Welfare Implications of EU Effort Sharing Decision and Possible Impact of a Hard Brexit

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Abstract

In this paper, we evaluate the recent developments of European climate policy from the perspective of the 2050 European commitments with regards to GHG emissions reduction. We use a non-cooperative meta-game approach for assessing European burden-sharing issues. We analyze the European Effort Sharing Decision proposed in July 2016 and evaluate its cost per member states. We simulate several other policy options regarding this sharing decision with the aim to stress the main policy implications of the new proposal. Considering the Brexit referendum that took place June 23, 2016 in the United Kingdom, we analyze different possible scenarios of British participation in European climate policy. We show that Brexit could have a significant negative impact on the United Kingdom's climate-policy cost and a relatively positive effect on the remaining twenty-seven EU member states.

Keywords: Effort Sharing Decision, Brexit, European Union, Climate policy, Game theory

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1. Introduction

The aim of this paper is twofold. First, we provide an economic assessment of the EU burden-sharing rule recently submitted by the European Commission (EC), and we discuss the fairness issues associated with this rule. Second, we

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analyze the potential impact of the UK Brexit decision on the EU climate policy and the burden-sharing agreements.

In July 2016, the EC presented its proposal for a regulation to reduce GHG emissions in sectors not covered by the emissions trading system (ETS) with regards to post-2020 binding targets (European Commission, 2016). The proposal defines a new burden-sharing framework, called the Effort Sharing Decision (ESD), and proposes several new features of the European framework aimed at limiting GHG emissions. Unfortunately, the impact assessment done by the commission does not provide the welfare implication per member states (MS) of this new regulation even though the models used for this assessment (Primes and GEM-E3) allow for such an evaluation (Capros et al., 2011). Hence, the first goal of this paper is to analyze the EU burden-sharing rule in the context of 2050 European climate targets, which imply a reduction of GHG emissions by at least 80% domestically by 2050 as compared to 1990 levels (CEC, 2011a). We will evaluate MS welfare impacts for this new EU proposal and compare them with those occurring in some possible alternative rules.

In June 2016, the UK voted to leave the European Union (EU) (Menon and Salter, 2016) and, as a consequence, a number of European policies need to be revised. Among them, we find, of course, the European climate policy with commitments and economic instruments that are already in effect, such as the EU ETS (Anderson et al., 2016), the ESD discussed above and the upcoming pledges submitted recently at COP21 (Rogelj et al., 2015; United Nations Framework Convention on Climate Change, 2016a). At COP21, the EU MS adopted a binding target of at least a 40% reduction in domestic GHG emissions by 2030 compared to 1990. Brexit will force EU to reconsider the ESD without the UK participation. Thus, the second objective of this paper will analyze the impact of a hard Brexit on the European climate policy. For that purpose we will use the fair burden-sharing model for Europe, already introduced in Babonneau et al. (2016).

This paper is organized as follows. Section 2 introduces the burden-sharing model used for assessing the welfare implications of the EU ESD and explains how the Brexit component is taken into consideration in our game theoretical approach. Section 3 discusses implementation issues such as the calibration of the payoff functions and the reference scenario. In Section 4, we provide an economic assessment of the recent ESD and of the possible impacts of a hard Brexit on the long-term European climate policy. Eventually, Section 5 concludes our analysis.

2. A model to assess EU28 burden-sharing

In the literature, the design of climate agreements is usually the result of a fully normative approach in which a benevolent planner (e.g., EC) completely organizes the international permit trading system. This approach determines the emissions budget share given to each country and decides how much of this share is allocated per period by region. These types of approaches entirely bypass the possibility for each country to strategically exploit its share of the cumulative emission budget, even though this aspect of the policy is explicitly addressed in the recent EC proposal on burden-sharing (European Commission, 2016). Recently, a dynamic game model has been proposed in Babonneau et al. (2016) to represent the non-cooperative timing strategies of EU countries in the exploitation of their respective emissions budget share. In this game, the players are the 28 EU countries. The strategies are the supply schedules of emission rights on the European carbon market, and the payoffs are the discounted sums of welfare gains (or losses). A coupled constraint on the emission budget is imposed. The game has, therefore, a two-level structure. At the lower level, a competitive carbon market defines carbon prices and emission levels for each country based on the total emission rights supply. At the higher level, each country decides, for each period, its own emission rights supply, considering the share of global cumulative emission budget it has received. A first version of the model, using a game theoretic approach, has been proposed in Babonneau et al. (2013) and Haurie et al. (2014) to analyze a fair distribution of effort among twelve coalitions of countries worldwide. The same approach has been used in Babonneau et al. (2016) to assess the EU climate policy.

2.1. The European burden-sharing model

For the sake of clarity, let us recall the mathematical formulation of the European burden-sharing game proposed in Babonneau et al. (2016). There are m countries indexed $j = 1, \dots, m$, that generate emissions e_j^t on periods $t \in \{0, 1, \dots, T-1\}$. The model assumes:

1. **A competitive market for emission permits**, which clears at each period, denoting ω_j^t the supply of permits by country j at period t. Then, $\Omega^t = \sum_{j=1}^m \omega_j^t$ is the total supply of permits on the market at period t and $p^t(\Omega^t)$ the clearing permit price at period t.
2. **A cumulative emissions budget** denoted `Bud` imposes a limit on cumulative emissions from all countries over the T periods. This budget is distributed among the players. Let $\theta_j \in [0, 1]$ be the share of player j, with

$\sum_{j=1}^{m} \theta_j = 1$. The θ parameters are thus design variables that will change the game structure, and, therefore, the equilibrium solution.

In the proposed information structure, each player (country) j defines for itself a permit supply schedule $(\omega_j^t : t = 0, \dots, T-1)$. The total supply of permits on the market at period t is $\Omega^t = \sum_{j=1}^{m} \omega_j^t$. The payoff of player j at equilibrium satisfies :

$$\max_{\omega_j} \left\{ \sum_{t=0}^{T-1} \beta_j^t (\pi_j^t(\mathbf{e}_j^t(\Omega^t)) + p^t(\Omega^t)(\omega_j^t - \mathbf{e}_j^t(\Omega^t))) \right\}, \tag{1}$$

subject to actions chosen by the other players and under the budget-sharing constraint

$$\sum_{t=0}^{T-1} \omega_j^t \leq \theta_j \texttt{Bud}. \tag{2}$$

Here β_j^t is a discount rate (equal to 5%), and $\pi_j^t(e_j^t)$ represents the economic benefits obtained from emissions by country j at time t. One assumes positive diminishing marginal returns, i.e. $\pi_j^{t\prime}(e_j^t) > 0$ and $\pi_j^{t\prime\prime}(e_j^t) < 0$.

We assume a competitive market for emission permits that clears at each period. Given a price p^t, each country chooses emissions to achieve

$$\max_{e_j} \left\{ \pi_j^t(e_j^t) + p^t(\omega_j^t - \mathbf{e}_j^t(\Omega^t)) \right\}.$$

Equilibrium conditions of profit maximization and market clearing are then

$$\begin{aligned} \pi_j^{t\prime}(e_j^t) &= p^t, \quad t = 0, \dots, T-1; \quad j = 1, \dots, m, & (3) \\ \Omega^t &= \sum_{j=1}^{m} e_j^t, \quad t = 0, \dots, T-1. & (4) \end{aligned}$$

Note that compared to the existing EU climate-policy architecture, the game structure proposed here assumes implicitly that EU ETS is extended to non-ETS sectors. This assumption is consistent with the scenario "one-off flexibility" currently debated in the new regulation (European Commission, 2016) related to the post-2020 binding target. In this scenario, one aims at facilitating the access to EU ETS for MS with a national emissions-reduction target significantly above both the EU average target and their cost-effective reduction potential. Moreover, the banking and borrowing option that is assumed in the game is also considered in the same document through inter-temporal flexibility. Our assumption is that with increasing abatements the need for equalization of carbon prices between ETS and non-ETS sectors should become a crucial issue (Tol, 2009).

