economic and environmental implications of unilateral abatement policy with and without complementary measures, i.e. border tax adjustments and integrated emission trading. The model builds on the partial equilibrium analysis in Böhringer and Lange (2005a) (see also Böhringer and Lange 2005b) that discusses different abatement policies in a closed economy context. In our framework we abstract from possible impacts of climate policy on government revenues, labour supply and welfare and focus on output, energy intensity and carbon emissions instead. The model provides basic insights for the numerical simulation analysis in section 3.

2.1 Formal Setup

The model encompasses two countries (commonly denoted by r), the domestic country d and the foreign country f. The representative household in each country disposes of initial wealth w_r, $r \in \{d, f\}$. It derives utility from consumption only. In order to establish consistency with the numerical framework, we adopt the Armington assumption (Armington 1969) of product heterogeneity in international trade: The standard goods produced in d and in f are imperfect substitutes in household preferences. Prices for these goods $p_{r_c}^{r_p}$ form on competitive markets, including imports and exports. The representative firm in r chooses the quantity of the good produced for the domestic market q_d^r, for the foreign market q_f^r and energy intensity of production μ^r. Quantities and energy intensity determine emissions $E = \mu^r(q_f^r + q_d^r)$ in country r.

Costs of production $C(\mu, q) = c(\mu)q$ are constant returns to scale with respect to quantity and decreasing and concave in energy intensity, i.e. $c'(\mu) < 0, c''(\mu) > 0$. By c^r we denote the marginal cost function in region r, its derivative is expressed by c_1^r.

The government of the domestic country lauches emission trading with full auctioning to achieve a certain emission target $\bar{E}$ for its country. In our simple deterministic setup such an emission trading system is equivalent to a carbon tax τ. Furthermore, the domestic government can impose a tariff κ on imported goods and pay a tax rebate for exported goods (border tax adjustment), or it can sell off emission allowances abroad (integrated emission trading).

To keep the model tractable, the household disposes of a fixed income (no labour supply decision) and thus maximises its utility in consumption only. We denote Marshallian demand by the household in country r_c for the good produced in r_p by

$$q_{r_c}^{r_p} = d_{r_c}^{r_p}(p_{r_c}^d, p_{r_c}^f, w_{r_c}). \tag{1}$$

Utility maximisation with Cobb-Doublas utility functions

$$u_{r_c}(q_{r_c}^d, q_{r_c}^f) = k(q_{r_c}^d)^{\alpha_{r_c}}(q_{r_c}^f)^{1-\alpha_{r_c}}$$

yields the following demand functions:

$$
q_d^d = \frac{\alpha_d w_d}{p_d^d} \qquad q_d^f = \frac{(1-\alpha_d) w_d}{p_d^f},
$$

$$
q_f^d = \frac{\alpha_f w_f}{p_f^d} \qquad q_f^f = \frac{(1-\alpha_f) w_f}{p_f^f}.
$$

As the demand functions are separable, a price increase for one good has no effect on the absolute demand for the other good. This is a special feature of CD preferences, which is not present in a CES framework. Thus we abstract from income effects of taxation and concentrate on substitution effects instead. Finally we assume that $0 < \alpha_d < 1, 0 < \alpha_f < 1$[1].

We will now formally state the problem of the representative firm in the domestic and in the foreign country: The firm maximises profits by choosing energy intensity and quantities produced, taking prices for its products as given. As a first benchmark for a later comparison of policies we formulate the problem of the firm in the absence of carbon abatement policy ("laissez-faire", LF).

The profit function of the domestic firm is

$$
\Pi^d = p_d^d q_d^d + p_d^f q_f^d - c^d(\mu^d)(q_d^d + q_f^d),
$$

and the one of the foreign firms is

$$
\Pi^f = p_d^f q_d^f + p_f^f q_f^f - c^f(\mu^f)(q_d^f + q_f^f).
$$

Profit maximisation leads to the first order conditions of the firm (with $r \in \{d, f\}$)

$$
\begin{aligned}
p_d^d - c^d(\mu^d) &= 0, && (2)\\
p_f^d - c^d(\mu^d) &= 0, && (3)\\
c_1^d(\mu^d) &= 0. && (4)
\end{aligned}
$$

The first two conditions say that prices are -both for domestic and foreign goods- equal to their marginal costs of production. The last condition states that energy intensity is increased to the point that its marginal costs are zero.

We conclude that $p_d^d = p_f^d =: p^d$ as well as $p_d^f = p_f^f =: p^f$. The production of goods in the domestic country results in emissions

$$
E^{LF} = \mu^d(q_f^d + q_d^d).
$$

To make our problem interesting, in the following we assume

Assumption 1 (Emission Cap) *The emission cap $\bar{E}$ imposed by the domestic government is lower than E^{LF}, i.e. $0 < \bar{E} < E^{LF}$.*

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[1] Otherwise demand for one of the goods breaks down and an analysis of demand effects of the policies becomes senseless.

One important feature of our specification of the production technology is the following: Although the standard good is produced for two different markets (home and abroad), the choice of energy efficiency is the same for both quantities. The implicit assumption, that industries do not build separate production lines for different markets, is standard.

The following subsection discusses the problem of the firm under the different policy regimes.

2.2 Abatement Policies

Unilateral Abatement Policy We use unilateral abatement policy (UAP) as a second benchmark in our comparison of domestic carbon policies that address the problems of competitiveness and leakage in an international context. The government of the domestic country auctions emission allowances to ensure that total emissions of domestic production do not exceed $\bar{E}$. This corresponds to the governement setting a carbon tax τ (where τ is equivalent to the price of the allowance). We state the profit functions and first order conditions of both firms under UAP[2].

Under UAP, the profit function of the domestic firm is given by

$$\Pi^d = p_d^d q_d^d + p_d^f q_f^d - c^d(\mu^d)(q_d^d + q_f^d) - \tau\mu^d(q_d^d + q_f^d).$$

From this, the associated first order conditions can be derived:

$$\begin{aligned} p_d^d - c^d(\mu^d) - \tau\mu^d &= 0 \quad (5)\\ p_f^d - c^d(\mu^d) - \tau\mu^d &= 0 \quad (6)\\ c_1^d(\mu^d) + \tau &= 0 \quad (7) \end{aligned}$$

Again we conclude that $p_d^d = p_f^d =: p^d$.

The profit function of the foreign firm is

$$\Pi^f = p_d^f q_d^f + p_f^f q_f^f - c^f(\mu^f)(q_d^f + q_f^f),$$

and consequently we derive the first order conditions

$$\begin{aligned} p_d^f - c^f(\mu^f) &= 0 \quad (8)\\ p_f^f - c^f(\mu^f) &= 0 \quad (9)\\ c_1^f(\mu^f) &= 0 \quad (10) \end{aligned}$$

As above $p_d^f = p_f^f =: p^f$. The first order conditions of the foreign firm remain unchanged in comparison to the laissez-faire case.

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[2] All variables used in this and the next section should have indices indicating the policy case, as they take different values across the three scenarios. For ease of exposition, this additional index has been dropped here, but will be set in the next section.

The government sets τ so that in equilibrium emission remain below the cap

$$\bar{E} \geq \mu^d(q_d^d + q_f^d). \tag{11}$$

Border Tax Adjustment In the second policy scenario the government uses border tax adjustments (BTA) to offset differences in taxation for imported and exported goods. A quantity-based tariff κ is levied on the imported good. It is set to match the tax on the "average" carbon content of the good. With BTA, the carbon content of the import good is measured as if it had been produced domestically[3]. Characteristicly for a tariff, we do not need information about foreign emissions.