This system implicitly defines after-trade equilibrium emissions, $\mathbf{e}_j^t(\Omega^t)$, and the permit price, $\mathbf{p}^t(\Omega^t)$. By differentiating (3) and (4) we can compute the derivatives

$$\begin{aligned} \mathbf{p}^{t\prime}(\Omega^t) &= \frac{1}{\sum_{j=1}^{m} \frac{1}{\pi_j^{t\prime\prime}(\mathbf{e}_j^t(\Omega^t))}} && (5) \\ \mathbf{e}_j^{t\prime}(\Omega^t) &= \frac{1}{\sum_{i=1}^{m} \frac{\pi_j^{t\prime\prime}(\mathbf{e}_j^t(\Omega^t))}{\pi_i^{t\prime\prime}(\mathbf{e}_i^t(\Omega^t))}}. && (6) \end{aligned}$$

Applying the standard Kuhn-Tucker multiplier method, with multipliers ν_j, we obtain the following first-order necessary conditions for a Nash equilibrium

$$\begin{aligned} \nu_j &= \beta_j^t(p^t(\Omega^t) + p^{t\prime}(\Omega^t)(\omega_j^t - \mathbf{e}_j^t(\Omega^t))) && (7) \\ & \qquad t = 0, \ldots, T-1; \quad j = 1, \ldots, m. \\ 0 &= \nu_j(\theta_j \mathtt{Bud} - \sum_{t=0}^{T-1} \omega_j^t) && (8) \\ 0 &\leq \theta_j \mathtt{Bud} - \sum_{t=0}^{T-1} \omega_j^t && (9) \\ 0 &\leq \nu_j. && (10) \end{aligned}$$

Negotiations could then focus on the design of the budget-sharing scheme, i.e., finding the proportions $\theta_j \geq 0,\ j = 1, \ldots, m$ of the budget allocated to each country, satisfying $\sum_{j=1}^{m} \theta_j = 1$.

2.2. *Taking Brexit into account*

Let us explain how Brexit is taken into consideration in this game theoretic analysis.

2.2.1. *The current UK situation within EU*

In 2014, according to UNFCCC inventory[1] (United Nations Framework Convention on Climate Change, 2016b), the UK was the second-largest European

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[1] GHG emissions with LULUCF.

GHG emitter, with 518 Mt CO_2-eq emitted, representing 13.1% of EU28 emissions. As highlighted by Pye et al. (2015), the UK was the first G20 country to adopt legislation on GHG emissions. In 2000, the British government launched the country's Climate Change Programme, with the aim of achieving not only the GHG emissions defined within the Kyoto Protocol but to go beyond this goal by emitting 20% less carbon dioxide than in 1990 in 2010. The Climate Change Programme introduced several economic instruments, e.g., a climate-change levy, an energy-efficiency improvement program, and a UK Emissions Trading Scheme (UK ETS). The UK ETS was the first national, multi-sector CO_2 emissions trading program ever implemented (Smith and Swierzbinski, 2007; Dahan et al., 2015). In 2008, the Climate Change Act (United Kingdom Government, 2008) established a mandate of an 80% cut in GHG emissions by 2050. Since 2007, the UK has participated in the EU ETS, a central pillar of EU climate policy and the first cap-and-trade system dedicated to carbon emissions implemented at an international level. The EU ETS was inspired by the UK ETS. The EU ETS applies to all 28 EU MSs and to three of the four partners of the European Free Trade Association (Norway, Iceland, and Liechtenstein). The ETS covers 45% of EU GHG emissions and more than 11,000 energy-intensive plants from power generation and manufacturing industries. According to the UK government about 1,000 power stations and industrial plants in the UK participate in the EU ETS.

2.2.2. The situation after Brexit

After Brexit, the UK should effectively continue its transition to a low-carbon economy as pointed out by Lord Nicholas Stern: "*The UK's commitment on climate change is longstanding and based on a understanding that it is global issue and should not be altered by its future departure from the European Union*"[2]. Further, it seems very unlikely that the UK would revise its international climate change commitments (Scott, 2016).

We assume in our analysis a hard Brexit, meaning that the UK cannot participate any more to the EU game. the UK timing strategy is represented by the following domestic model:

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[2] Lord Stern responds to speech by the UK Secretary of State for Energy and Climate Change Amber Rudd, see http://www.lse.ac.uk/GranthamInstitute/news/lord-stern-responds-to-speech-by-amber-rudd/

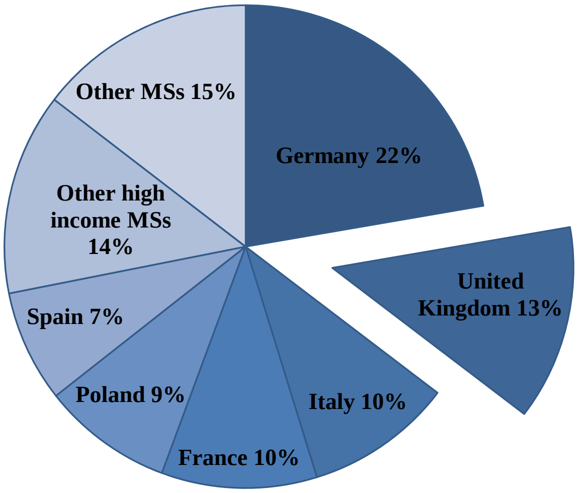

Figure 1: Share of CO_2 emissions per MS in 2014. Source:United Nations Framework Convention on Climate Change (2016b) (Other high income MSs: Austria, Belgium, Denmark, Ireland, Luxembourg, Finland, Netherlands, and Sweden).

$$\max_{e_{uk}} \left\{ \sum_{t=0}^{T-1} \beta_{uk}^{t} \pi_{uk}^{t}(e_{uk}^{t}) \right\}, \tag{11}$$

subject to UK budget constraint

$$\sum_{t=0}^{T-1} e_{uk}^{t} \leq \mathtt{Bud}_{\mathtt{uk}}. \tag{12}$$

The UK's CO_2 target is implemented domestically through a domestic carbon price, without any access to the EU emissions trading system. Other European countries continue to participate in the European climate framework with a reduced budget from which the UK emissions budget has been subtracted, i.e. $\mathtt{Bud}$-$\mathtt{Bud}_{\mathtt{uk}}$.

3. Identification of welfare losses

In this section, we discusse the implementation issues of the European burden-sharing model described above.

3.1. Payoffs

To identify the payoff functions of the game defined above we apply regression analysis based on an ensemble of 200 numerical simulations of different possible European climate-policy scenarios performed with GEMINI-E3. In each scenario, we assume a carbon tax is implemented at the European level without emissions trading and we suppose only carbon emissions are taxed. We computed the following (undiscounted) values for each country and each time period:

- The abatement level relative to the reference emissions ($\bar{e}_j^t$) expressed in a million tons of carbon; The abatement is thus defined by $\bar{e}_j^t - e_j^t$
- The welfare cost measured by household surplus, and represented by the compensating variation of income (CVI) expressed in \$ (see Bernard and Vielle (2003) for details);
- The gains in the terms of trade (GTT) representing spill-over effects due to changes in international prices. In a climate change policy these GTTs come mainly from the drop in fossil energy prices that result from the decrease of world energy demand. The GTTs are expressed in US\$.

We obtain the abatement cost (AC) by subtracting the GTT from the surplus, which defines the deadweight loss of taxation, i.e., the domestic cost that would occur in a closed economy and that depends only on abatement done within the country. The GTT represents the imported cost (negative for energy-exporting countries and positive for net energy-importing countries such as European countries). This imported cost or benefit is a function of the global EU carbon abatement.

Using regression analysis[3], one estimates the parameters $\alpha_j^1(t)$, $\alpha_j^2(t)$, $\alpha_j^3(t)$ and $\alpha_j^4(t)$ in a polynomial of degree 4 describing the abatement cost $AC_j^t(e_j^t)$ of player j at period t, as a function of the abatement level. To maintain convexity of the cost function, the regression analysis is done under constraints $AC_j^{t\prime}(\cdot) \geq 0$ and $AC_j^{t\prime\prime}(\cdot) \geq 0$.

$$AC_j^t(e_j^t) = \alpha_j^1(t)\,(\bar{e}_j^t - e_j^t) + \alpha_j^2(t)\,(\bar{e}_j^t - e_j^t)^2 + \alpha_j^3(t)\,(\bar{e}_j^t - e_j^t)^3 + \alpha_j^4(t)\,(\bar{e}_j^t - e_j^t)^4. \tag{13}$$

The 10-year time periods (t) are 2020, 2030, 2040, 2050.

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[3] All estimators ($\alpha_j^k(t)$ and $\mu_j(t)$) including standard deviations are available upon request.

Figure 2 presents the marginal abatement cost (MAC) curves (i.e. the derivative of the abatement cost function with respect to the abatement) for main European countries estimated for the year 2030. It shows where it is the cheapest to abate carbon emissions (Poland, Germany, Spain, and new MSs) and where it is the most expensive (France, Italy, and other high-income MSs). The UK (black curve) is part of the first group.

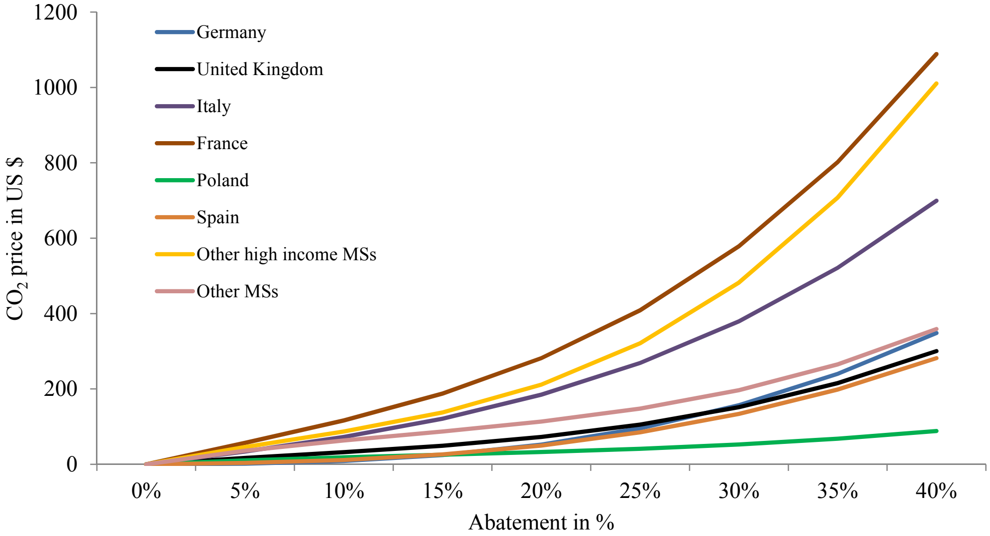

Figure 2: Marginal abatement cost function in 2030 in US$ per ton of CO$_2$ wrt to percentage of CO$_2$ emissions reduction

The GTT of player j is assumed to be a linear function of the EU abatement in a given period

$$GTT_j^t(e_j^t) = \mu_j(t) \sum_i (\bar{e}_i^t - e_i^t), \quad j = 1, \dots, m, \tag{14}$$

and the parameters $\mu_j(t)$ are also estimated from the GEMINI-E3 runs. Using these definitions, the economic benefits $\pi_j^t(.)$ introduced in (1) is defined as the opposite of welfare loss induced by abatement

$$\pi_j^t(e_j^t) = GTT_j^t(e_j^t) - AC_j^t(e_j^t), \quad j = 1, \dots, m. \tag{15}$$

3.2. The GEMINI-E3 reference scenario

The GEMINI-E3 reference scenario is built on the time period of 2007-2050 with yearly timesteps; all prices given in this paper are in 2007 US$. Assumptions on population and GDP are based on joint work of the Economic Policy

Committee and the European Commission (DG ECFIN) published in 2011 (CEC, 2011b). This work supposes European GDP will grow by 1.6% per year between 2010-2050. Evolution of energy prices is based on assumptions from the *current policies* scenario of the *World Energy Outlook 2013* of the International Energy Agency (International Energy Agency, 2013). It is assumed that in 2050 the price of oil will reach \$162, the price of imported gas in Europe will be equal to \$15.6 per Mbtu and the price of steam coal imported to OECD countries will reach \$125 per ton.

Note that in this reference scenario, no climate policy is implemented. This will serve to evaluate the burden of implementing the European climate policy for each participating country, considering the 2050 target and existing 2020 objectives. Our reference is consistent with the "no-policy baseline scenario" performed within the EMF28 project (Knopf et al., 2013), in which most of the models suggest a more modest CO_2 emissions increase. Our emissions will generate a cumulative emissions budget of 173 Gt CO_2 over the period 2011-2050. According to EC (CEC, 2011b), the UK's GDP will grow at 1.9% per annum from 2015 to 2050. This assumption does not consider any possible negative economic impact caused by Brexit (Kierzenkowski et al., 2016; PricewaterhouseCoopers, 2016). In our reference scenario, the UK's CO_2 emissions grow at an annual rate of 0.7% and represent, during the period from 2011-2050, 14% of EU28 CO_2 emissions.

4. Economic assessment of the effort sharing decision and Brexit

In this section, we first design and assess different EU burden-sharing agreements up to 2050 based on recent propositions of the EU Commission and we compare these agreements with a more equitable burden-sharing in which relative contributions are equalized. Second we evaluate the potential economic impacts of the recent Brexit decision on the long-term EU climate policy, assuming a complete and hard leave of the UK. All detailed results of the scenarios discussed in this section are reported in appendices A.1 and A.2.

In all following simulations, we focus on the period 2011-2050 and we constrain MS to satisfy an EU emissions budget during that period that is compatible with the pathway associated with an 80% reduction by 2050. In this paper, we consider only CO_2 emissions from energy combustion. According to Babonneau et al. (2016), this budget is estimated to 99 Gt CO_2 whose 13.7 Gt CO_2 is for the UK.

4.1. EU burden-sharing scenarios

Let us first define three burden-sharing scenarios for the period 2011-2050 partly by extending up to 2050 the so-called "Effort Sharing Decision" (ESD) proposed recently by the EU commission. The scenarios then differ in how they combine European Trading Scheme (ETS) and non-ETS mechanisms in a unified EU carbon permit scheme. Let us now describe and justify the generation of these scenarios in-more depth.

The "Energy–Climate" directive adopted in 2008 divided the European economy into two parts (Böhringer, 2014; Böhringer et al., 2009): (i) sectors subject to the European trading scheme (ETS) were chosen from those most energy-intensive (primarily electricity generation), and (ii) all other sectors (non-ETS), including the fossil energy consumption of households. The ETS is an exchange tradable permits market for firms, characterized by one CO_2 price (Venmans, 2012). The allocation of allowances is mainly based on free allowances with some auctioning. However, in the future, it is planned that auctioning will become the default method (Hepburn et al., 2006). For the non-ETS market, CO_2 abatement objectives are based on the so called "Effort Sharing Decision" (ESD).