Formally stated:

$$\kappa = \tau\mu^d. \tag{12}$$

Exporters receive a tax refund of κ per quantitiy sold which matches their emission in production. The formal setup is as follows:

The profit function of the domestic firm is

$$\Pi^d = p_d^d q_d^d + p_d^f q_f^d - c^d(\mu^d)(q_d^d + q_f^d) - \tau\mu^d(q_d^d + q_f^d) + \kappa q_f^d$$

First order conditions (domestic firm):

$$\begin{aligned} p_d^d - c^d(\mu^d) - \tau\mu^d &= 0 && (13)\\ p_f^d - c^d(\mu^d) - \tau\mu^d + \kappa &= 0 && (14)\\ c_1^d(\mu^d) + \tau &= 0 && (15) \end{aligned}$$

Condition 13 states that the price for the domestic good is equal to its marginal cost plus the tax on emissions times energy intensity (which amounts to a tax on quantities produced). Condition 14 states that the price for the export good is marginal costs plus tax on emissions minus the rebate. Condition 15 says that the marginal costs of energy intensity are equal to minus the tax on emissions.

The profit function of the foreign firm is given by

$$\Pi^f = p_d^f q_d^f + p_f^f q_f^f - c^f(\mu^f)(q_d^f + q_f^f) - \kappa q_d^f$$

First order conditions (foreign firm):

$$\begin{aligned} p_d^f - c^f(\mu^f) - \kappa &= 0 && (16)\\ p_f^f - c^f(\mu^f) &= 0 && (17)\\ c_1^f(\mu^f) &= 0 && (18) \end{aligned}$$

---

[3] In fact, the measurement of emissions as related to imports is critical for the implementation of BTA, both from a legal and a practical viewpoint. For a discussion of this issue we refer to section 4.

Condition 16 says that the price for the import good is equal to its marginal costs plus the environmental tariff. According to condition 17, the price for the foreign good at home is equal to its marginal cost, as in the LF and UAP case. Similarly, condition 18 states that the marginal cost of energy intensity is zero in equilibrium.

As before the government sets τ so that the emission cap is achieved:

$$\bar{E} \geq \mu^d (q_d^d + q_f^d). \tag{19}$$

Note that κ applies to quantities of goods, not emissions. This is the systematic difference with respect to the third policy scenario.

Integrated emission trading In the third policy scenario the government designs an integrated emission trading (IET) scheme: Foreign producers have to purchase emission certificates for their imports into the domestic country at a price τ. In contrast to an emission trading with BTA it is emissions that are targeted by the IET, not quantities. Goods exported to the foreign country are exempt from the environmental duty.

Formally, the model is as follows

Profit function of the domestic firm

$$\Pi^d = p_d^d q_d^d + p_d^f q_f^d - c^d(\mu^d)(q_d^d + q_f^d) - \tau \mu^d q_d^d$$

First order conditions (domestic firm)

$$\begin{aligned} p_d^d - c^d(\mu^d) - \tau\mu^d &= 0 & (20)\\ p_f^d - c^d(\mu^d) &= 0 & (21)\\ c_1^d(\mu^d)(q_d^d + q_f^d) + \tau q_d^d &= 0 & (22) \end{aligned}$$

Condition 20 states that the price of the domestic good is equal to its marginal cost plus the tax on quantities - it is identical to the BTA case. Condition 21, in contrast, says that the price for exports is equal to marginal cost, as in the LF case. Other than in the BTA case, the firm internalises the effect of the energy intensity decision on the carbon price. Condition 22 says that the marginal cost of energy intensity is equal to the tax times the fraction of the domestic good over total domestic output.

The profit function of the foreign firm is given by

$$\Pi^f = p_d^f q_d^f + p_f^f q_f^f - c^f(\mu^f)(q_d^f + q_f^f) - \tau \mu^f q_d^f$$

Note the difference with the profit function under BTA: Under IET, the actual emissions of the foreign firm are taxed, and thus its energy intensity is the basis for the duty.

First order conditions (foreign firm)

$$
\begin{aligned}
p_d^f - c^f(\mu^f) - \tau\mu^f &= 0 && (23)\\
p_f^f - c^f(\mu^f) &= 0 && (24)\\
c_1^f(\mu^f)(q_d^f + q_f^f) + \tau q_d^f &= 0 && (25)
\end{aligned}
$$

Condition 23 states the price for the export good is equal to marginal costs times the emission tax (on quantities), mimicking condition 20 for the domestic firm. Condition 24 says that the price of the foreign good is equal to its marginal costs. As in the case of the domestic firm, condition 25 says that the marginal cost of energy intensity is equal to the tax times the fraction of exports over total foreign output.

Note that we have chosen to keep the same emission cap across all three policy scenarios. Thus the domestic government sets a cap on domestic emissions, i.e. emissions caused by domestic production

$$\bar{E} \geq \mu^d(q_d^d + q_f^d). \tag{26}$$

However, taxes τ can vary accross scenarios.

Quite importantly, in the integrated emission trading scheme presented in our analysis the importers do not participate in the domestic market for emission allowances directly. Their allowances are "set aside", i.e. the domestic government issues additional allowances at the domestic carbon price. A logical extension of IET would be a cap on emissions caused by domestic consumption: Both domestic producers and importers would have to compete for emission allowances to sell their products in the domestic market. This would change the trade paradigm, abandoning the origin in favour of the destination principle. Consumption, not production, would be the basis for a carbon tax. However, as foreign emissions remain unregulated under BTA and UAP, such an altered version of IET can not be compared directly to the other two policies and is therefore not considered here. This feature holds also true in our numerical analysis.

2.3 Equilibrium conditions

In this section we derive equilibrium conditions and prove the existence of an equilibrium.

Utility maximisation by households yields demand functions that specify quantities as function of prices. Profit maximisation by firms yields first order conditions that determine prices as function of all other variables. The government sets taxes and tariffs to enforce its rules, in particular, the emission cap.

Formally, equilibrium conditions take the following form:

1. Zero-Profit (FOCs of the firms)

$$p_{r_c}^{r_p} = P(q_d^{r_p}, q_f^{r_p}, \mu^{r_p}, \tau, \kappa)$$

$$\mu^{r_p} = M(q_d^{r_p}, q_f^{r_p}, \tau, \kappa)$$

2. Utility maximisation (FOCs of the households)

$$q_{r_c}^{r_p} = d_{r_c}^{r_p}(p_{r_c}^d, p_{r_c}^f, w_{r_c})$$

3. Emission cap

$$\bar{E} \geq E(q_d^d, q_f^d, q_d^f, q_f^f, \mu^{r_p})$$

The functional form of the conditions has been derived in the previous subsection. In order to guarantee the existence of an equilibrium we impose the standard assumption on the marginal cost functions $c^d(.)$ and $c^f(.)$ to avoid corner solutions.

Assumption 2 (Inada condition) *The marginal cost functions* $c^r(.)$ *satisfy*

$$\lim_{\mu \to 0} c_1^r(\mu) \to -\infty.$$

Moreover, there exist unique $\hat{\mu}^d$ *and* $\hat{\mu}^f$ *such that*

$$c_1^d(\hat{\mu}^d) = c_1^f(\hat{\mu}^f) = 0.$$

From this assumption we derive

Proposition 1 *Under assumptions 1 and 2 unique equilibria exist in all three scenarios.*

Proof. See appendix. ■

2.4 Policy Outcomes

In this section, we use the model of the preceding section to analyse economic and environmental impacts of alternative policy options in climate policy. We address both competitiveness and leakage, i.e. we focus on production levels and energy intensities.