The ESD sets GHG emissions targets for MSs according to their economic capacity on the basis of their relative wealth measured by GDP per capita. Two rounds of ESD were already defined, one for the year 2020 adopted in 2007 and the other one recently proposed for the year 2030 (European Commission, 2016). Table 1 shows these two ESDs, and figure 3 plots the GHG abatement target with respect to GDP per capita for each MS. The relation between the GHG target and wealth can be approximated accurately by a polynomial function as shown in figure 3 (ESD 2020 and ESD 2030). For our analysis, we replicate the same rule for the all periods (i.e., 2011-2050) and apply the same trend. We define an aggregate CO_2 emissions reduction for the whole period equal to 43%, i.e., (173-99)/173, and allocate this target to MS, using the same polynomial function with a constant term adjusted to fit the requested CO_2 aggregated emissions reduction. This burden-sharing is presented in the last column of table 1 and in the figure 3 through a black line. Our ESD corresponds to a downward translation with respect to the 2030 ESD.

Table 1: Effort-sharing decision

	GDP per capita	ESD target 2020	ESD target 2030	ESD target 2011-2050
	year 2013	in % of 2005 levels		in % of 2011-2050
	Source: European Commission (2016)			emissions
Bulgaria	5800	20%	0%	-14%
Romania	7200	19%	-2%	-16%
Croatia	10200	11%	-7%	-20%
Hungary	10200	10%	-7%	-20%
Poland	10200	14%	-7%	-20%
Latvia	11300	17%	-6%	-22%
Lithuania	11800	15%	-9%	-23%
Slovakia	13600	13%	-12%	-26%
Estonia	14400	11%	-13%	-27%
Czech Republic	14900	9%	-14%	-28%
Portugal	16300	1%	-17%	-30%
Greece	16500	-4%	-16%	-31%
Slovenia	17400	4%	-15%	-32%
Malta	18100	5%	-19%	-33%
Cyprus	21000	-5%	-24%	-37%
Spain	22100	-10%	-26%	-39%
Italy	26500	-13%	-33%	-45%
United Kingdom	31900	-16%	-36%	-50%
France	32100	-14%	-36%	-50%
Germany	35000	-14%	-37%	-52%
Belgium	35400	-15%	-38%	-52%
Finland	37400	-16%	-39%	-53%
Austria	38100	-16%	-39%	-53%
Netherlands	38700	-16%	-39%	-54%
Ireland	39000	-20%	-39%	-54%
Sweden	45400	-17%	-40%	-54%
Denmark	45500	-20%	-40%	-54%
Luxembourg	85600	-20%	-40%	-54%
European Union (28)	26700	-10%	-30%	-43%

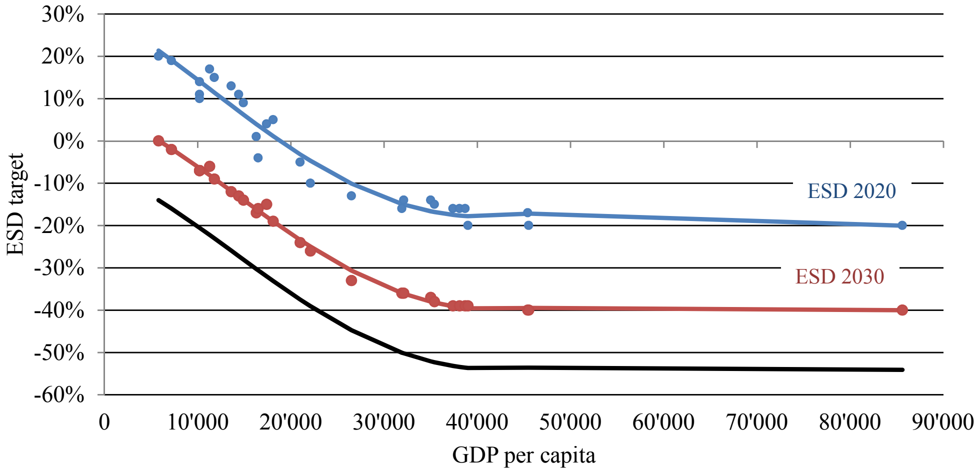

Figure 3: Effort-sharing target for year 2020 and 2030 and the period 2011-2050

First, we simulate a scenario using the burden-sharing defined above applied to all CO_2 emissions (ETS and non ETS). This scenario is called *full ESD*. The welfare changes are reported in table 2. The *full ESD* scenario generates a high range of welfare changes. Of course, countries with high-income levels suffer significant losses, while low-income countries benefit from generous allocations. The acceptability of such a rule is, therefore, questionable and clearly not in line to what the European Commission calls a "fair sharing of effort"; even though it is difficult to define what is fair for the Commission as no welfare change by MSs is reported in the impact-assessment report (European Commission, 2016). Note that our simulations might overestimate the allocation sharing as we apply it to all CO_2 emissions and not only to non-ETS emissions. Thus, it is interesting to compare this scenario with the one that corresponds to a uniform European CO_2 tax in which the European Commission determines the level of the carbon price with the aim of minimizing the aggregated European welfare loss. This scenario is equivalent to an ETS market extended to all sectors, including households emissions with no free allowance. This scenario penalizes mainly low-income MSs in contrast to the previous scenario and demonstrates the need of emissions trading to enforce the acceptability of EU climate targets. For Eastern European countries that joined the EU in 2004 or later, their welfare changes are mainly driven by high abatement cost. Indeed, these MSs (e.g., Bulgaria, Estonia, Romania, Poland, and Slovakia) are all characterized by high energy intensity compared to MSs (Grossi and Mussini, 2017) that joined much earlier. Therefore, any carbon price implementation without a burden-sharing mechanism will inevitably penalize these MSs.

We then combine these two scenarios with the goal to approximate the EU architecture that is based on an ETS market with a national target for other emissions sources. First, we assume that flexibility mechanisms are implemented to link the two markets (ETS and non-ETS). This assumption is in line with the impact assessment report. In this case, we might have an equalization of CO_2 prices between the two markets. Second, we define an allocation for each country that is based on an effort-sharing rule for non-ETS emissions and full auctioning for the ETS market. This allocation is approximated by a weighted combination of our ESD allocations and the emissions computed in the equalization of the CO_2 price scenario as shown in (16),

$$\theta_j = \frac{\frac{\gamma_j \theta_j^{ESD}\texttt{Bud} + (1-\gamma_j)\sum_t e_j^{t\ TAX}}{\psi}}{\texttt{Bud}}, \tag{16}$$

where γ_j is the share of emissions in non-ETS sectors, θ_j^{ESD}, the share computed in the *full ESD* scenario, $e_j^{t\ TAX}$, the emissions in the *uniform tax* scenario, and ψ a normalization factor (equal to 1.04) that ensures that the sum of θ_j is equal to one. The results of such burden-sharing is reported in table 2. This scenario, called the *EU architecture*, reduces the variability of welfare changes while addressing fairness concerns (Capros et al., 2011). This last point is illustrated in figure 4, in which we plot welfare changes in respect to GDP per capita. High-income countries pay for low-income countries. Finally, we perform a scenario, called *Welfare equalization*, that equalizes welfare change in % of household consumption. In this Rawlsian (Rawls, 1971) approach to distributive justice, the "optimal design" consists of finding the θ_j's such that the welfare loss among the countries is equalized. This scenario will be used as a benchmark scenario in the next section on Brexit.