Our first proposition compares the three policies with the laissez-faire scenario. They show how domestic economic activity is slowed down by emission reduction.

Proposition 2 (Laissez Faire vs. Abatement Policies) *A comparison of the laissez-faire and the unilateral abatement policy yields*

$$(\mu^d)^{LF} > (\mu^d)^{UAP} \qquad (\mu^f)^{LF} = (\mu^f)^{UAP}$$

$$(p^d)^{LF} < (p^d)^{UAP} \qquad (p^f)^{LF} = (p^f)^{UAP}$$

$$(q_d^d + q_f^d)^{LF} > (q_d^d + q_f^d)^{UAP} \qquad (q_d^f + q_f^f)^{LF} = (q_d^f + q_f^f)^{UAP}$$

A comparison of the laissez-faire and a border tax adjustment policy yields

$$(\mu^d)^{LF} > (\mu^d)^{BTA} \qquad (\mu^f)^{LF} = (\mu^f)^{BTA}$$

$$(p_d^d)^{LF} < (p_d^d)^{BTA} \qquad (p_d^f)^{LF} < (p_d^f)^{BTA}$$

$$(p_f^d)^{LF} < (p_f^d)^{BTA} \qquad (p_f^f)^{LF} = (p_f^f)^{BTA}$$

$$(q_d^d + q_f^d)^{LF} > (q_d^d + q_f^d)^{BTA} \qquad (q_d^d + q_f^d)^{LF} > (q_d^d + q_f^d)^{BTA}$$

A comparison of the laissez-faire and a global emission trading system yields

$$(\mu^d)^{LF} > (\mu^d)^{IET} \qquad (\mu^f)^{LF} > (\mu^f)^{IET}$$

$$(p_d^d)^{LF} < (p_d^d)^{IET} \qquad (p_d^f)^{LF} < (p_d^f)^{IET}$$

$$(p_f^d)^{LF} < (p_f^d)^{IET} \qquad (p_f^f)^{LF} < (p_f^f)^{IET}$$

$$(q_d^d + q_f^d)^{LF} > (q_d^d + q_f^d)^{IET} \qquad (q_d^d + q_f^d)^{LF} > (q_d^d + q_f^d)^{IET}$$

Proof. See appendix ■

First, whereas unilateral abatement policy only reduces the economic performance of the domestic country[4], border tax adjustment and integrated emission trading have consequences for the foreign country as well. The taxation of emissions leads both to an increase in energy efficiency and to an increase in consumer prices for domestic goods and thus to a reduction in demand for them, both in the domestic and in the foreign market. Both border tax adjustment and integrated emission trading amount to levying an environmental tariff on imports, thus increasing the price for the imported good. The former is a indirect carbon duty, the latter a direct one, i.e. under a BTA policy, a tariff is levied on imports independent of emissions caused by production, under IET the foreign producer has an incentive to increase energy efficiency as he pays for the emissions caused by his imports to the domestic market.

Energy Intensities The next step in the analysis of policy outcomes is the comparison of equilibrium energy intensities. The equilibrium choice of energy intensity is important for the understanding of the policy outcome in general.

Proposition 3 (Comparison of energy intensities) *In equilibrium, energy intensities in the domestic and the foreign country satisfy the following inequalities*

$$(\mu^d)^{UAP} > (\mu^d)^{BTA} \qquad (\mu^f)^{UAP} = (\mu^f)^{BTA}$$

$$(\mu^d)^{UAP} = (\mu^d)^{IET} \qquad (\mu^f)^{UAP} > (\mu^f)^{IET}$$

$$(\mu^d)^{BTA} < (\mu^d)^{IET} \qquad (\mu^f)^{BTA} > (\mu^f)^{IET}$$

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[4] Remember, though, that our choice of Cobb-Douglas preferences excludes wealth effects from the analysis.

Concerning the domestic country, proposition 3 states that energy intensity is equal under UAP and IET, whereas, compared to them, BTA lowers it. This is a somewhat surprising result. From proposition 2 we know that carbon abatement leads to an increase in energy efficiency - this is part of the economic answer to making emissions costly. While it is still aggregate domestic emissions that are capped under both BTA and IET, the pressure exerted by the carbon levy is now limited to the output produced for the domestic country because exports are exempt. This makes the energy efficiency/quantity reduction trade-off more pronounced which explains why energy efficiency under BTA increases vis-a-vis UAP. The same influence exists in the case of IET, however, it is exactly offset by the lowered price pressure on the export good.

The results for the energy intensity of the foreign country are straightforward: Neither UAP nor BTA affect equilibrium energy intensity which remains at its maximum laissez-faire level. In contrast under IET, by levying a duty on the carbon content of the import good the domestic country exerts an abatement influence on the foreign firm, inducing it to increase its energy efficiency.

Prices and Quantities The next proposition presents a comparison of equilibrium prices and quantities under the three policies. While the comparison of UAP on the one hand and BTA and IET on the other hand is straightforward, comparing BTA and IET turns out to be somewhat difficult. This is due to the fact that the duty levied on the import good depends on the domestic production function in the case of BTA and on the foreign production function in the case of IET. Thus, with some variables being directly comparable, a full comparison requires an additional assumption on the two cost functions. We assume that they are identical.

Assumption 3 (Cost Symmetry) *The marginal cost function is equal for both countries* $c^d(.) \equiv c^f(.)$.

Subsequently, all inequalities that require assumption 3 are labelled by an index s.

Proposition 4 (Comparison of prices and quantities) *In equilibrium, quantities and prices chosen under UAP and under BTA compare as follows*

$$(p_d^d)^{UAP} < (p_d^d)^{BTA} \qquad (p_f^f)^{UAP} = (p_f^f)^{BTA}$$

$$(p_f^d)^{UAP} > (p_f^d)^{BTA} \qquad (p_d^f)^{UAP} < (p_d^f)^{BTA}$$

$$(q_d^d + q_f^d)^{UAP} < (q_d^d + q_f^d)^{BTA} \qquad (q_d^f + q_f^f)^{UAP} > (q_d^f + q_f^f)^{BTA}$$

Under UAP and IET, the comparison yields

$$(p_d^d)^{UAP} < (p_d^d)^{IET} \qquad (p_f^f)^{UAP} < (p_f^f)^{IET}$$

$$(p_f^d)^{UAP} > (p_f^d)^{IET} \qquad (p_d^f)^{UAP} < (p_d^f)^{IET}$$

$$(q_d^d + q_f^d)^{UAP} = (q_d^d + q_f^d)^{IET} \qquad (q_d^f + q_f^f)^{UAP} > (q_d^f + q_f^f)^{IET}$$

Under BTA and IET equilibrium prices and quantities compare as follows

$$(p_d^d)^{BTA} < (p_d^d)^{IET} \qquad (p_f^f)^{BTA} < (p_f^f)^{IET}$$

$$(p_f^d)^{BTA} > (p_f^d)^{IET} \qquad (p_d^f)^{BTA} <_s (p_d^f)^{IET}$$

$$(q_d^d + q_f^d)^{BTA} > (q_d^d + q_f^d)^{IET} \qquad (q_d^f + q_f^f)^{BTA} >_s (q_d^f + q_f^f)^{IET}$$

Proposition 4 states the central economic implications of the three policy regimes in our theoretical framework.

In the following we explain the major insights. As for domestic production, we see that, in comparison to UAP, both BTA and IET lead to an increase in the (gross) price for the domestic good and to a decrease in the price for the export good. Both effects are more pronounced under IET than under BTA. The price decrease under both regimes for the export good follows directly from the rebate. The price increase for the domestic good is a consequence of the higher abatement effort in the domestic market under BTA and IET, which is necessary to reach the emission target while exports are tax exempt. As foreign companies can use the energy efficiency margin to adjust to the domestic climate policy under IET, domestic markets are under greater pressure to adapt than under BTA - hence the price effect.

The foreign market is not directly affected by UAP and BTA - the price for the foreign good remains unaltered in comparison to LF. In contrast, the energy efficiency effort induced by IET in the foreign country leads to more costly production and thus a higher price. The price of the export good increases under BTA and IET, a plausible result of the duties levied. Higher energy efficiency under IET in the foreign country makes the effect more pronounced for this policy as long as we assume symmetry of cost functions.

The output effects of the policies are driven by changes in prices. Domestic production increases under BTA vis-a-vis UAP, showing that this policy achieves the intended effect on domestic competitiveness. The proof shows that an increase in exports under BTA offsets a decrease in the consumption of the domestic good. The same two effects apply to the comparison of IET and UAP. In this case, however, they offset each other: Domestic production is equal under IET and UAP. Consequently, BTA is more effective in protecting domestic competitiveness than IET.

Clearly, the foreign country produces more under UAP than it does under BTA and IET, as its production is not affected by domestic regulation. Production is higher under BTA than under IET (assuming symmetry of cost functions), as imports are cheaper and the price of the foreign good remains unchanged under BTA.

One word concerning assumption 3: It is a sufficient, not a necessary condition. In fact a glance at the proof of proposition 4 shows that all assertions hold as long as marginal costs of producion abroad are not much lower than at home. A change in the results is conceivable only when the foreign country has much cheaper abatement options than the domestic one.

Emissions Finally, we turn to the environmental implications. The results we have derived so far answer this question, since foreign emissions depend on quantities produced in the foreign country and on foreign energy intensity. Recall that the emission cap imposed on domestic production is equal under the three policies. In contrast, as we see from Corollary 5, the policies have a different impact on foreign emissions.

Corollary 5 (Comparison of foreign emissions) *Emissions in the foreign country relate to each other as follows*

$$(E^f)^{UAP} > (E^f)^{BTA} \qquad (E^f)^{UAP} > (E^f)^{IET}$$

$$(E^f)^{BTA} >_s (E^f)^{IET}$$

Corollary 5 shows that both BTA and IET lead to a reduction in foreign emissions compared to the case of UAP. In the case of BTA, this is a mere quantity effect: A decrease in imports to the domestic country leads to a decrease in output. In the case of IET, higher energy efficiency adds up with reduced sales abroad. As for the comparison of foreign emissions under BTA and IET, we need assumption 3 to achieve an unambiguous result, which is that under a IET policy in the domestic country, the induced abatement in the foreign country is larger. Symmetry of cost functions is only a sufficient condition: The results hold as long as marginal costs of production are higher abroad. This is plausible because under IET foreign producers increase their energy efficiency, which under BTA they do not. Only if their costs of doing so are very small, much smaller than in the domestic country, the (then) larger output under IET could offset the effect of increased energy efficiency and foreign emissions would be higher than under BTA. I

To sum up, both BTA and IET achieve the target of mitigating negative competitiveness effects of unilateral climate policy and leakage. While BTA is more effective in the former, IET tends to be more effective in the latter.

3 Numerical General Equilibrium Analysis

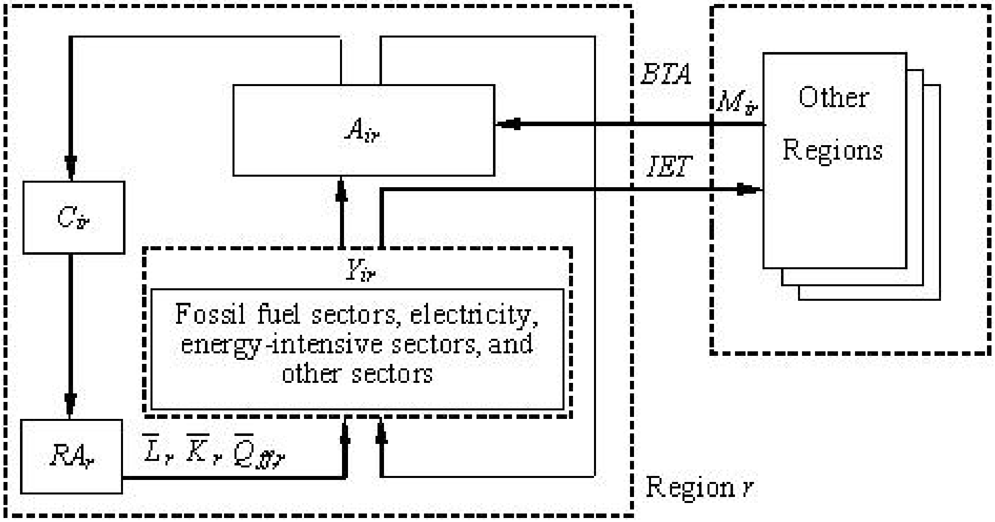
While our stylized theoretical framework provides basic insights into economic and environmental implications of alternative domestic policy options, a numerical analysis can take real-world complexities into consideration. In the political discourse, offsetting measures such as BTA and IET have been proposed to protect selected industries (i.e. energy-intensive and export-oriented sectors) only. For a comprehensive policy analysis we therefore apply a standard multi-sector, multi-region CGE model of international energy use and global trade to assess, spillover effects to and market interactions with remaining industries. Importantly, such an analysis was not possible within our one-sector theoretical framework.

Below, we start our numerical analysis with a non-technical summary of model framework, introduce the policy scenarios and discuss our numerical results contrasting them with our theoretical findings.

3.1 Modelling approach

Figure 1 provides a diagrammatic structure of the open-economy CGE model used for comparative-static impact analysis of BTA and IET regimes. For details and an algebraic formulation of the core model see Böhringer and Lange (2005a).

Figure 1: Diagrammatic overview of the model structure



A representative agent RA_r in each region r is endowed with labour $\bar{L_r}$, capital $\bar{K_r}$ and fossil-fuel resources $\bar{Q}_{ff,r}$ which may be used for fossil fuel production. The representative agent maximises utility from consumption of a composite good C_r which combines demands for energy and non-energy commodities at a constant-elasticity-of-substitution (CES). Production Y_{ir} of commodities i in region r is described by nested separable CES functions with the price-dependent use of capital, labour, energy and material in production. Carbon emissions are linked to the emission-relevant use of fossil fuels, while carbon abatement occurs by fuel switching or energy savings in production and final consumption. The modelling of international trade is based on the Armington approach of product heterogeneity, so that domestic and foreign goods of the same variety are distinguished by their origin (Armington, 1969). All goods used in the domestic market in intermediate and final demand correspond

Table 1: Model dimensions

Production sectors	Countries and Regions
Energy	*EU regions*
COA Coal	EU15 Old Member States
CRU Crude oil	EU12 New Member States
GAS Natural gas	
OIL Refined oil products (REI)	
ELE Electricity (REI)	
Energy-intensive sectors	*Non-EU countries and regions*
ORE Ferrous metals (EII)	OOE Rest of OECD
PPP Paper products and publishing (EII)	RUS Former Soviet Union
NMM Mineral products nec (EII)	SMA Rest of South and Middle America
NFM Metals nec (EII)	CHN China (including Hongkong)
ATP Air transport (REI)	SEA Rest of South and East Asia
CRP Chemicals, rubber and plastics (REI)	OPC OPEC
	XRW Rest of the World
Non-energy-intensive sectors	
ROI Rest of industry (NEI)	
CGD Savings good	

to a CES composite A_{ir} that combines the domestically produced variety Y_{ir} and imports M_{ir} of the same variety from other regions. Domestic production Y_{ir} either enters the formation of the Armington good A_{ir} or is exported (X_{ir}) to other regions to satisfy their import demand. Trade with other regions is represented by a set of horizontal export demand and import supply functions at exogenous world import and export prices. A balance of payment constraint, which is warranted through flexible exchange rates, incorporates the benchmark trade deficit or surplus.