4.2. Brexit scenarios

We now assume, as described in section 2.2, that the UK fulfills its CO_2 pledges individually through a domestic carbon price and does not participate in the EU CO_2 market. The UK budget, estimated at 13.7 Gt CO_2, implies that the UK would be able to implement a 20% and 80% reduction in CO_2 emissions by 2020 and 2050, respectively, from 1990 levels. We now simulate the four scenarios presented in the previous numerical section but with a game that excludes the UK. This means we have to recompute a new set of θ_j for each scenarios, and

Table 2: Discounted welfare cost as a % of total discounted household consumption

	Welfare equalization	Full ESD	Uniform tax	EU architecture
Austria	1.17	3.31	0.14	2.26
Belgium	1.17	4.13	0.37	2.84
Bulgaria	1.17	-24.62	11.34	-1.44
Croatia	1.17	0.85	2.41	0.53
Cyprus	1.17	3.19	-1.44	0.77
Czech Republic	1.17	-18.79	7.97	-2.27
Denmark	1.17	2.50	-0.38	1.13
Estonia	1.17	-11.32	6.14	-2.05
Finland	1.17	2.70	1.56	1.74
France	1.17	2.94	0.42	2.20
Germany	1.17	1.42	0.74	0.83
Greece	1.17	-3.50	-1.12	-4.22
Hungary	1.17	-2.06	1.65	-1.24
Ireland	1.17	3.31	0.22	1.94
Italy	1.17	2.54	0.99	1.65
Latvia	1.17	-0.99	0.85	-1.30
Lithuania	1.17	-2.42	0.36	-2.19
Luxembourg	1.17	6.47	-1.66	4.90
Malta	1.17	2.73	0.18	0.68
Netherlands	1.17	3.29	-0.21	1.76
Poland	1.17	-14.36	9.55	-1.15
Portugal	1.17	-0.42	0.61	-0.49
Romania	1.17	-6.68	5.00	-1.03
Slovakia	1.17	-3.31	3.50	-1.00
Slovenia	1.17	0.68	2.38	0.76
Spain	1.17	0.63	1.26	0.45
Sweden	1.17	3.38	0.01	2.48
United Kingdom	1.17	2.12	1.39	1.57
European Union (28)	1.17	1.17	1.17	1.17

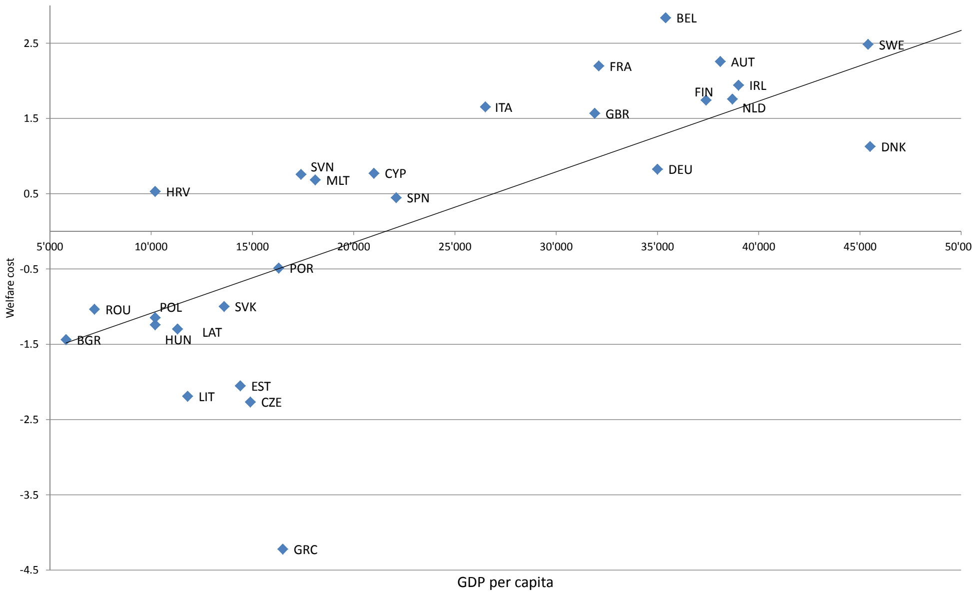

Figure 4: Welfare cost in relation to GDP per capita - *EU architecture* scenario (Luxembourg, coordinate (85'600,4.9) is outside of the figure)

also to solve the model presented in section 2.2 for the UK climate policy. Table 3 shows the change in welfare cost with respect to the no-Brexit scenario. Within a Brexit scenario and without any access to emission trading with the rest of EU, the UK's discounted welfare cost would be equal to 1.65% of its discounted household consumption. This means that with respect to all scenarios, except the full effort-sharing decision rule, the UK suffers from an increase in the cost of its climate policy by leaving the EU. In comparison to the *EU architecture* scenario, the discounted cost of the British climate policy increases by US$43 billion. Indeed, in the *EU architecture* scenario, the UK receives some extra CO_2 quotas with respect to its domestic target (i.e., 13.8 Gt CO_2 - 13.7 Gt CO_2) and benefits from less abatement cost by buying some European emissions credit. The Brexit cost is exacerbated in the *welfare equalization* (US$260 billion) and *uniform tax* (US$142 billion) scenarios because the UK bears a relatively high welfare cost in comparison to the EU average. In contrast, in these two scenarios, all other EU MSs are better off, simply because the average welfare cost decreases without the UK. Within the *EU architecture* scenario, MSs that are net sellers of permits suffer from less revenue and, in contrast, net buyers experience some benefits.

We now consider another situation in which the UK continues to participate in

Table 3: Absolute difference in discounted welfare cost (in percentage point: negative number means a welfare improvement) for Brexit scenario

	Welfare equalization	Full ESD	Uniform tax	EU architecture	Third country status
Austria	-0.11	0.02	-0.03	-0.03	0.01
Belgium	-0.11	0.03	-0.05	-0.04	0.01
Bulgaria	-0.11	1.20	-0.30	-0.01	-0.28
Croatia	-0.11	0.20	-0.07	0.00	-0.04
Cyprus	-0.11	0.22	-0.13	-0.04	-0.01
Czech Republic	-0.11	0.91	-0.26	0.04	-0.18
Denmark	-0.11	0.07	-0.05	-0.02	0.00
Estonia	-0.11	0.77	-0.23	-0.02	-0.20
Finland	-0.11	0.10	-0.05	-0.03	-0.03
France	-0.11	0.02	-0.03	-0.02	0.01
Germany	-0.11	0.08	-0.04	-0.01	-0.01
Greece	-0.11	0.33	-0.16	0.09	0.01
Hungary	-0.11	0.21	-0.06	0.02	-0.04
Ireland	-0.11	0.07	-0.06	-0.03	0.01
Italy	-0.11	0.06	-0.04	-0.02	-0.01
Latvia	-0.11	0.19	-0.06	0.04	-0.01
Lithuania	-0.11	0.19	-0.07	0.03	-0.02
Luxembourg	-0.11	0.01	-0.06	-0.07	0.06
Malta	-0.11	0.18	-0.12	-0.07	-0.08
Netherlands	-0.11	0.05	-0.05	-0.03	0.01
Poland	-0.11	0.81	-0.22	0.06	-0.16
Portugal	-0.11	0.13	-0.04	0.01	-0.02
Slovakia	-0.11	0.32	-0.10	0.04	-0.06
Slovenia	-0.11	0.19	-0.08	-0.01	-0.04
Spain	-0.11	0.13	-0.06	0.00	-0.02
Sweden	-0.11	-0.01	-0.02	-0.04	0.01
Romania	-0.11	0.44	-0.11	0.03	-0.09
European Union (27)	-0.11	-0.11	-0.11	-0.11	0.00
United Kingdom	0.48	-0.47	0.26	0.08	0.06

the European tradable market through as a third-country access status (Müller and Slominski, 2016; Emerson, 2016; Pisani-Ferry et al., 2016), a similar status as the one obtained by Norway or Liechtenstein in the existing EU ETS market. In this scenario, called *third country status*, we assume that the budget allowed to the UK is equal to 13.7 Gt CO_2 (i.e., its domestic target), and the budget allowed to each EU MS is equal to the one computed in the EU27 architecture scenario. Table 3 shows (last column) the welfare changes with respect to the EU28 architecture. The UK would benefit from a third-access status with a Brexit cost reduced by 20% (shifting from 0.08% to 0.06%). This benefit is coming from the access to emissions credit with low price in comparison to domestic abatement. For European MSs net sellers benefit from more revenue coming from CO_2 selling. In contrast, net buyers experience welfare losses.