The model is based on consistent accounts of national production and consumption, trade and energy flows for 2001 as provided by the GTAP 6 database (Dimaranan and McDougall, 2006). Forward calibration of the 2001 economies to the target year 2020 is based on energy trends for EU Member States (EU, 2003) and on international energy projections for non-European economies (US Department of Energy, 2005).

Table 1 summarises the regional and sectoral aggregation of the model. The regional aggregation of the GTAP database includes nine regions that are central in the climate policy debate on competitiveness and leakage. The member states of the European Union are aggregated to two major regions, EU15 (old member states) and EU12 (new member states). The sectoral aggregation in the model has been chosen to distinguish energy-intensive sectors from the rest of the economy. It captures key dimensions in the analysis of greenhouse gas abatement, such as differences in carbon intensity and the degree of substitutability across carbon-intensive goods. The primary and secondary energy goods identified in the model are coal, natural gas, crude oil, refined oil products, and electricity. The remaining sectors are aggregated to a composite industry that produces a non-energy-intensive macro good.

In order to assess economic and environmental implications of complementary measures (i.e. BTA and IET), the EU is assumed to impose a unilateral emission cap and to apply offseting measures to (five) energy-intensive and export-oriented sectors, i.e. ferrous metals (ORE), non-ferrous metals (NFM), chemicals (CRP), mineral industries (NMM) and paper products and publishing (PPP). Numerical modelling of both regimes is consistent with our theoretical approach in section 2: Under BTA, both the duty levied on imports and the rebate for the EU exports from the covered sectors are quantity-based, i.e. the BTA level is determined by the *EU average carbon content* in the production of the corresponding energy-intensive goods *in the specific sector*. Thus, no information about energy intensities of foreign producers is necessary under the BTA regime. Under the IET, the EU exporters and the EU importers face the allowance price which is applied to the actual carbon content of the respective energy-intensive industry. For importers into the EU, the price of emission allowances is exogenous. The allowances are from a set-aside budget. BTA and IET do *not* apply to energy-producing, remaining energy-intensive and non-energy-intensive sectors. Partial sectoral coverage of the BTA and IET regimes is the major characteristic distinguishing the numerical analysis from the theoretical one. Below we refer to energy-intensive and export-oriented industries under BTA and IET regimes in aggregate manner as EII sectors. To account for relevant market interactions, we display results for both remaining energy-intensive sectors (REI) and non-energy-intensive sectors (NEI).

3.2 Policy scenarios

We illustrate the economic and environmental implications of BTA and IET regimes using three stylized policy scenarios for the year 2020. Across all scenarios, the unilateral emission reduction target of the EU-27 is set at 20% versus business-as-usual (BAU) emissions levels in 2020. This is a realistic assumption given emission reduction targets vs. 1990/2005 levels within the EU Energy Package and the degree of flexibility regarding the access of EU ETS firms to CDM projects. We further assume efficient implementation of the emission reduction target through unrestricted intra-EU emission trading between energy-intensive and non-energy-intensive industries. Revenues from the auctioned allowances are rebated as lump-sum transfers to the representative agent in the EU as lump-sum transfers. All non-EU regions are assumed - consistent with our theoretical approach - not to have committed to binding emissions reduction targets in 2020.

As a reference case, scenario UAP reflects the efficient emission trading scheme, thereby abstaining from any offsetting measures to mitigate negative competitiveness implications on covered energy-intensive and export-oriented industries. In scenarios BTA and IET, border tax adjustments and integrated emission trading, respectively, are introduced into the emissions trading scheme. Under the BTA regime, both tax compensation for the EU exports from the covered sectors and tariffs for the respective EU imports are quantity based, while the sector-specific level of BTA is determined by the EU average carbon content in the production of the corresponding energy-intensive goods. Under the IET regime, the EU exporters and the EU importers face the allowance price which is applied to the actual carbon content of the respective energy-intensive industry (see previous section for more details).

3.3 Results

In this section, we report effects of alternative policy options on the market for emissions permits (Figure 2) and the associated output effects for the EU and non-EU regions (Table 2), before addressing the issues of international carbon leakage (Table 3 and 4). The effects are measured with respect to business-as-usual (BAU) situation in which no policy measures are taken[5].

Figure 2: Emissions allowance price (in $US per ton of CO2) in 2020

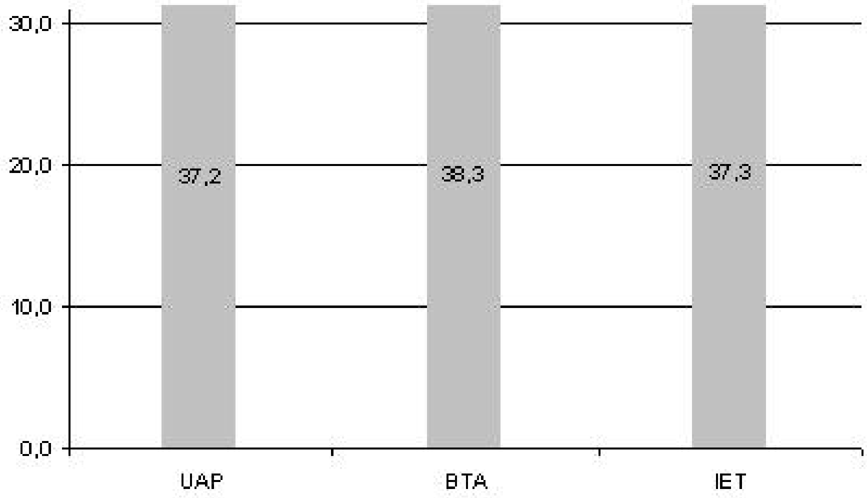


Figure 2 depicts the impacts on the market for emissions permits in 2020 across our scenarios. Due to the exogenous constraint to reduce carbon emissions by 20% vs. BAU in the EU-27, the allowance price amounts to roughly $ 37 US per ton CO_2 in the reference scenario (UAP). Cost-effective implementation of the target suggests that emission reduction is undertaken where it is cheapest. In our simulation, old and new EU Member States reduce 19 and 23% versus BAU levels, respectively. Obviously, multi-sectoral modelling approach allows to account for potentially important general equilibrium interactions: The

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[5] In our theoretical framework, we refer to the BAU situation as a laissez-faire case.

introduction of the BTA scheme (yielding scenario BTA) and the IET scheme (yielding scenario IET) in selected commodity markets surpass the carbon market. In our numerical setup, the impacts are quite modest: Under BTA, allowance price increases by roughly three per cent compared to the reference case. The introduction of the IET scheme causes the allowance price to increase by less than one per cent compared to the UAP scenario.