5. Conclusion

In this paper, we have evaluated the EU climate policy ratified at COP21, on the 2050 horizon, in the context of the ESD proposed recently by the European Commission (2016). Using a meta-game approach, we approximated the EU architecture combining an ETS market with national binding commitments. We have shown that ESD allows reaching an affordable and fair burden-sharing in which, high-income MSs pay for low-income countries and, at the same time, ensure overall cost-efficiency. However, our analysis assumes that policy options already defined in the EU proposal, such as one-off flexibility between ETS and non-ETS and inter-temporal flexibility, are fully implemented.

The decision of the UK to leave the EU will no doubt impact European climate policy. The UK played a pivotal role in EU climate policy and represents the second-largest European emitter of GHG. The UK, Denmark, and Sweden belong to the MSs that have implemented an ambitious climate policy for many years. A possible exclusion of The UK from a EU CO_2 market will, of course, have a direct impact on the cost of European climate policy. Our first assessment shows that the European countries could experience some welfare improvements, if one assumes that the UK has to implement its emissions-reduction target through a domestic carbon price and is not allowed to participate in any European instrument. On its side, the UK could suffer a cost from not participating in the EU CO_2 market, a cost estimated by our model at US$43 billion within the *EU architecture* scenario. If the UK could negotiate a status similar to Norway's, then the Brexit cost would be reduced by 20% (i.e., US$9 billion).

These simulations assume that the EU ETS covers all sectors and not only energy-intensive industries. Considering the current EU policy design, we can argue that the non-participation of the UK in the existing EU ETS would penalize mainly these industrial sectors for which the energy prices are a key factor of their competitiveness. Of course, other sectors that are not included in the ETS would also be affected because they are already integrated into the current effort-sharing decision, but the impact would probably be less significant. However, new sectors will certainly be included in the ETS market in the forthcoming decades because increased flexibility between markets would lead to significant overall abatement cost reduction, as pointed-out in the EC proposal (European Commission, 2016), and the dichotomy between the two sectors would ultimately cease to exist.

Also, as in other economic affairs and international cooperations there is a possibility for the UK to cooperate with the USA in creating or reinforcing bilateral partnerships (Oliver and Williams, 2016), and, thus, mitigating this cost increase. In any case, a possible exclusion of the UK from an EU CO_2 market would reinforce the leadership role of the EU founding MSs, in particular for Germany (Oliver, 2016), which emits now about a quarter of aggregated EU GHG emissions.

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Appendix A Scenario detailed results

We report in the following two appendices detailed result of the ESD and Brexit scenarios described and discussed in the core of the paper. For each scenario, tables give the following information: θ_j, the budget allocated to each MS in Mt of CO_2 (i.e. $\theta_j \cdot \texttt{Bud}$), the welfare cost in percentage of discounted household consumption (HC) and its decomposition between abatement cost, GTT and permits exchange. More information are available upon request.

A.1 Results of EU28 scenarios

The following scenarios are discussed in Section 4.1.

A.1.1 Welfare equalization

		Budget	Welfare cost	Welfare decomposition in % of HC		
	θ_j	in Mt CO_2	in % of HC	Abatement cost	GTT	CO_2 trading
AUT	0.018	1803	1.17	1.35	-1.20	1.03
BEL	0.032	3208	1.17	1.68	-1.31	0.80
CYP	0.004	411	1.17	5.58	-7.03	2.62
CZE	0.014	1361	1.17	9.76	-1.82	-6.77
DNK	0.018	1810	1.17	2.14	-2.53	1.56
EST	0.004	392	1.17	9.37	-3.25	-4.95
FIN	0.015	1475	1.17	2.25	-0.69	-0.39
FRA	0.122	12097	1.17	1.10	-0.68	0.75
DEU	0.140	13859	1.17	1.57	-0.83	0.43
GRC	0.051	5006	1.17	6.63	-7.76	2.30
HUN	0.013	1268	1.17	2.48	-0.84	-0.48
IRL	0.014	1409	1.17	2.39	-2.17	0.95
ITA	0.118	11647	1.17	1.44	-0.45	0.18
LAT	0.003	297	1.17	2.40	-1.56	0.33
LIT	0.003	299	1.17	2.28	-1.93	0.82
LUX	0.006	549	1.17	2.46	-4.13	2.83
MLT	0.001	131	1.17	4.39	-4.23	1.01
NLD	0.043	4291	1.17	1.77	-1.98	1.38
POL	0.062	6120	1.17	8.86	0.67	-8.36
POR	0.015	1466	1.17	1.63	-1.02	0.56
SVK	0.008	825	1.17	3.84	-0.34	-2.33
SVN	0.005	450	1.17	3.03	-0.66	-1.20
SPN	0.090	8894	1.17	2.03	-0.77	-0.09
SWE	0.017	1648	1.17	0.59	-0.58	1.16
GBR	0.149	14730	1.17	1.55	-0.16	-0.22
BGR	0.008	815	1.17	11.61	-0.29	-10.15
ROU	0.019	1900	1.17	4.33	0.66	-3.82
HRV	0.008	839	1.17	2.66	-0.25	-1.24
EU28	1.000	99000	1.17			

A.1.2 Full ESD

	θ_j	Budget in Mt CO_2	Welfare cost in % of HC	Welfare decomposition in % of HC Abatement cost	GTT	CO_2 trading
AUT	0.013	1299	3.31	1.35	-1.20	3.17
BEL	0.023	2249	4.13	1.68	-1.31	3.76
CYP	0.004	381	3.19	5.58	-7.03	4.64
CZE	0.034	3335	-18.79	9.76	-1.82	-26.73
DNK	0.016	1558	2.50	2.14	-2.53	2.89
EST	0.006	571	-11.32	9.37	-3.25	-17.44
FIN	0.012	1232	2.70	2.25	-0.69	1.14
FRA	0.090	8914	2.94	1.10	-0.68	2.52
DEU	0.135	13327	1.42	1.57	-0.83	0.67
GRC	0.062	6166	-3.50	6.63	-7.76	-2.37
HUN	0.016	1627	-2.06	2.48	-0.84	-3.70
IRL	0.011	1122	3.31	2.39	-2.17	3.09
ITA	0.098	9657	2.54	1.44	-0.45	1.54
LAT	0.003	343	-0.99	2.40	-1.56	-1.84
LIT	0.004	412	-2.42	2.28	-1.93	-2.77
LUX	0.004	371	6.47	2.46	-4.13	8.14
MLT	0.001	122	2.73	4.39	-4.23	2.56
NLD	0.034	3385	3.29	1.77	-1.98	3.50
POL	0.113	11187	-14.36	8.86	0.67	-23.89
POR	0.018	1743	-0.42	1.63	-1.02	-1.02
SVK	0.011	1092	-3.31	3.84	-0.34	-6.81
SVN	0.005	466	0.68	3.03	-0.66	-1.69
SPN	0.095	9414	0.63	2.03	-0.77	-0.63
SWE	0.011	1045	3.38	0.59	-0.58	3.37
GBR	0.127	12592	2.12	1.55	-0.16	0.73
BGR	0.016	1609	-24.62	11.61	-0.29	-35.93
ROU	0.030	2925	-6.68	4.33	0.66	-11.67
HRV	0.009	853	0.85	2.66	-0.25	-1.56
EU28	1.000	99000	1.17			