These results are mainly driven by increased production and emission levels resulting in a higher demand for emission allowances in covered energy-intensive sectors (EII). The introduction of the BTA and IET regimes in selected commodity markets partially shifts emission abatement from covered energy-intensive industries (EII) with relatively low abatement costs to non-energy-intensive sectors (NEI) with relatively high abatement costs. Thus, countries with the BTA and IET regimes in energy-intensive sectors end up with higher marginal abatement costs compared to the unilateral abatement policy without any complementary measures.

The macroeconomic implications - measured as changes in production level - for both EU and non-EU regions are summarised in Table 2. Referring to the central topic of our theoretical framework, we find that European energy-intensive sectors covered by offsetting measures (EII) are best off under the BTA regime: For these industries, the decrease in the production level in the BTA scenario is much less pronounced due to lower export price than under alternative scenarios. Vice versa, the EII sectors in non-EU regions are worst off under the BTA scenario as this (quantity-based) regime does not allow the respective industries to adjust energy intensity in the production process and makes imports to the EU more expensive. These quantitative results confirm the assertions from the theoretical analysis as EII sectors in the EU appear to be least exposed to international competition and therefore better protected under the BTA regime (see proposition 4). However, from a general equilibrium perspective, the introduction of the BTA and IET scheme in selected energy-intensive sectors leads to production level adjustments in the non-covered sectors. In Table 3 we report production level implications for (i) (important) energy-producing and remaining energy-intensive sectors (REI), (ii) non-energy-intensive sectors (NEI) and (iii) regional economies. In the EU-27, REI sectors are able to slightly extend production level due to lower energy prices, while non-energy-intensive sectors (NEI) decrease output to comply with the total emission reduction target. The increase in production level in energy-intensive sectors is, however, does not outweigh the output decrease in the non-energy intensive sectors which results in overall output losses for the EU-27. Remarkably, these losses are particularly pronounced under the BTA regime. While confirming theoretical results for the covered energy-intensive sectors, the multi-sectoral analysis thus reverses the insight of the theoretical analysis if the aggregate production level of regional economies is taken into consideration.

As we have seen, unilateral carbon abatement policies in the EU-27 induce adjustments of production (and consumption) patterns towards less carbon intensity and associated energy use. Neglecting economic benefits from improved environmental quality, such adjustments decrease real income and macroeconomic consumption, thereby generating welfare losses. Our simulation results for the EU-27 indicate, however, that efficient implementation of the given emission reduction target in the reference case (UAP) is consistent with fairly small welfare losses - expressed by the Hicksian Equivalent Variation (HEV) - as compared to an unconstrained business-as-usual situation. Introduction of the BTA and IET regimes has a

Table 2: Output effects [% vis-à-vis BAU]

	EII			*REI*			*NEI*			*TOTAL*		
	UAP	BTA	IET	UAP	BTA	IET	UAP	BTA	IET	UAP	BTA	IET
EU15	-1.88	0.41	-1.77	-12.78	-12.48	-12.77	-0.15	-0.32	-0.16	-0.16	-0.32	-0.17
EU12	-3.22	-2.37	-3.14	-8.83	-8.73	-8.82	-0.27	-0.37	-0.28	-0.30	-0.40	-0.31
EU27	-2.03	0.10	-1.92	-11.87	-11.62	-11.86	-0.16	-0.32	-0.17	-0.18	-0.32	-0.18
OOE	0.34	-0.19	0.37	0.96	0.90	0.96	-0.02	0.01	-0.03	-0.02	0.01	-0.02
RUS	0.82	0.12	0.68	1.01	0.79	0.97	0.07	0.12	0.07	0.08	0.13	0.08
SMA	0.54	-0.19	0.58	2.13	2.08	2.12	-0.02	0.03	-0.02	-0.02	0.03	-0.02
CHN	0.31	-0.19	0.27	0.65	0.46	0.50	0.00	0.06	0.00	0.00	0.06	0.00
SEA	0.82	-0.42	0.78	1.05	0.87	1.06	-0.03	0.05	-0.03	-0.03	0.05	-0.03
OPC	1.95	0.76	0.90	2.40	2.27	2.29	0.06	0.14	0.10	0.08	0.15	0.11
XRW	1.28	0.03	0.89	3.29	2.82	3.03	-0.05	0.07	-0.01	-0.04	0.08	0.00

EU15 Old Member States, **EU12** New Member States, **OOE** Rest of OECD, **RUS** Former Soviet Union, **SMA** Rest of South and Middle America, **CHN** China (including Hongkong), **SEA** Rest of South and East Asia, **OPC** OPEC, **XRW** Rest of the World. **EEI** energy-intensive and export-oriented sectors to which the BTA and IET regimes may be applied (ORE, PPP, NMM, NFM and CRP), **REI** energy-intensive but not-export oriented sectors to which the BTA and IET regimes are not applied (ATP, ELE and OIL), **NEI** non-energy-intensive sectors (ROI).

Table 3: Environmental effects [% vis-à-vis BAU]

	EII			*REI*			*NEI*			*TOTAL*		
	UAP	BTA	IET	UAP	BTA	IET	UAP	BTA	IET	UAP	BTA	IET
EU15	-10.80	-8.12	-10.70	-32.10	-32.10	-32.10	-7.76	-7.90	-7.75	-19.40	-19.40	-19.40
EU12	-13.40	-11.80	-13.20	-30.00	-30.20	-30.00	-16.20	-16.50	-16.30	-23.10	-23.20	-23.10
EU27	-7.66	-7.50	-7.64	-22.90	-22.90	-22.90	-8.85	-9.00	-8.84	-20.00	-20.00	-20.00
OOE	0.55	-0.07	-0.07	1.04	1.00	1.03	0.32	0.33	0.34	0.74	0.71	0.74
RUS	1.10	-0.09	-0.51	1.66	1.45	1.64	0.51	0.48	0.54	1.22	0.99	1.07
SMA	0.66	-0.20	-0.40	2.22	2.16	2.24	0.06	0.08	0.06	0.98	0.89	0.89
CHN	0.61	0.08	0.00	1.57	1.43	1.56	0.42	0.46	0.41	1.18	1.06	1.13
SEA	0.93	-0.29	-1.06	1.51	1.34	1.54	0.52	0.59	0.54	1.15	0.94	0.96
OPC	1.98	0.45	-1.28	1.58	1.42	1.47	0.54	0.59	0.52	1.15	0.93	0.72
XRW	2.75	-0.31	-5.21	3.87	3.39	3.63	0.11	0.16	0.10	2.41	1.86	1.47

EU15 Old Member States, **EU12** New Member States, **OOE** Rest of OECD, **RUS** Former Soviet Union, **SMA** Rest of South and Middle America, **CHN** China (including Hongkong), **SEA** Rest of South and East Asia, **OPC** OPEC, **XRW** Rest of the World. **EEI** energy-intensive and export-oriented sectors to which the BTA and IET regimes may be applied (ORE, PPP, NMM, NFM and CRP), **REI** energy-intensive but not-export oriented sectors to which the BTA and IET regimes are not applied (ATP, ELE and OIL), **NEI** non-energy-intensive sectors (ROI).

Table 4: Carbon emission reduction (% vis--vis BAU)

	UAP	BTA	IET
WORLD	-1.83	-1.95	-1.95

negligible impact (-0.04%) on social welfare in the EU-27[6].