A.1.3 Uniform tax

	θ_j	Budget in Mt CO_2	Welfare cost in % of HC	Welfare decomposition in % of HC		
				Abatement cost	GTT	CO_2 trading
AUT	0.021	2045	0.14	1.35	-1.20	–
BEL	0.035	3468	0.37	1.67	-1.31	–
CYP	0.005	450	-1.44	5.57	-7.02	–
CZE	0.007	689	7.97	9.78	-1.81	–
DNK	0.021	2104	-0.38	2.14	-2.52	–
EST	0.003	321	6.14	9.39	-3.24	–
FIN	0.014	1413	1.56	2.25	-0.69	–
FRA	0.136	13455	0.42	1.09	-0.68	–
DEU	0.149	14780	0.74	1.57	-0.83	–
GRC	0.056	5579	-1.12	6.63	-7.74	–
HUN	0.012	1216	1.65	2.48	-0.84	–
IRL	0.016	1537	0.22	2.39	-2.17	–
ITA	0.120	11906	0.99	1.44	-0.44	–
LAT	0.003	304	0.85	2.40	-1.55	–
LIT	0.003	325	0.36	2.28	-1.92	–
LUX	0.007	644	-1.66	2.46	-4.12	–
MLT	0.001	137	0.18	4.39	-4.22	–
NLD	0.049	4881	-0.21	1.77	-1.97	–
POL	0.034	3386	9.55	8.88	0.67	–
POR	0.016	1564	0.61	1.63	-1.02	–
SVK	0.007	686	3.50	3.85	-0.34	–
SVN	0.004	412	2.38	3.03	-0.66	–
SPN	0.089	8807	1.26	2.03	-0.77	–
SWE	0.020	1966	0.01	0.59	-0.58	–
GBR	0.144	14241	1.39	1.55	-0.16	–
BGR	0.005	502	11.34	11.64	-0.29	–
ROU	0.014	1400	5.00	4.34	0.66	–
HRV	0.008	782	2.41	2.66	-0.25	–
EU28	1.000	99000	1.17			

A.1.4 EU architecture

	θ_j	Budget in Mt CO_2	Welfare cost in % of HC	Welfare decomposition in % of HC Abatement cost	GTT	CO_2 trading
AUT	0.016	1547	2.26	1.35	-1.20	2.12
BEL	0.027	2667	2.84	1.68	-1.31	2.47
CYP	0.004	417	0.77	5.58	-7.03	2.23
CZE	0.017	1701	-2.27	9.76	-1.82	-10.21
DNK	0.018	1817	1.13	2.14	-2.53	1.52
EST	0.004	438	-2.05	9.37	-3.25	-8.17
FIN	0.014	1384	1.74	2.25	-0.69	0.18
FRA	0.103	10244	2.20	1.10	-0.68	1.78
DEU	0.147	14599	0.83	1.57	-0.83	0.08
GRC	0.064	6344	-4.22	6.63	-7.76	-3.09
HUN	0.016	1536	-1.24	2.48	-0.84	-2.89
IRL	0.013	1305	1.94	2.39	-2.17	1.72
ITA	0.110	10939	1.65	1.44	-0.45	0.66
LAT	0.004	349	-1.30	2.40	-1.56	-2.14
LIT	0.004	405	-2.19	2.28	-1.93	-2.54
LUX	0.004	423	4.90	2.46	-4.13	6.57
MLT	0.001	134	0.68	4.39	-4.23	0.52
NLD	0.041	4040	1.76	1.77	-1.98	1.97
POL	0.069	6875	-1.15	8.86	0.67	-10.67
POR	0.018	1755	-0.49	1.63	-1.02	-1.09
SVK	0.010	954	-1.00	3.84	-0.34	-4.50
SVN	0.005	464	0.76	3.03	-0.66	-1.61
SPN	0.097	9591	0.45	2.03	-0.77	-0.81
SWE	0.013	1289	2.48	0.59	-0.58	2.48
GBR	0.140	13832	1.57	1.55	-0.16	0.18
BGR	0.009	896	-1.44	11.61	-0.29	-12.75
ROU	0.022	2187	-1.03	4.33	0.66	-6.02
HRV	0.009	868	0.53	2.66	-0.25	-1.88
EU28	1.000	99000	1.17			

A.2 Results of Brexit scenarios

These scenarios are discussed in Section 4.2.

A.2.1 Welfare equalization

		Budget	Welfare cost	Welfare decomposition in % of HC		
	θ_j	in Mt CO_2	in % of HC	Abatement cost	GTT	CO_2 trading
AUT	0.021	1825	1.06	1.31	-1.20	0.95
BEL	0.038	3238	1.06	1.63	-1.31	0.74
CYP	0.005	412	1.06	5.45	-7.01	2.63
CZE	0.016	1386	1.06	9.50	-1.81	-6.62
DNK	0.021	1825	1.06	2.09	-2.52	1.50
EST	0.005	395	1.06	9.14	-3.24	-4.84
FIN	0.018	1494	1.06	2.20	-0.69	-0.44
FRA	0.144	12265	1.06	1.07	-0.68	0.68
DEU	0.165	14076	1.06	1.53	-0.83	0.36
GRC	0.059	5025	1.06	6.47	-7.75	2.33
HUN	0.015	1282	1.06	2.42	-0.84	-0.52
IRL	0.017	1422	1.06	2.33	-2.17	0.90
ITA	0.138	11800	1.06	1.40	-0.44	0.11
LAT	0.004	299	1.06	2.34	-1.56	0.27
LIT	0.004	302	1.06	2.21	-1.92	0.77
LUX	0.006	551	1.06	2.41	-4.11	2.77
MLT	0.002	132	1.06	4.27	-4.21	1.01
NLD	0.051	4327	1.06	1.72	-1.97	1.31
POL	0.073	6212	1.06	8.64	0.66	-8.24
POR	0.017	1483	1.06	1.58	-1.02	0.50
SVK	0.010	834	1.06	3.74	-0.34	-2.34
SVN	0.005	455	1.06	2.95	-0.66	-1.24
SPN	0.106	9002	1.06	1.97	-0.77	-0.14
SWE	0.020	1672	1.06	0.57	-0.58	1.07
BGR	0.010	825	1.06	11.30	-0.29	-9.95
ROU	0.023	1924	1.06	4.22	0.66	-3.81
HRV	0.010	845	1.06	2.59	-0.25	-1.28
EU27	1.000	85307	1.06			
GBR		13693	1.65	1.81	-0.16	–