We finally turn to the impacts on environmental effectiveness that constitutes - from the perspective of the European Union - the central trade-off with pure competitiveness considerations: Under UAP, unilateral abatement policy leads to an increase in emissions in non-abating regions, reducing the global environmental effectiveness (see Table 3). Although both BTA and IET occur to be a suitable strategy to reduce the leakage rate, Table 3 illustrates - in accordance with expectations from our theoretical framework - the central reasoning behind the superiority of the IET scheme as compared to the BTA regime in terms of environmental effectiveness. The central insight from our numerical analysis is that the IET scheme induces a considerably lower emissions level in EII sectors outside Europe than the BTA scheme in all model regions (except of OOE), while increase in energy efficiency represents the main driver behind this result. Finally, the general equilibrium perspective provides further insights into the global environmental effectiveness of alternative offsetting measures: Under the BTA and IET regimes, the reduction of the global carbon emission level is feasible compared to the unilateral case. However, from the global perspective, the IET regime does not induce a lower emission level compared to the BTA regime (Table 4).

4 Discussion and conclusion

In 2007, the European Council developed an ambitious plan for the post-Kyoto era, envisioning a unilateral reduction in CO_2 emissions in Europe by 20% (compared to 1990 levels) by 2020. Evidently, such a unilateral environmental policy causes concerns about its effects on competitiveness, particularly for the European energy-intensive industries. Moreover, the relocation of industries to regions outside Europe threatens to reduce the effectiveness of the measures (leakage). This paper assesses two policies that have been proposed to mitigate these problems: Border tax adjustments (BTA) and integrated emission trading (IET). Our contribution is to characterise both policies, to analyse the channels affecting their economic and environmental effectiveness and to quantify the outcome. Referring to the central theme of our theoretical analysis, we find that energy-intensive sectors in the EU are best off under the BTA regime, while the IET scheme induces a considerably lower leakage rate than the BTA scheme. The numerical analysis puts this view into perspective: While the theoretical conclusions hold true for sectors participating in either BTA or IET (i.e. energy-intensive sectors), the presence of non-participating (i.e. non-energy-intensive) sectors can lead to a

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[6] We report the welfare implications for EU-27 only, since a direct comparison of the welfare impacts for other regions or globally would be misleading. This is due to the fact that environmental effectiveness of alternative policy options for these regions differs across three scenarios (see Table 3 and 4). It should be emphasised that environmental quality does not enter into the utility function.

reversion of the result on competitiveness. The carbon rebate for exports granted under both BTA and IET means that a part of the abatement burden is shifted from the ETS sectors to the non-ETS sectors increasing the overall costs of abatement. Finally, the numerical analysis confirms the global environmental effectiveness of both policies, with little difference in the impacts of BTA and IET.

These results show the importance of a careful implementation of both policies. In the sequel we briefly discuss the related legal and practical problems. By imposing a duty on imports both BTA and IET interfere with free trade policies. It is a legal matter whether and to what extent the policies are compatible with the GATT treaty on international free trade[7]. In their analysis of BTA, Ismer and Neuhoff (2004) conclude that BTA do not violate the treaty if they are based on the "best-available technology" assumption, i.e. the assumed carbon content of imported goods must correspond to goods produced with the least carbon intensive technology. The macroeconomic models applied in this paper do not, of course, allow for a precise descripture of the full spectrum of available technologies. By fixing the carbon content of imported goods to the energy efficient European production level we are, however, broadly in line with the 'best-available technology' assumption.

As for the practical implementation, the ultimate choice of an appropriate offsetting measure should be based on two considerations, concerning the institutional arrangements and the degree of international cooperation. The implementation of both instruments is likely to go along with considerable administrative efforts in the domestic or foreign country, respectively. Additional to the domestic environmental administration (national carbon registers) authorities must be established to define benchmarks, to measure and to report carbon content of the imported goods. While the BTA regime calls for a home-based authority defining carbon standards, IET requires international cooperation to run comparable institutions (branch offices) abroad. Thus, IET represents, in principle, an intermediate step in multilateral cooperation on climate change issues. The introduction of the IET regime could finally result in launching emission reduction schemes with binding constraints abroad, which could then be linked with the domestic scheme[8]. In that case, IET would be an example of the export of EU regulation - a phenomenon that has recently attracted attention (compare the article "Brussels rules OK - How the European Union is becoming the world's chief regulator" in *The Economist* of September 27, 2008). Instead, BTA is per-se a non-cooperative policy option. Its introduction may cause retaliatory measures by trading partners resulting in the welfare-decreasing trade wars. The study of such a scenario requires a game-theoretic setup.

Assuming the practical and legal issues being settled, our numerical analysis shows that a straightforward implementation of BTA and IET can run into difficulties. In order to avoid the distortion of competitiveness by BTA policy makers may consider adopting a different paradigm of emission reduction. Instead of fixing a cap for domestic production they may prefer to cap emissions related to domestic consumption. Analysing the implications of such a change of paradigm, however, is left to future research.

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[7] Note, however, that environmental border tax adjustments have been used in U.S. trade policy for some thirty years (cf. Hoerner, 1998).

[8] For a detailed analysis of the linking of abatement schemes compare Anger (2008) and Aleexeva-Talebi and Anger (2007).

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Appendix

The appendix presents the proofs of Propositions 1 through 4 and Corollary 5. All proves build on transformations of the first order conditions of the firms and the emission cap. We start by presenting the transformed first order conditions which give rise to equations determining prices.

P-UAP We eliminate the emission tax τ with the help of the first order condition for μ_d, equation 7, and thus obtain the following set of price equations:

$$p_d^d = c^d(\mu^d) - c_1^d(\mu^d)\mu^d \qquad p_f^d = c^d(\mu^d) - c_1^d(\mu^d)\mu^d$$

$$p_d^f = c^f(\mu^f) \qquad p_f^f = c^f(\mu^f)$$

P-BTA As before, eliminating τ and κ by equations 15 and 12 yields a set of price equations:

$$p_d^d = c^d(\mu^d) - c_1^d(\mu^d)\mu^d \qquad p_f^d = c^d(\mu^d)$$

$$p_d^f = c^f(\mu^f) - c_1^d(\mu^d)\mu^d \qquad p_f^f = c^f(\mu^f)$$

P-IET In the case of IET, we use the definition of Cobb-Douglas demand functions of private households as well as the first order conditions for μ^d and μ^f, equation 22 and 25, to obtain

$$p_d^d = \frac{c^d(\mu^d)}{c^d(\mu^d) + \gamma^d c_1^d(\mu^d)\mu^d}[c^d(\mu^d) - c_1^d(\mu^d)\mu^d] \qquad p_f^d = c^d(\mu^d)$$

$$p_d^f = \frac{c^f(\mu^f)}{c^f(\mu^f) + \gamma^f c_1^f(\mu^f)\mu^f}[c^f(\mu^f) - c_1^f(\mu^f)\mu^f] \qquad\qquad p_f^f = c^f(\mu^f)$$

with $\gamma^d = \frac{\alpha_f w_f}{\alpha_d w_d}$ and $\gamma^f = \frac{(1-\alpha_f)w_f}{(1-\alpha_d)w_d}$.