A.2.2 Full ESD

		Budget	Welfare cost	Welfare decomposition in % of HC		
	θ_j	in Mt CO_2	in % of HC	Abatement cost	GTT	CO_2 trading
AUT	0.015	1279	3.33	1.31	-1.20	3.22
BEL	0.026	2214	4.16	1.63	-1.31	3.83
CYP	0.004	377	3.40	5.45	-7.01	4.97
CZE	0.039	3301	-17.88	9.50	-1.81	-25.57
DNK	0.018	1533	2.57	2.09	-2.52	3.01
EST	0.007	565	-10.54	9.14	-3.24	-16.44
FIN	0.014	1212	2.80	2.20	-0.69	1.29
FRA	0.103	8781	2.96	1.07	-0.68	2.57
DEU	0.154	13120	1.50	1.53	-0.83	0.80
GRC	0.072	6100	-3.18	6.47	-7.75	-1.91
HUN	0.019	1612	-1.85	2.42	-0.84	-3.43
IRL	0.013	1104	3.38	2.33	-2.17	3.22
ITA	0.112	9528	2.59	1.40	-0.44	1.64
LAT	0.004	340	-0.80	2.34	-1.56	-1.59
LIT	0.005	408	-2.23	2.21	-1.92	-2.52
LUX	0.004	365	6.49	2.41	-4.11	8.19
MLT	0.001	121	2.91	4.27	-4.21	2.85
NLD	0.039	3331	3.35	1.72	-1.97	3.60
POL	0.130	11083	-13.55	8.64	0.66	-22.85
POR	0.020	1724	-0.29	1.58	-1.02	-0.85
SVK	0.013	1081	-2.99	3.74	-0.34	-6.39
SVN	0.005	461	0.87	2.95	-0.66	-1.42
SPN	0.109	9300	0.76	1.97	-0.77	-0.44
SWE	0.012	1029	3.37	0.57	-0.58	3.38
BGR	0.019	1595	-23.42	11.30	-0.29	-34.43
ROU	0.034	2899	-6.25	4.22	0.66	-11.12
HRV	0.010	845	1.05	2.59	-0.25	-1.29
EU27	1.000	85307	1.06			
GBR		13693	1.65	1.81	-0.16	–

A.2.3 Uniform tax

	θ_j	Budget in Mt CO_2	Welfare cost in % of HC	Welfare decomposition in % of HC		
				Abatement cost	GTT	CO_2 trading
AUT	0.024	2053	0.11	1.31	-1.20	–
BEL	0.041	3483	0.32	1.63	-1.31	–
CYP	0.005	452	-1.57	5.44	-7.02	–
CZE	0.008	715	7.71	9.52	-1.81	–
DNK	0.025	2114	-0.43	2.08	-2.52	–
EST	0.004	324	5.91	9.16	-3.24	–
FIN	0.017	1422	1.51	2.20	-0.69	–
FRA	0.158	13513	0.38	1.06	-0.68	–
DEU	0.174	14878	0.70	1.53	-0.83	–
GRC	0.066	5618	-1.28	6.47	-7.74	–
HUN	0.014	1223	1.58	2.42	-0.84	–
IRL	0.018	1546	0.16	2.33	-2.17	–
ITA	0.140	11967	0.95	1.39	-0.44	–
LAT	0.004	305	0.79	2.34	-1.55	–
LIT	0.004	327	0.29	2.21	-1.92	–
LUX	0.008	646	-1.71	2.40	-4.12	–
MLT	0.002	138	0.06	4.27	-4.22	–
NLD	0.057	4900	-0.25	1.72	-1.97	–
POL	0.041	3459	9.32	8.66	0.67	–
POR	0.018	1572	0.56	1.58	-1.02	–
SVK	0.008	692	3.40	3.75	-0.34	–
SVN	0.005	414	2.30	2.96	-0.66	–
SPN	0.104	8864	1.20	1.97	-0.77	–
SWE	0.023	1971	-0.01	0.57	-0.58	–
BGR	0.006	512	11.04	11.33	-0.29	–
ROU	0.017	1415	4.89	4.23	0.66	–
HRV	0.009	786	2.34	2.59	-0.25	–
EU27	1.000	85307	1.06			
GBR		13693	1.65	1.81	-0.16	–

A.2.4 EU architecture

	θ_j	Budget in Mt CO_2	Welfare cost in % of HC	Welfare decomposition in % of HC Abatement cost	GTT	CO_2 trading
AUT	0.018	1544	2.23	1.31	-1.20	2.12
BEL	0.031	2663	2.80	1.63	-1.31	2.48
CYP	0.005	417	0.73	5.45	-7.01	2.30
CZE	0.020	1718	-2.22	9.50	-1.81	-9.91
DNK	0.021	1816	1.11	2.09	-2.52	1.54
EST	0.005	441	-2.07	9.14	-3.24	-7.97
FIN	0.016	1389	1.71	2.20	-0.69	0.21
FRA	0.120	10221	2.17	1.07	-0.68	1.79
DEU	0.171	14627	0.81	1.53	-0.83	0.11
GRC	0.074	6342	-4.13	6.47	-7.75	-2.86
HUN	0.018	1541	-1.22	2.42	-0.84	-2.80
IRL	0.015	1304	1.92	2.33	-2.17	1.75
ITA	0.128	10955	1.63	1.40	-0.44	0.68
LAT	0.004	350	-1.26	2.34	-1.56	-2.05
LIT	0.005	405	-2.15	2.21	-1.92	-2.45
LUX	0.005	421	4.83	2.41	-4.11	6.54
MLT	0.002	135	0.61	4.27	-4.21	0.56
NLD	0.047	4037	1.73	1.72	-1.97	1.98
POL	0.081	6927	-1.08	8.64	0.66	-10.39
POR	0.021	1759	-0.48	1.58	-1.02	-1.05
SVK	0.011	958	-0.96	3.74	-0.34	-4.36
SVN	0.005	465	0.75	2.95	-0.66	-1.55
SPN	0.113	9612	0.44	1.97	-0.77	-0.76
SWE	0.015	1285	2.45	0.57	-0.58	2.46
BGR	0.011	904	-1.45	11.30	-0.29	-12.46
ROU	0.026	2200	-1.00	4.22	0.66	-5.88
HRV	0.010	870	0.53	2.59	-0.25	-1.81
EU27	1.000	85307	1.06			
GBR		13693	1.65	1.81	-0.16	–

A.2.5 Third country status

		Budget	Welfare cost	Welfare decomposition in % of HC		
	θ_j	in Mt CO_2	in % of HC	Abatement cost	GTT	CO_2 trading
AUT	0.016	1544	2.27	1.35	-1.20	2.13
BEL	0.027	2663	2.85	1.68	-1.31	2.48
CYP	0.004	417	0.76	5.58	-7.03	2.22
CZE	0.017	1718	-2.44	9.76	-1.82	-10.38
DNK	0.018	1816	1.13	2.14	-2.53	1.52
EST	0.004	441	-2.25	9.37	-3.25	-8.37
FIN	0.014	1389	1.72	2.25	-0.69	0.16
FRA	0.103	10221	2.21	1.10	-0.68	1.79
DEU	0.148	14627	0.81	1.57	-0.83	0.07
GRC	0.064	6342	-4.21	6.63	-7.76	-3.08
HUN	0.016	1541	-1.28	2.48	-0.84	-2.93
IRL	0.013	1304	1.95	2.39	-2.17	1.73
ITA	0.111	10955	1.64	1.44	-0.45	0.65
LAT	0.004	350	-1.31	2.40	-1.56	-2.15
LIT	0.004	405	-2.21	2.28	-1.93	-2.57
LUX	0.004	421	4.96	2.46	-4.13	6.62
MLT	0.001	135	0.61	4.39	-4.23	0.45
NLD	0.041	4037	1.76	1.77	-1.98	1.97
POL	0.070	6927	-1.31	8.86	0.67	-10.83
POR	0.018	1759	-0.51	1.63	-1.02	-1.11
SVK	0.010	958	-1.06	3.84	-0.34	-4.56
SVN	0.005	465	0.71	3.03	-0.66	-1.66
SPN	0.097	9612	0.43	2.03	-0.77	-0.83
SWE	0.013	1285	2.50	0.59	-0.58	2.49
BGR	0.009	904	-1.72	11.61	-0.29	-13.03
ROU	0.022	2200	-1.13	4.33	0.66	-6.12
HRV	0.009	870	0.49	2.66	-0.25	-1.93
EU27	0.862	85307	1.06			
GBR	0.138	13693	1.63	1.55	-0.16	0.24