From assumption 1 we infer that the emission caps, i.e. constraints , and , are binding. Thus they give rise to one more equation respectively. Both the transformed first order conditions above and Cobb-Douglas demand functions enter into their transformation. They take the form of fix-point equations.

$$(\mu^d)^{UAP} = \frac{\bar{E}}{\alpha^d w^d + \alpha^f w^f}[c^d(\mu^d) - c_1^d(\mu^d)\mu^d] \tag{27}$$

$$(\mu^d)^{BTA} = \frac{\bar{E}}{\alpha^d w^d + \alpha^f w^f \left(1 - \frac{c_1^d(\mu^d)\mu^d}{c^d(\mu^d)}\right)}[c^d(\mu^d) - c_1^d(\mu^d)\mu^d] \tag{28}$$

$$(\mu^d)^{IET} = \frac{\bar{E}}{\alpha^d w^d + \alpha^f w^f}[c^d(\mu^d) - c_1^d(\mu^d)\mu^d] \tag{29}$$

We are now prepared for the proofs.

Proposition 1 (Existence of Equilibria)

The existence of equilibria is guaranteed by general equilibrium theory (cf. MasCollel et al. 1995, ch. 10). Uniqueness of equilibria follows from the unique determination of μ^d and μ^f by equations 2 and 4 for the Laissez-Faire case, 27 and 10 for the UAP case, 28 and 18 for the BTA case, 29 and 25 for the IET case. For equations 2, 4, 10, 18 and 25 this is a direct consequence of the properties of the marginal cost function $c(.)$. For equations 27, 28 and 29 this follows from the fact that the right-hand side of the equations is falling, starting from infinity as μ^d goes to zero, leading to a unique crossing point with the left-hand side.

Proposition 2 (Laissez-Faire vs. Policies)

The claim that domestic energy intensity under Laissez-Faire, $(\mu^d)^{LF}$, is higher than domestic energy intensities μ^d under the three policies can easily be seen from the following argument: The LF equilibrium is identical to the policy equilibria if we set the emission cap $\bar{E}$ to the value of domestic emissions $(E^d)^{LF}$ under LF. However, due to assumption 1 we know that the $\bar{E}$ is smaller than that. Comparing the policy μ^ds with $(\mu^d)^{LF}$ is thus equivalent to comparing μ^ds in equations 27, 28 and 29 with $\bar{E}$ shifted upwards. Clearly, such a change increases the RHS of the equations and thus the equilibrium value of μ^d. The same argument applies to the comparison of μ^f under LF and IET, whereas a comparison of the first order conditions for μ^f under LF, equation 4, and under UAP and BTA, equations 10 and 18, shows the identity of the foreign energy intensities μ^f.

The comparison of equilibrium prices under LF and the three policies ensues from a comparison of the first order conditions, using the inqualities for μ^d and μ^f we just derived.

We concentrate on the case of p_d^d, the arguments are similar for the other prices. Due to our assumptions on the cost function $c^d(\mu)$, we know first that $-c_1^d(\mu^d)\mu^d > 0$ and we calculate second that

$$\frac{\partial(c^d(\mu^d) - c_1^d(\mu^d)\mu^d)}{\partial\mu^d} = -c_2^d(\mu^d) < 0.$$

Due to the first inequality we may conclude that p_d^d would be higher under LF than under any policy if all formulae (of the first order conditions 2, 5, 13 and 20) were evaluated at $(\mu^d)^L F$. The second inequality shows that the claim holds a forteriori true at an evaluation at the true values of p_d^d under UAP, BTA and IET.

Using the definition of the demand functions 4, the comparison of equilibrium quantities $q_{r_d}^{r_f}$ follows directly from the comparison of prices.

Proposition 3 (Energy Intensities)

Energy intensities μ^d under UAP, BTA and IET can be compared by virtue of equations 27, 28 and 29. The equality of $(\mu^d)^{UAP}$ and $(\mu^d)^{IET}$ is obvious. The inequality $(\mu^d)^{BTA} < (\mu^d)^{UAP} = (\mu^d)^{IET}$ follows from the fact that the denominator of the RHS of equation 28 is larger than that of 27 and 29.

To understand why $(\mu^f)^{IET}$ is smaller than $(\mu^f)^{BTA}$ we have to derive equations characterizing $(\mu)^f$. In case of BTA this is simply 18. In case of IET, we use 25, P-IET and 4 to obtain

$$c_1^f(\mu^f) = -\tau\frac{c^f(\mu^f)}{c^f(\mu^f) + \gamma^d(c^f(\mu^f) + \tau\mu^f)}.$$

As τ is implicitly determined by 29 as a positive number, and given our assumption on c^f, we may infer that $c_1^f(\mu^f) < 0$ which yields the claim. The equality of $(\mu^f)^{UAP}$ and $(\mu^f)^{BTA}$ is a trivial consequence of the first order conditions 10 and 18.

Proposition 4 (Competitiveness)

The proof of Proposition 4 resembles the one of Proposition 2. Essentially, we use equations P-UAP, P-BTA, P-IET, the emission constraints 4, 4 and 4 and the results on energy intensities μ^d and μ^f from Proposition 3 to compare prices, and the comparison of prices to compare quantities. We will concentrate on the case of p_d^d as before, and then explain the need of the symmetry assumption 3 in the comparison of the BTA and IET policy.

The functional form of the equation for p_d^d under P-UAP and P-BTA is identical. The inequality $(p_d^d)^{UAP} < (p_d^d)^{BTA}$ is a direct consequence of the one we have proved above, $(\mu^d)^{UAP} > (\mu^d)^{BTA}$, and the fact that the RHS of P-UAP(p_d^d) and P-BTA(p_d^d) is a decreasing function of μ^d (compare the proof of Proposition 2). The inequality $(p_d^d)^{UAP} < (p_d^d)^{IET}$ is due to the factor $\frac{c^d(\mu^d)}{c^d(\mu^d)+\gamma^d c_1^d(\mu^d)\mu^d} > 1$ in front of $c^d(\mu^d) - c_1^d(\mu^d)\mu^d$ (which is identical to the RHS of P-UAP(p_d^d)) and the equality $(\mu^d)^{UAP} = (\mu^d)^{BTA}$ shown before.

The comparison of $(p_d^d)^{BTA}$ and $(p_d^d)^{IET}$ is trickier. First, we have to show that $(p_f^d)^{BTA} > (p_f^d)^{IET}$. This follows from $(\mu^d)^{BTA} < (\mu^d)^{IET}$ and the fact that the $c(.)$ is a decreasing function (cf. P-BTA and P-IET). From the comparison of the p^d_f and the definition of the demand functions 4, we conclude that $(q^f_d)^{BTA} < (q^f_d)^{IET}$. Now, given that the emission cap $\bar{E}$ is the same under both BTA and IET and that $(\mu^d)^{BTA} < (\mu^d)^{IET}$, we may conclude that domestic production is higher under BTA than under IET. So in particular $(q^d_d)^{BTA} > (q^d_d)^{IET}$, and thus $(p^d_d)^{BTA} < (p^d_d)^{IET}$.

A glance at P-BTA(p^f_d) and P-IET(p^f_d) shows the difficulty of a comparison of $(p^f_d)^{BTA}$ and $(p^f_d)^{IET}$ - the two formulae contain different cost functions $c^f(.)$ and $c^d(.)$. Without further assumptions, we cannot expect to obtain an answer to the question how the two prices compare. Assumption 3 is sufficient to establish the relations stated in Proposition 4, as is immediate for the case of p^f_d from a comparison of P-BTA(p^f_d) and P-IET(p^f_d) and $(\mu^f)^{BTA} > (\mu^f)^{IET}$. It is obvious from the formulae that a weaker assumption than 3 could lead to the same result.

Corollary 5 (Leakage)

The results on the relation of foreign emissions under the three policies are a direct consequence of the relation of quantities, derived in Proposition 4, and of energy intensities, derived in Proposition 3.